Managing Recoverable Aircraft Components in the PPB and Related Processes

Executive Summary

James Bigelow

Rand

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PREFACE

Current defense research at Rand includes wartime capability assessment, with special attention to the relationship between support resources and capability. Much of this work is geared toward understanding the Planning, Programming, and Budgeting (PPB) process, and how it is connected with day-to-day management processes, from a systems point of view.

This report describes a methodology developed as part of the work: ORACLE—Oversight of Resources And Capability for Logistics Effectiveness. It is one of two volumes prepared as final documentation of the study effort "Assessing the Peacetime Materiel Readiness and Wartime Sustainability of U.S. Air Forces," sponsored by the Office of the Assistant Secretary of Defense (Manpower, Installations, and Logistics) under Contract MDA903-81-C-0381. The volumes have the general title *Managing Recoverable Aircraft Components in the PPB and Related Processes.* The present report is an executive summary intended for high-level logistics managers who wish to know what this methodology can do for them but who do not want to be burdened with the details of implementation. It should be of interest to managers of the PPB system and to planners in the service commands. The companion report contains technical details.

SUMMARY

INTRODUCTION

This report describes a methodology called ORACLE—Oversight of Resources And Capability for Logistics Effectiveness. ORACLE's purpose is to assess the effects of varying certain resource levels on the peacetime materiel readiness and wartime sustainability of U.S. air forces, so that resource requirements can be better estimated and justified. Peacetime materiel readiness and wartime sustainability are among the general goals established in the Planning, Programming, and Budgeting (PPB) process, which then translates the goals into a five-year program of activities and capabilities and puts together a detailed budget for the first year of the program. Then the execution process uses the budgeted dollars to carry out the program. ORACLE is intended primarily for use in the PPB process, but we feel it can also be useful during execution. We have built a prototype of ORACLE that deals with requirements to buy and repair recoverable aircraft components (e.g., components that can be repaired, such as guns, radars, and landing gear). The prototype reflects Air Force data and procedures, but the methodology, suitably modified, could also be useful in a Naval Air Force context.

To help manage approximately 150,000 aircraft components during execution, the Air Force Logistics Command (AFLC) uses the D041 system.[1] Each quarter, D041 estimates how many of each component must be bought and repaired in each of ten to 13 future quarters to support the program. Because "item managers" (here, "item" is synonymous with "component") base their day-to-day decisions in large part on these estimates, dollar requirements used in the PPB process should be consistent with the D041 estimates. Indeed, pursuant to DoD instruction 4140.24, the dollar totals used in the PPB process are D041 estimates accumulated across components. In the Navy, the Aviation Supply Office (ASO) has a similar system to help them manage approximately 64,000 components. The LEVELS program estimates buy requirements for individual components, and STRAT accumulates requirements to obtain dollar figures for the PPB system. ASO also has programs to estimate repair requirements, both for individual

[1]"Recoverable Consumption Item Requirements Computation System (D041)," AFLC Regulation 57-4, February 1980.

components and in aggregate form. (For simplicity, however, we will hereafter refer to the Navy system as LEVELS/STRAT and omit mention of the programs that estimate repair requirements, even though the ORACLE methodology encompasses both buy and repair requirements.) Both D041 and LEVELS/STRAT are so large and cumbersome that only one program can be investigated each time they are exercised. The PPB process, however, must consider many different programs and their resource implications. Moreover, both D041 and LEVELS/STRAT change frequently,[2] and requirements estimates used in the PPB process must be updated to remain consistent.

THE ORACLE METHODOLOGY

The ORACLE methodology constructs an aggregate database as an additional product of the standard D041 quarterly exercise (or the LEVELS/STRAT exercise). The database thus reflects all changes in D041 or LEVELS/STRAT data or methodology that have occurred since the previous exercise. This database is small enough to fit in a portable microcomputer and can be rapidly manipulated by a spreadsheet-like program to "mimic," in aggregate form, the responses of the D041 or LEVELS/STRAT system to program changes. The ORACLE database is aggregated, so its user can estimate dollar requirements for any desired group of components, rather than individual component requirements.

D041 develops the net buy and repair requirements for a component by first building the gross requirement from a variety of individual pieces and then subtracting different types of assets until either the assets or the requirement is exhausted. The sum of pieces include: operating requirements (components that fail and must be replaced), pipeline requirements (components in transit or repair), safety levels (to cover random fluctuations in pipeline contents), War Reserve Materiel requirements (to cover activities specified in wartime planning scenarios), and additives (anything not in another category). Assets include serviceable components on hand, components repairable at

[2]Component data (e.g., assets, demand rates) are updated during each exercise. Also, AFLC is currently modifying the D041 methodology. D041 currently bases its requirements on a backorder criterion (i.e., expected number of unfilled requisitions at base supply). The new D041 will use an aircraft availability criterion, which the Air Force PPB process already uses to measure peacetime materiel readiness and wartime sustainability. (The availability of an aircraft type is the percentage of that type possessing a full complement of serviceable components.) Similarly, the Navy has a major "resystemization" effort under way that is intended eventually to replace LEVELS/STRAT (although current Navy plans afford aircraft availability no role).

base level, components repairable at depot level, etc. (Most of the operating requirements—i.e., components that fail—can be repaired at base or depot level and returned to service.) D041 reports these computations in a standard product called the item computation worksheet.

The ORACLE database contains the item computation worksheet entries aggregated across components. Entries are weighted by the purchase price of the component, so the results express the total dollar value of components. (For aggregating the depot repair requirement, we also use the depot repair cost as a weight.) Entries may be aggregated over any group of components, e.g., all F-xx components, or all navigational instruments. These aggregated figures may indicate potential problems soon to face the logistics system, for example, that a high and growing value of F-xx components will be tied up in transit between the flight line and the depot.

In D041, the average number of a component tied up in transit from base to depot is proportional to the component's level of flying activity. Similarly, the number that fail and must be replaced in an interval of time (the operating requirement) is proportional to the hours flown in that interval. ORACLE aggregates these and other proportionality factors in the same way as the worksheet entries. The aggregated factors indicate which activities by which weapon systems give rise to large requirements. Moreover, the factors can be combined to determine average transit and repair times for groups of components, average condemnation percentages, average depot repair percentages, etc. These quantities may show, for example, the degree to which a high value of components in transit from base to depot is due to: (a) a high percentage of components being repaired at the depot rather than the base; (b) a long transportation time; (c) a high rate of failures per flying hour; or (d) a lot of flying activity.

Finally, for each component, ORACLE calculates the sensitivity of its required purchases and repairs to changes in any programmed quantities that are inputs to D041 or LEVELS/STRAT. Then ORACLE aggregates these sensitivities the same way as the worksheet entries. In the Air Force, program inputs include peacetime flying hours, programmed depot maintenance of aircraft, engine overhauls, peacetime aircraft availabilities (see footnote 2), and such wartime parameters as sortie rates and attrition rates. (Because of differences between LEVELS/STRAT and D041, the Navy list of program inputs is not as rich.) To rapidly assess the resource implications of changing the programs (as the PPB process must), one multiplies the program change by the appropriate sensitivity factor. If there is more than one program change, one computes the resource implications of each and adds them together. Or one may back-calculate to determine what reduction

in, say, 1987 programmed F-16 peacetime flying hours will yield a needed savings in the 1985 budget, or what reduction in the planned 1987 F-16 wartime sortie rate will offset the 1985 budgetary impact of an increase in 1987 F-16 peacetime flying hours.

The aggregated sensitivities provide only an approximate means to estimate the effects of program changes. To test the accuracy of the approximation, we built a test version of D041 and a prototype ORACLE to mimic it. For very large program changes (e.g., changes as large as 50 percent in peacetime flying hours), estimates made using the sensitivities agree extremely well with the results of submitting the alternative programs to the test version of D041.[3]

There are many potential users of the ORACLE methodology, although different users would need their ORACLE databases aggregated differently. In the Air Force, AFLC might aggregate across components requiring similar repair techniques, to help allocate repair workloads among the Air Logistics Centers (ALCs). Or, AFLC might aggregate across items managed or repaired at a given ALC to help allocate repair and buy dollars to the ALCs. Individual ALCs might aggregate over components repaired in the same shop or requiring the same skill for repair, to estimate future needs for shop capacities or particular manpower skills. The weapon system manager, another potential ORACLE user, might wish to aggregate items only to the subsystem level, rather than all the way to the level of his weapon system. In the Navy, potential users include the Naval Air Logistics Center, which manages the Navy depots, and the Aviation Supply Office, which is responsible for buying and managing aircraft components.

SOME REMAINING ISSUES

The ORACLE methodology fails to address some problems in the planning and justification of component requirements. Two of the most important are forecasting and the tracking and control of execution.

Forecasting is a problem because of the two (or more) year delay between the start of the PPB process and the eventual results of execution. In that time, demand rates, depot repair percentages,

[3]AFLC currently calculates average costs per flying hour for buying and repairing components, and the PPB process uses them to adjust the requirements when the programmed flying hours are changed. But our validation exercise demonstrated that using the sensitivities mimics D041 more closely. Moreover, there are sensitivities relating requirements to many program quantities in addition to flying hours.

condemnation percentages, etc., will change for many components. Flying programs will be altered. Modification programs will design new components to enter the inventory. D041 and LEVELS/STRAT optimistically assume that all of these changes can be anticipated perfectly, and hence they tend to underestimate future requirements. The ORACLE database inherits this flaw, since it mimics D041 or LEVELS/STRAT.

A contingency allowance would cover requirements that cannot be anticipated in detail, but that experience shows will nevertheless emerge. To determine how large the contingency allowance should be, one might examine historical D041 databases. How much do demand rates of different types of components fluctuate over time? How long is a component likely to remain active in the inventory? Under what conditions will it be retired in favor of a newly designed component? And what do these factors imply for future dollar requirements?

Even if future year programmed resources included a contingency allowance, there would remain an uncertainty in the requirement for that year. In some years, enough requirements will emerge to outstrip funding, and the shortage in funding will eventually result in shortages in some components. Even when total funding is ample, the difficulty in forecasting demands for individual components guarantees that some components will be underbought.

To cope with the inevitable shortages, item managers can redistribute stock among flight lines, or from wholesale to other echelons. Or they can affect key factors that influence component availability, such as transportation or repair times, by assigning high priority to the components that are short. However, close attention can be given to only a limited number of components, so it is important to single out the components that are in critically short supply.

To aid in this task, the Air Force is developing the "Combat Analysis Capability" system. Under that system, weapon system managers will be given access to Rand's Dyna-METRIC model, and the databases needed by Dyna-METRIC will be assembled and kept current. Dyna-METRIC relates aircraft availability in peacetime and wartime to component repair times, demand rates, etc. It identifies which components are likely to keep aircraft unavailable in peacetime or wartime and provides diagnostics to suggest how to work around the shortages.

We think that by itself, ORACLE should have significant value for resource planning. In conjunction with an improved forecasting capability and an execution tracking and control system, ORACLE's value can only be enhanced.

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GLOSSARY

AFLC	Air Force Logistics Command.
ALC	Air Logistics Center (an Air Force depot).
ASO	Aviation Supply Office (Navy).
CAC	Combat Analysis Capability (a future Air Force data and computation system). (See also Dyna-METRIC.)
D041	Recoverable Consumption Item Requirements Computation System (Air Force).
Dyna-METRIC	A model used to assess the effect of spare parts and their repair on sortie generation and aircraft availability in dynamic (e.g., wartime) scenarios. This model is at the heart of the CAC system.
EOH	Programmed Engine Overhauls at the depot (Air Force).
FH	Flying Hour.
FSC	Federal Supply Class.
LCMS	Logistics Capability Measurement System (a computation system in use by the Air Force during the PPB process).
LEVELS	Computer program used by ASO (Navy) to compute buy requirements for individual components. There are similar programs to estimate repair requirements for individual components.
LMI	Logistics Management Institute (works for Air Force).
MIL	Manpower, Installations and Logistics.
NALC	Naval Air Logistics Center (the management headquarters for the Navy depots).
NARF	Naval Air Rework Facility (a Navy depot).
OIM	Organizational and Intermediate Maintenance.
ORACLE	Overview of Resources And Capability for Logistics Effectiveness.
OSD	Office of the Secretary of Defense.
OWRM	Other War Reserve Materiel (see also WRM, PWRM).
PDM	Programmed Depot Maintenance of aircraft (Air Force). (Comparable to SDLM in the Navy.)
POL	Petroleum, Oil, and Lubricants.
PPB	Planning, Programming, and Budgeting.

PPBS	Planning, Programming, and Budgeting System.
PWRM	Prepositioned War Reserve Materiel (see also WRM, OWRM).
RRR	Remove, Repair, Replace.
SDLM	Standard Depot Level Maintenance of aircraft (Navy). (Comparable to PDM in the Air Force.)
SM	System Manager (Air Force).
STRAT	Computer program used by ASO (Navy) to estimate total dollar requirements to buy components. There is a similar program to estimate total dollar requirements to repair components.
WRM	War Reserve Materiel (see also PWRM, OWRM).
WRSK	War Reserves Spares Kit.

I. INTRODUCTION

This report describes a prototype methodology called ORACLE—Oversight of Resources And Capability for Logistics Effectiveness. ORACLE's purpose is to assess the effects of varying certain logistics policies and resource levels on the peacetime materiel readiness and wartime sustainability of the U.S. air forces. The methodology is intended primarily for use in the annual Planning, Programming, and Budgeting System (PPBS) exercises, so that support resources can be better planned and justified. But we feel it can also be useful during execution—i.e., in budget allocation decisions, and in management decisions involving the actual obligation and expenditure of funds for logistics resources.

Planning and spending justification take place in the Planning, Programming, and Budgeting (PPB) process. The actual purchase and management of physical resources is what we call "execution." The PPB process, it is widely perceived, frequently fails to provide enough logistics resources to achieve the desired capabilities during execution. We believe a major reason is that the execution processes do not provide the right kinds of information about resource requirements to the PPBS. ORACLE addresses this issue.

The present ORACLE prototype deals only with policies and resources related to recoverable (that is, repairable) aircraft components. Aircraft are typically composed of thousands of components, such as guns, fire control systems, landing gear, jet engine parts, and radars. As aircraft fly in peacetime or wartime, components will occasionally fail and be removed from the aircraft. Replacements must be provided by repairing failed components either in the field or at depot level or buying new components from manufacturers. The prototype ORACLE methodology described here only provides estimates of dollars needed to buy components and to repair them at depot level. However, we believe that given the appropriate data, the methodology could be extended to cover individual repair resources such as manpower, repair parts, test equipment, or facilities space. It could also be adapted to estimate transportation requirements.

We intend our methodology to be useful to both the Air Force and Naval Air Force. However, we developed our prototype using Air Force data, to which we had better access than we did to Navy data. Thus, the methodology outlined here is more suited in detail to the Air Force

and will require some adaptation before it can be transferred into a Navy context.

The remainder of this report is organized as follows. Section II discusses the management of aircraft components throughout PPB and execution and states some criteria that a methodology should satisfy to improve the flows of information in that process. Sections III and IV give an overview of the ORACLE methodology, which we think satisfies these criteria, and discuss how the methodology operates and what results can be obtained from its use. Finally, Sec. V mentions some of the problems that the ORACLE methodology does not solve and some possible next steps.

II. COMPONENT MANAGEMENT IN PPB AND EXECUTION

Management in the Air Force or in the Navy is accomplished through a multistage process. The highest-level management activities occur in the PPB process. Planning sets general goals. Programming translates these goals into a five-year program of activities to be carried out and capabilities to be achieved and maps out how to accomplish the program within resource limits. Budgeting puts together a detailed plan of expenditures for the first year of the program. Once the PPB process has done its work (which includes reconciling the program with funding limits imposed by Congress), the final program is used to guide the lower-level management activities that we call execution. Execution includes the allocation of funds to the major commands of the services, and their obligation and expenditure for carrying out the program. Obviously, it behooves the services to make sure that enough money is allocated to accomplish the program, and since Congress is unwilling to provide more funds than necessary, the PPB process must accurately estimate the dollar requirements implied by any program.

Peacetime materiel readiness and wartime sustainability are among the goals set during planning and hence should be reflected in the programs chosen in the PPB process. The Air Force PPB process currently uses "aircraft availability"[1] to measure peacetime materiel readiness as it is affected by recoverable components. The Air Force also uses aircraft availability in a wartime scenario, coupled with the planned wartime sortie rates, as their measure of wartime sustainability. The Navy has commenced an effort to use aircraft availability in the PPB process to help measure the peacetime readiness and wartime sustainability of the Naval Air Force. But to date, the Navy has not possessed the tools to do so.[2]

[1]The availability of a given type of aircraft is defined as the percentage of that type of aircraft that possesses a full complement of serviceable components. Aircraft availability does not accurately estimate the number of aircraft actually in condition to fly sorties of a particular kind. This number will depend on other resources than components. Some aircraft with all their components serviceable will be undergoing maintenance and hence be unavailable to fly sorties. Other aircraft may have unserviceable components and yet be able to fly missions for which those components are not critical. But aircraft availability is generally recognized as the present best measure of the effect of component support on combat capability.

[2]The tools used in the Air Force PPB process to relate recoverable components to aircraft availability are the Logistics Management Institute (LMI) Aircraft Availability Model [1] and the Synergy Overview Model [2], which together form the Logistics Capa-

The Air Force Logistics Command (AFLC) manages components during execution with the help of a massive information management system called D041: Recoverable Consumption Item Requirements Computation System [3]. Data concerning demands, repair times, inventories, etc., of each of approximately 150,000 recoverable components are collected continuously and used once each quarter to update the D041 database. Each quarter, the D041 system uses these data and programs of future flying and other activities (i.e., the program determined by the PPB process) to project the number of each component that should be repaired at the depot and the number that should be bought in each of the next ten to 13 future quarters.

Because the D041 system is so centrally involved in estimating what components need to be bought and repaired during execution, it seems only reasonable that the methods used in the PPB process to estimate funds for component buys and repairs should be consistent with the requirements calculated by D041. Indeed, pursuant to a DoD instruction [4], AFLC accumulates the requirements calculated by D041 across components to obtain dollar figures for use in the PPB process.

But D041 has severe shortcomings as a provider of inputs to the PPB system. First, D041 is so large and cumbersome that only one program can be investigated on each of the four occasions that D041 is exercised annually. During the PPB process, however, many different programs must be considered, along with their resource implications, before one can be selected and money allocated to support it. Moreover, D041 bases its requirements on a backorder criterion (i.e., expected number of unfilled requisitions at base supply), and may enable the support system to achieve low backorders and exemplary fill rates (i.e., likelihood that a requisition can be filled immediately upon receipt) but mediocre aircraft performance. But in the PPB process, the goals of peacetime readiness and wartime sustainability are expressed in terms of aircraft availability. Thus the execution system is not currently able to respond to the program in the manner desired by high-level management. AFLC is currently modifying D041 to base requirements for individual components on aircraft availability. Indeed, this is just the latest in a long sequence of changes to the D041 methodology, and still more changes are scheduled for the future. Thus, the D041 with which the PPB estimating methods must be consistent is itself a moving target.

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bility Measurement System (LCMS). The LMI model deals with the relation between components and availability in peacetime, whereas the Synergy model does so for wartime. Recently, the Synergy model has been extended to deal with petroleum, oil, and lubricants (POL) and munitions as well as with components. The Navy is exploring the use of these and other tools for their own PPB process.

All that has been said above about component management in the Air Force applies with little change to the Navy. Their Aviation Supply Office (ASO) has a system like D041 that helps to manage approximately 64,000 recoverable aircraft components. A computer program called LEVELS [5] estimates buy requirements for individual components, and STRAT [6] accumulates requirements to obtain dollar figures for the PPB system. ASO has additional programs to estimate repair requirements both for individual components and in aggregated dollar form. (For simplicity, we will refer to the Navy system as LEVELS/STRAT, omitting mention of the programs that estimate repair requirements. However, the reader should understand that the ORACLE methodology encompasses repair as well as buy requirements.) The Navy system is too cumbersome to be queried at will concerning the effects of program changes on requirements. The data are updated regularly, and the system itself is changed from time to time. (The Navy has a major "resystemization" effort under way that is intended eventually to replace both the LEVELS/STRAT methodologies and the computer hardware on which they currently run. However, current Navy plans afford no place to aircraft availability.)

The PPB estimating methods of both services, therefore, need to satisfy a demanding set of conditions. They must quickly provide estimates of the cost implications of a wide variety of programs that differ in their peacetime flying, wartime sorties, and all other activities and capabilities specified in the program decided during the PPB process. The estimates must accurately reproduce the estimates that D041 or LEVELS/STRAT would have made, if there were time to submit alternative programs to these systems. And the PPB methods must be capable of being updated frequently, to remain consistent with D041 or LEVELS/STRAT despite changes in the databases and methodologies of these systems.

III. OVERVIEW OF THE ORACLE METHODOLOGY

A NEW PRODUCT FROM D041 OR LEVELS/STRAT

The ORACLE methodology satisfies the demanding conditions of the PPB process. ORACLE is designed to construct an aggregate database as an additional product of the standard D041 quarterly exercise (or the equivalent LEVELS/STRAT exercise in the Navy). This database is small enough to fit in a portable microcomputer and can be manipulated by a spread-sheet-like program to "mimic," in aggregate form, the response of the D041 or LEVELS/STRAT system to program changes. The aggregation takes place over groups of components, so that instead of estimating requirements for individual components, the ORACLE database user estimates dollar requirements for all F-15 components, or for all F-15 components that are repaired at a particular depot, or any other group of components desired by the user.

Because the ORACLE database is derived directly from the detailed execution methodology, it incorporates the same measures of capability used in execution, the same resource categories, and the same relations connecting the two. Because the database can be recreated systematically each time the execution methodology is exercised (given suitable additions to the D041 or LEVELS/STRAT computer programs), it can be updated frequently to reflect changes in the status of weapon systems and logistics support and even changes in the execution methodology itself. For example once D041 has been altered to use aircraft availability targets, an ORACLE database reflecting this could be constructed. And because the database is relatively easy to manipulate, one can rapidly assess the consequences of changes in the program.

We think there are many potential users of the ORACLE database outside the PPB process as well as inside. The AFLC might use it to allocate repair workloads among the Air Logistics Centers (ALCs). For this purpose, one might aggregate across components requiring similar repair techniques. For allocating funds to the ALCs for repair and purchasing, another of AFLC's tasks, aggregating across items managed or repaired at a given ALC might be useful. Individual ALCs might use it to estimate future needs for shop capacities or particular manpower skills. For this purpose, ORACLE could aggregate over components repaired in the same shop or requiring the same skill for repair. The

weapon system manager, another potential ORACLE user, might wish to aggregate items only to the subsystem level, rather than all the way to the level of his weapon system. In the Navy, potential users include the Naval Air Logistics Center (NALC), which manages the Navy depots (called Naval Air Rework Facilities, or NARFs), and the ASO, which is responsible for buying and managing aircraft components.

It is unlikely that any single user would need an ORACLE database aggregated in all of these different ways. But several different ORACLE databases could be constructed whenever D041 (or LEVELS/STRAT) is exercised. Since all of them would stem from the same D041 data and methodology, they would be mutually consistent, but each could be tailored to the specific needs of its user.

OVERVIEW OF D041

To test our ideas, we built a prototype of the ORACLE methodology based on Air Force data and procedures. We had to construct a special test version of D041 for the prototype to mimic, but the test version of D041 is in most respects the same as the production version. Our test version used an extract of the full D041 database consisting of 4596 components[1] in place of the approximately 150,000 components that the production version must deal with. The results shown in this section were generated by our prototype of ORACLE, mimicking the test version of D041.

Figure 1 shows, in schematic form, the component support system as modeled by D041. Peacetime component requirements are driven by programmed peacetime activities at the flight line (referred to as the OIM program, for Organizational and Intermediate Maintenance)[2] and by Programmed Depot Maintenance (PDM) of aircraft and Programmed Engine Overhauls (EOH). As a result of these activities, components fail and are removed from the aircraft or engine, and the

[1]The extract was taken from the D041 database as of March 31, 1980, and contains 4596 items characterized as follows. Each component is peculiar to one of 12 end items (i.e., there are no common components), including seven aircraft (B-52, C-5, C-135, C-141, F-4, F-15, and F-16) and the five engines used by them (F100, J-57, J-79, TF-33, and TF-39). Each component is installed directly on the end item; there are no subcomponents. Finally, nearly two-thirds of the components in the D041 database have had such low historical demands that their requirements are entirely established on the principle that "we ought to have one or two just in case." No such components are in our extract. Rather, all components in the extract have "demand-based" requirements.

[2]For engines and aircraft, the OIM program is expressed in numbers of flying hours, and this is the only kind of OIM program our prototype requires. For other kinds of equipment, the OIM program may be measured in terms of squadron months, equipment months, or drone recoveries.

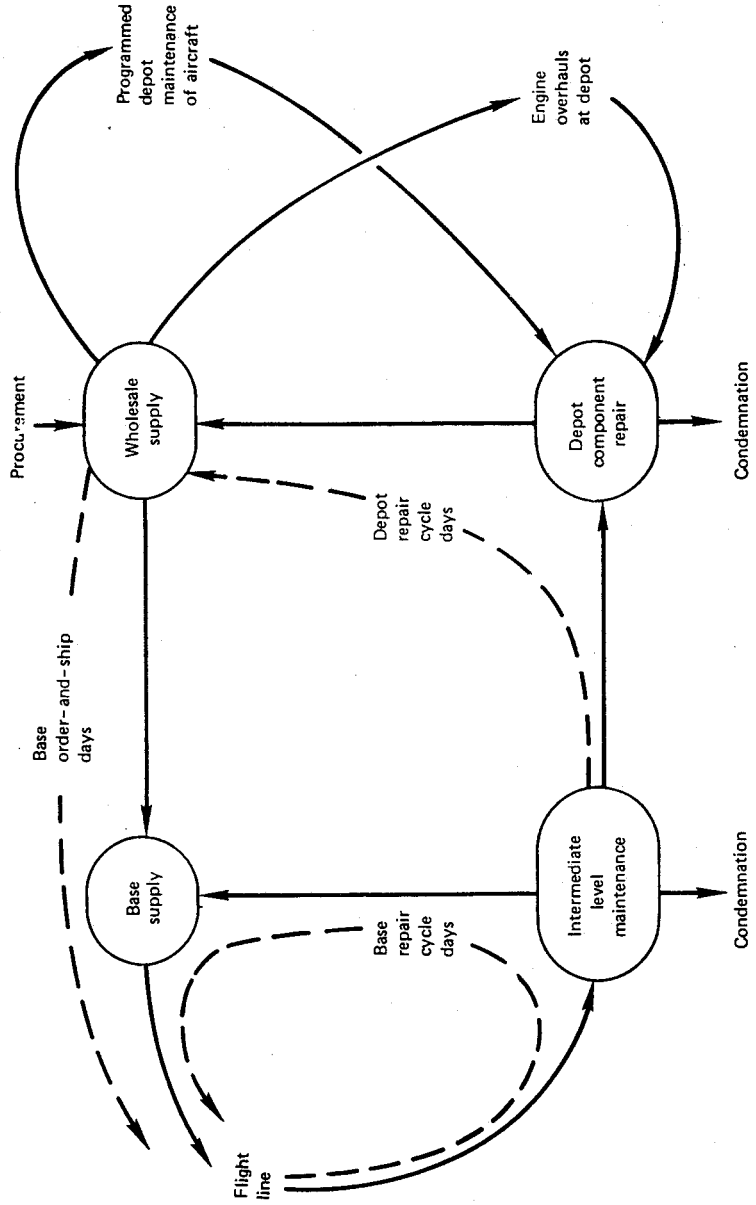

Fig. 1—The component support system as modeled in D041

component support system is asked to provide replacements. The requested replacements constitute "operating requirements." They accumulate over time as more and more components fail; but most failed components can be repaired and returned to service.

Since it takes time to transport and repair components, some number must always be in transportation and repair "pipelines" if replacements are to be provided in a timely fashion. Because the pipeline contents vary randomly and sometimes exceed the expected number, safety levels are provided. In the production version of D041 these are calculated so as to achieve a given backorder target at least cost. But because D041 is soon to be modified, our test version computes safety levels so as to achieve aircraft availability targets at least cost.

Figure 1 does not show it but components are also required to cover planned wartime activities (War Reserve Materiel (WRM) requirements). Finally, additive requirements include requirements for bench stock, foreign military sales—anything that is not calculated from a programmed activity.

Each quarter, D041 computes requirements for each of approximately 150,000 components in ten to 13 quarters[3] beyond the asset cutoff date[4] and presents the requirements in the form of an "item computation worksheet." The item computation worksheet develops the net buy and repair requirements for a component in each of the quarters of its projection (years, for the test version of D041) by first building up the gross requirement out of operating requirements, pipeline requirements, safety levels, WRM requirements, and additive requirements. Then it subtracts different types of assets (serviceable, potential repairs at base level, potential repairs at depot level, etc.) to arrive at the net buy and repair requirements for components.

THE AGGREGATED ITEM COMPUTATION WORKSHEET

Part of the database created by ORACLE is the standard item computation worksheet produced by D041 for each component (or the equivalent produced by LEVELS/STRAT) but aggregated to the weapon system (or other) level. In carrying out the aggregation, we weight the worksheet entries for a component by its purchase price, so

[3]Our test version of D041 estimates requirements ten years into the future and does it year by year, rather than quarter by quarter, as does the production version of D041.

[4]The last day of each quarter is the asset cutoff date for the D041 computation that takes place in the next quarter. As the name implies, data concerning assets on hand and on order are frozen as of that date. The next quarter's D041 computation uses these data to define the takeoff point for its projection of future requirements.

the results are all expressed as a total dollar value of components. (For aggregating the depot repair requirement, we use a weight equal to the repair cost at the depot as well.) The worksheets may be aggregated over all components belonging to a weapon system, or components repaired using a particular technology, or components in a particular FSC (Federal Supply Class—e.g., FSC 6605, Navigational Instruments), or components with long procurement times, or any other group.

Figures 2 and 3 show some aggregations over all items in the extract of some of the entries on the computation worksheet. Figure 2a shows that the gross requirement for any year is the sum of a level requirement that hardly changes from year to year and an operating requirement that accumulates. (Operating requirements were explained above. All other kinds of requirements are level requirements.) Figure 2b shows that the most important sources of assets in satisfying the gross requirement are repair at both base and depot in approximately equal amounts. The buy requirement merely serves to "top things off." Figure 3 differences the assets applied in successive years to determine how much must be bought or repaired in individual years. Note that annual incremental base and depot repairs are quite steady, but the buy requirement has a huge spike in the first year and then dwindles to almost nothing.

We can advance two possible explanations for this. First, it may be that in prior years too little money was provided to entirely satisfy the buy requirement. Indeed, requirements for WRM are never fully funded, and large sums are carried over year after year. Second, the wrong components may have been bought in previous years, so the first year spike may be regarded, in part, as correcting the mistakes of the past, which D041 then assumes will not recur in the future.

But, of course, these "mistakes" will continue. D041 "forecasts" requirements for a series of future years that are completely predictable in all respects. Every component's demands per flying hour (FH), repair and transportation times, condemnation rates, etc., are assumed known. No new components are assumed to enter the inventory except those anticipated at the time of the computation. Future programs are assumed not to change in subsequent PPB cycles. Obviously, all of these quantities cannot be anticipated perfectly. Some of them are certain to change by the time D041's prediction is due, and D041 is flawed by its failure to consider that unanticipated contingencies will arise. The ORACLE database inherits this flaw, since it is developed directly from D041 (or an alternative system) and is structured to reproduce the results that D041 would obtain. In the final section of this report, we will discuss the forecasting problem more fully.

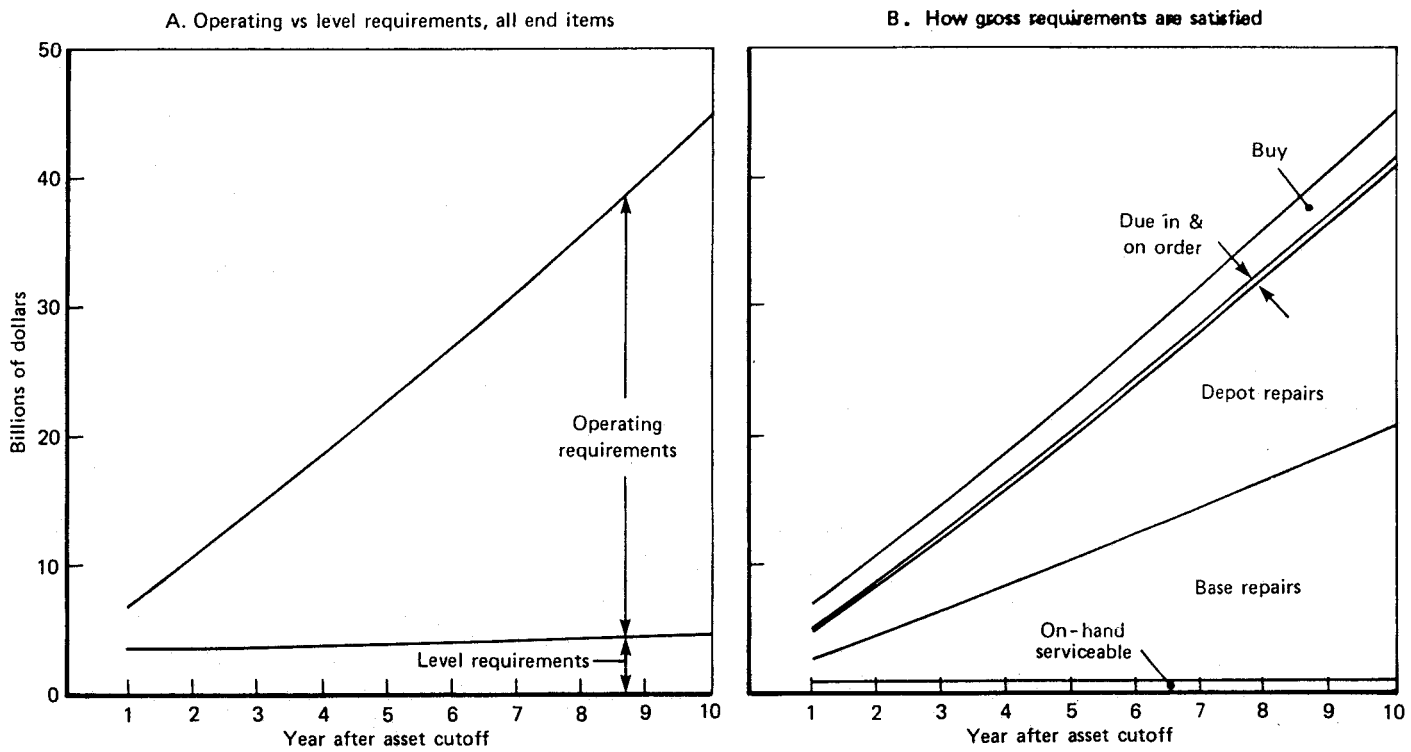

Fig. 2—The item computation worksheet aggregated over all components

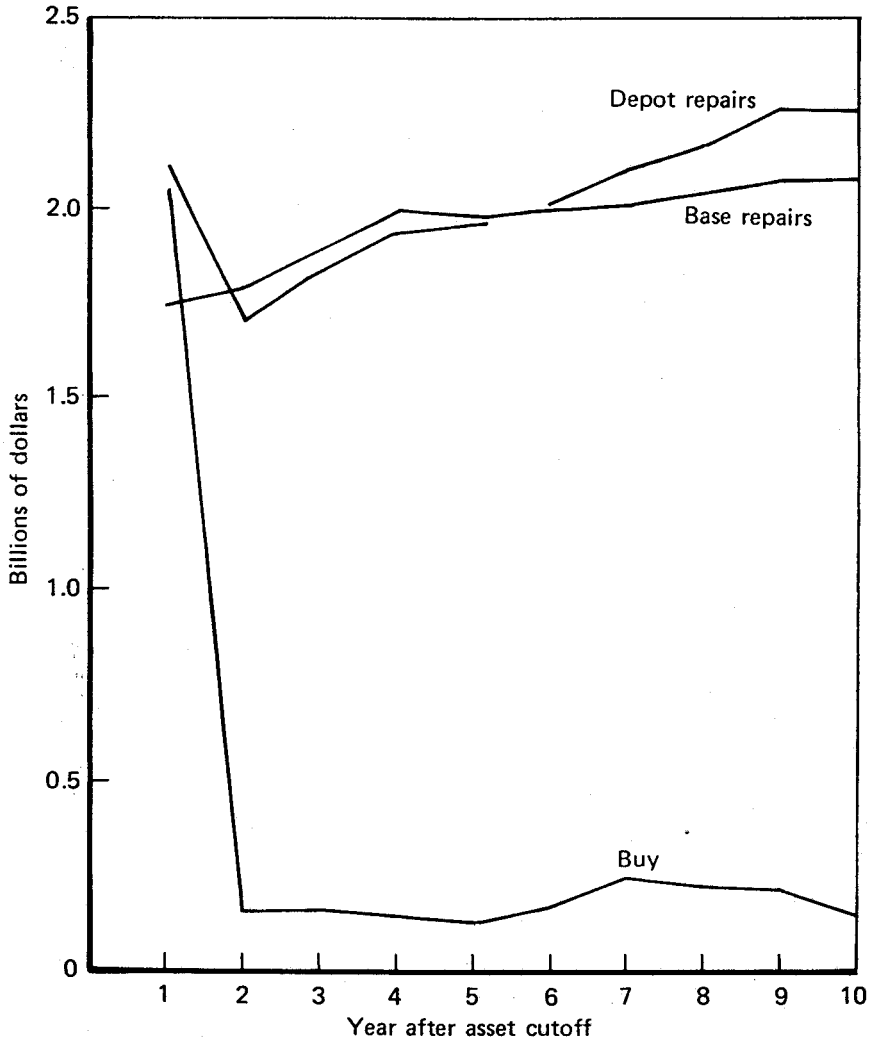

Fig. 3—Annual incremental buys and repairs for all components

Nonetheless, these aggregated figures may be useful. They may point out new demands that future programs will place on the logistics system. Perhaps, due to the changing mix of weapon systems in the force, the repair workload at base or depot may be expected to demand more or different skills. There are about half a dozen depots each in the Air Force and the Navy; perhaps the future workload will require

one depot to grow substantially while another shrinks drastically, unless work is reallocated among the depots. Or perhaps a high and growing value of components belonging to a particular weapon system will be tied up in transit between the flight line and the depot level.

DIAGNOSTIC FACTORS

The aggregated totals described above may provide indicators of some future problems, but to diagnose the reasons for the problems, and to suggest possible solutions, additional factors are needed. In D041, the average number of a component tied up in transit from base to depot, or in repair at the base, or in a variety of other "pipeline" segments, is equal to the level of flying activity of that component multiplied by the demands per flying hour and a pipeline length in days. Similarly, the number that fail and must be replaced in an interval of time (the operating requirement) is equal to the hours flown in that interval multiplied by the demands per flying hour. Other activities than flying hours are considered in D041, namely, PDM of aircraft and engine overhauls, and there are pipeline segments and operating requirements proportional to these as well.

The factors that multiply the flying hours, PDMs, or engine overhauls can be aggregated in the same way as the entries on the item computation worksheet, and over the same groups of components. The aggregated factors generated by our prototype ORACLE, which constitute a second part of the ORACLE database, are shown in Table 1 for engines and Table 2 for aircraft. They indicate which activities by which weapon systems give rise to large requirements.

For engines, perhaps the most interesting factors are those related to the engine overhaul programs. The operating requirement factor gives the value of the components that one expects to replace during an engine overhaul. The potential depot repairs factor shows how much of this value can be repaired, and the potential depot condemnation factor tells how much must be condemned. The final factor shows how much it costs to repair those components that can be repaired. Thus, the cost per EOH of repairing what can be repaired and replacing with new stock what must be condemned is the sum of the last two factors in a column. The TF-33 and TF-39 engines incur very high component-related costs during overhaul. The F100 stands out as having a high proportion of condemned items as compared to repaired items.

Turning now to Table 2, we note that the F-16 stands out as an aircraft for which base repair is relatively ineffective (or was in 1980, for

Table 1

FACTORS RELATING PROGRAMS TO OPERATING AND PIPELINE REQUIREMENTS FOR ENGINE COMPONENTS

FACTOR	END ITEM				
	F100	J057	J079	TF033	TF039
FACTORS RELATING TO DEACCUMULATED OIM PROGRAM					
PURCHASE PRICE ($/FH) OF:					
BASE PIPELINE RQMT/FH	21.79	5.31	7.60	6.86	17.17
DEPOT PIPELINE RQMT/FH	104.66	24.19	17.42	18.67	46.86
FACTORS RELATING TO ACCUMULATED OIM PROGRAM					
PURCHASE PRICE ($/FH) OF:					
OIM OPERATING RQMT/FH	579.22	159.13	196.50	233.11	508.69
POTENTIAL BASE REPAIRS/FH	10.34	18.55	30.48	73.45	91.90
POTENTIAL BASE CONDEMNATIONS/FH	0.01	0.04	0.26	0.03	0.04
POTENTIAL DEPOT REPAIRS/FH	536.86	135.85	150.46	156.10	413.51
POTENTIAL DEPOT CONDEMNATIONS/FH	32.01	4.70	15.29	3.54	3.24
REPAIR COST ($/FH) OF:					
POTENTIAL DEPOT REPAIRS/FH	96.36	38.44	18.24	13.53	22.73
FACTORS RELATING TO DEACCUMULATED PDM PROGRAM					
PURCHASE PRICE ($/PDM) OF:					
DEPOT PIPELINE RQMT/PDM	0.00	0.00	0.00	0.00	0.00

Table 1—continued

FACTORS RELATING TO ACCUMULATED PDM PROGRAM					
PURCHASE PRICE ($/PDM) OF:					
OPERATING RQMT/PDM	0.00	0.00	0.00	0.00	0.00
POTENTIAL DEPOT REPAIRS/PDM	0.00	0.00	0.00	0.00	0.00
POTENTIAL DEPOT CONDEMNATIONS/PDM	0.00	0.00	0.00	0.00	0.00
REPAIR COST ($/PDM) OF:					
POTENTIAL DEPOT REPAIRS/PDM	0.00	0.00	0.00	0.00	0.00
FACTORS RELATING TO DEACCUMULATED EOH PROGRAM					
PURCHASE PRICE ($/EOH) OF:					
DEPOT PIPELINE RQMT	7160.67	4115.61	1826.49	4248.36	100574.69
FACTORS RELATING TO ACCUMULATED EOH PROGRAM					
PURCHASE PRICE ($/EOH) OF:					
OPERATING RQMT/EOH	190819.19	143453.62	446100.19	1470576.00	2675034.00
POTENTIAL DEPOT REPAIRS/EOH	120555.37	125619.12	424734.12	1409687.00	2619036.00
POTENTIAL DEPOT CONDEMNATIONS/EOH	70264.06	17834.46	21366.25	60889.02	56003.30
REPAIR COST ($/EOH) OF:					
POTENTIAL DEPOT REPAIRS/EOH	26394.35	37022.37	48847.02	107639.19	88756.25

Table 2

FACTORS RELATING PROGRAMS TO OPERATING AND PIPELINE REQUIREMENTS FOR AIRCRAFT COMPONENTS

FACTOR	END ITEM						
	B052	C005	C135	C141	F004	F015	F016
FACTORS RELATING TO DEACCUMULATED OIM PROGRAM							
PURCHASE PRICE ($/FH) OF:							
BASE PIPELINE RQMT/FH	318.57	58.56	91.69	31.45	232.83	121.71	193.65
DEPOT PIPELINE RQMT/FH	788.07	100.94	194.89	71.39	798.81	262.42	780.06
FACTORS RELATING TO ACCUMULATED OIM PROGRAM							
PURCHASE PRICE ($/FH) OF:							
OIM OPERATING RQMT/FH	17448.32	3813.90	5389.67	1848.53	12035.15	6416.28	8186.92
POTENTIAL BASE REPAIRS/FH	12026.24	3004.43	4130.11	1265.40	8064.82	4700.69	2266.96
POTENTIAL BASE CONDEMNATIONS/FH	2.61	0.12	12.16	0.78	4.03	2.23	0.02
POTENTIAL DEPOT REPAIRS/FH	5377.49	777.60	1204.04	569.90	3887.07	1674.98	5859.20
POTENTIAL DEPOT CONDEMNATIONS/FH	41.99	31.72	43.47	12.44	79.46	38.39	60.82
REPAIR COST ($/FH) OF:							
POTENTIAL DEPOT REPAIRS/FH	628.53	91.81	247.94	83.33	599.65	135.39	1161.69
FACTORS RELATING TO DEACCUMULATED PDM PROGRAM							
PURCHASE PRICE ($/PDM) OF:							
DEPOT PIPELINE RQMT/PDM	22831.05	100011.69	13502.50	13499.61	12371.62	1534.99	52.47

Table 2—continued

FACTORS RELATING TO ACCUMULATED PDM PROGRAM							
PURCHASE PRICE ($/PDM) OF:							
OPERATING RQMT/PDM	640950.19	2607569.00	268044.31	352183.00	323996.12	40390.04	1252.76
POTENTIAL DEPOT REPAIRS/PDM	623807.12	2601267.00	259270.31	311058.75	306670.75	40279.38	954.30
POTENTIAL DEPOT CONDEMNATIONS/PDM	17143.60	6297.84	8774.27	41125.45	17325.52	110.66	298.46
REPAIR COST ($/PDM) OF:							
POTENTIAL DEPOT REPAIRS/PDM	243956.31	310054.31	50637.56	56355.93	34525.67	3212.88	287.00
FACTORS RELATING TO DEACCUMULATED EOH PROGRAM							
PURCHASE PRICE ($/EOH) OF:							
DEPOT PIPELINE RQMT	31.41	0.00	96.83	46.99	4407.22	0.00	0.00
FACTORS RELATING TO ACCUMULATED EOH PROGRAM							
PURCHASE PRICE ($/EOH) OF:							
OPERATING RQMT/EOH	818.80	0.00	2524.40	3327.82	227749.25	0.00	0.00
POTENTIAL DEPOT REPAIRS/EOH	0.00	0.00	1703.38	0.00	204790.19	0.00	0.00
POTENTIAL DEPOT CONDEMNATIONS/EOH	818.80	0.00	821.01	3327.82	22959.43	0.00	0.00
REPAIR COST ($/EOH) OF:							
POTENTIAL DEPOT REPAIRS/EOH	0.00	0.00	402.83	0.00	28248.97	0.00	0.00

the components in our extract). Over 70 percent of its operating requirement per flying hour is sent to the depot for repair, compared with 20 to 30 percent for the other aircraft. This is because in 1980, when the data used here were current, the F-16 was just beginning to enter the Air Force. Most of its components were still under warranty and had to be returned to the manufacturer for repair. This was coded in D041 as repair at depot level.

The PDM-related factors are extremely low for the F-15 and F-16, compared to the other aircraft. It is planned that neither the F-15 nor the F-16 will ever undergo scheduled maintenance at the depot (barring any work involved with modifications). So PDM-related factors had been entered into the D041 database for only a few components.

The factors in Tables 1 and 2 can be combined to determine average transit and repair times for groups of components, average condemnation percentages, average depot repair percentages, and perhaps other diagnostic quantities. These diagnostic quantities could help determine, for example, the degree to which a high value of repairable components in transit from base to depot is due to: (a) a high percentage of components being repaired at the depot rather than the base; (b) long transportation times; (c) a high rate of failures per flying hour; or (d) merely a lot of flying activity. We have already noted that a very high fraction of F-16 components was being sent to the depot for repair in 1980; although in this case there was a perfectly reasonable explanation, in another case the diagnostics might highlight a real problem. For example, if one calculates the depot OIM pipeline length, which includes transportation from the flight line to the depot and repair at the depot, one finds that it averages around 60 days for all of the aircraft and engines shown in Tables 1 and 2. Is 60 days a reasonable time? Might it not be possible to shorten the pipeline at relatively little expense? This would reduce the requirement for stocks of components and at the same time make the depot more capable of responding in a timely fashion to the needs of the operating forces.

SENSITIVITIES OF REQUIREMENTS TO PROGRAM CHANGES

Finally, it is relatively simple to determine, for each item in the D041 database, the sensitivity of its required purchases and repairs to small changes in various programmed activities and capabilities. These sensitivities are nothing more than derivatives of the requirements (e.g., dollars to buy F-15 parts with procurement lead times over two years for delivery in 1988) with respect to the programmed quantities

(e.g., peacetime F-15 flying hours in 1988).[5] Program quantities a user might change include any that are inputs to D041 or LEVELS/STRAT. The categories of resources affected by changes in these quantities include any calculated during the standard D041 or LEVELS/STRAT computation, of which the most useful are likely to be dollars required to buy and repair components.

The third and final part of the ORACLE database consists of these sensitivities aggregated across the same groups of components and in the same way as the item computation worksheet entries. Table 3 shows the programmed quantities that can be varied independently in our prototype and the different requirements whose sensitivities to these quantities we have calculated. The aggregate sensitivities can help solve two problems with the use of D041 to provide inputs to the PPB process. First, the PPB process considers many different programs in the course of reconciling planning goals with resource limits. The resource implications of all these different programs must be rapidly assessed, but D041 cannot respond rapidly. Second, D041 projects requirements only $2^1/_2$ to $3^1/_4$ years beyond the asset cutoff date. If AFLC's input to the PPB process is to cover the five program years, D041's projection of requirements must be extended $7^1/_2$ years beyond asset cutoff.

To estimate the budgetary implications of changes in such programmed quantities as C-5 peacetime flying hours, or F-15 planned wartime sortie rate, one need only multiply the program change by the appropriate sensitivity factor. If there is more than one program change, one need only compute the budgetary implications of each and add them together. The fact that several program changes can be considered simultaneously suggests using the sensitivities to trade off one programmed quantity against another. For example, suppose one decides to increase the F-16 peacetime flying hours. Then one may estimate what reduction in the planned F-16 wartime sortie rate will leave the dollar requirement to buy components at the same level. Or one might estimate what reduction in C-5 peacetime flying would leave the dollar requirement for buying components constant. The second example would have to involve flying programs three or more years in the future, because C-5 components are not useful to support F-16s, and the decision to trade flying hours of the one weapon system for the other must be made early enough that the proper components can be ordered and delivered by the time of the program change. But the first example might reasonably trade current year F-16 peacetime flying for

[5]The derivative is the rate of change in the dollar requirement as the programmed quantity is varied by a small amount.

Table 3

MENU OF SENSITIVITIES CALCULATED IN PROTOTYPE ORACLE

Programmed Quantities That Can Be Varied Independently[a]	Calculated Quantities That Respond to Changes in Programmed Quantities[b,c]
Peacetime[d]	
Flying hours per year	Total gross requirements
PDMs per year	Serviceable on-hand assets applied[h]
EOH per year	Base repairs applied[h]
Target availability[e]	Depot repairs applied (value of assets)[h,i]
Probability of meeting target availability[e]	On order/due in assets applied[h]
	Required buy of 0-1 year lead time items[j]
	Required buy of 1-2 year lead time items[j]
Wartime[d,f]	Required buy of 2-3 year lead time items[j]
Sorties per day per aircraft	Depot repairs applied (cost of repair)[i]
Sortie length, hours	
Attrition losses per sortie	
Day RRR WRSK repair arrives[g]	
Day resupply from wholesale arrives[g]	
Target availability[e]	
Probability of meeting target availability[e]	

[a] In the prototype, each programmed quantity is specified in each year of a ten-year period. Programmed quantities for different years can be varied independently.

[b] Our prototype aggregates these calculated quantities and their sensitivities to the "end item" (i.e., aircraft or engine) level. That is, one of the quantities will be "value of the total gross requirement for all F-15 components." Another will be "required buy (in dollars) of all C-5 components with a 1-2 year lead time." In the interest of simplicity, the prototype does not consider components common to two or more end items.

[c] All sensitivities are calculated for each of the ten years of the program. For example, the prototype calculates the sensitivity of total gross requirements in year 3 to a change in flying hours in year 5.

[d] There are peacetime and wartime programs for all end items, engines as well as aircraft. Engines inherit their peacetime flying hours and wartime sorties, attrition, etc., from the aircraft in which they are installed. But engines have their own independent engine overhaul programs, and are not involved in PDM programs, whereas aircraft have PDM programs and do not participate in engine overhauls.

Table 3—continued

[e]The form of aircraft availability used by the prototype assumes that full advantage will be taken of opportunities to cannibalize--for example, to obtain a serviceable radio from an aircraft already in need of, say, a fire control computer, and to use the radio to make a second aircraft "available." This form of availability requires two parameters: the percentage of aircraft one desires to be available (the "target availability"), and the probability of meeting that target. An alternative form of availability assumes no cannibalization. It requires only one parameter, the expected percentage of aircraft one desires to be available. The form of availability currently used by the Air Force to calculate war reserve requirements assumes cannibalization is allowed. The form to be incorporated in D041 to compute peacetime requirements assumes no cannibalization.

For peacetime, the prototype needs availability targets for every end item, engine or aircraft. So the F-16 needs a target (e.g., 84 percent available with a probability of 0.5), and the F100 engine that is installed in the F-16 needs a separate target (e.g., 90 percent availability with a probability of 0.5). The availability of the aircraft/engine combination will be lower than the availability of either the aircraft or engine separately. By giving engines and aircraft separate peacetime targets, the prototype conforms to current Air Force practice.

For wartime, the prototype needs availability targets only for aircraft, and it applies them to the aircraft/engine combination. Engines do not have separate wartime targets. This, too, conforms with current Air Force practice.

[f]The wartime program is specified for ten years, but it is not a ten-year war. Rather, requirements are calculated assuming there is a war only in year 1, or only in year 2, etc. That is, we consider ten different, mutually exclusive wars.

[g]The War Reserves Spares Kit (WRSK) is intended to support an Air Force squadron deploying away from its peacetime location from the date of its deployment until supply lines from the wholesale system are established (nominally, a 30-day period). The squadron takes with it repair capability for some of the components in the WRSK (the Remove, Repair, and Replace, or RRR components), but it takes some days to set up this capability and begin repair operations.

[h]Assets applied are assets that can be used to offset some of the total gross requirement. For some components, the available assets will exceed the total gross requirement; the excess does not contribute to applied assets.

[i]Depot repairs are valued in two ways. First, they are valued at the purchase price of the component. In this form they are directly comparable to the total gross requirement and to the other categories of applied assets. Second, they are valued at the cost of their repair. This is a dollars requirement in the budget.

[j]The required buy of components is split into three parts, according to the length of time required to procure new components (the procurement lead time). Components with a lead time of less than one year can be ordered in the same year in which they are required. Components with a lead time between one and two years must be ordered the year before, and components with a lead time between two and three years must be ordered two years before. D041 contains no lead times longer than three years.

wartime sorties, since both programs involve the same weapon system and, hence, to a large degree, the same components.

The sensitivities could also be used in place of average cost factors to extend the D041 projection of requirements to the $7^1/_2$ years needed by the PPB process. As is done today, one would start with the requirements calculated by D041 for the last year of its projection and adjust it by applying program differences between this and subsequent years to the appropriate sensitivities (instead of to average cost factors). The use of sensitivities would improve the results in two ways. First, as explained above, requirements estimates made using the sensitivities replicate D041's behavior much better than estimates made using average cost factors. Second, requirements are sensitive to many programmed quantities (see Table 3) in addition to peacetime flying hours, so adjustments can be made for a variety of program differences. The only average cost factors available are average costs per peacetime flying hour. Using this method requires, of course, that one assume that the sensitivities in the last year of the D041 forecast period are typical of all later years. But this assumption must be made whether one uses average cost factors or sensitivities.

AFLC's current solution to both problems is to calculate average costs per flying hour for repairs and purchase requirements. AFLC excludes one-time and WRM requirements from the last year of the D041 projection and partitions the remaining requirements among weapon systems. The requirements thus associated with each weapon system are divided by that system's programmed flying hours. To project requirements beyond D041's horizon, these average cost factors are multiplied by the flying programs for future years. To adjust the requirements when the programmed flying hours are changed, the requirements projected for any given year are incremented (decremented) by the product of the average cost factors and the increase (decrease) in flying hours of the corresponding weapon system.

The sensitivities computed by the ORACLE methodology can take the place of, and improve upon, the average cost per flying hour factors. Figure 4 compares the two approaches for the F-4; results are similar for all weapon systems. For the repair cost, the two methods compare quite well, but for the buy cost, the average cost is much smaller than the sensitivity. As shown in the next section, use of the sensitivities can replicate the component-by-component D041 computation extremely well. Thus, the average costs per flying hour of buying components must yield a poor approximation.

In the simple case that a weapon system's flying program is constant from year to year, this striking disagreement is easy to explain. D041 will predict that, once past mistakes have been rectified by the first

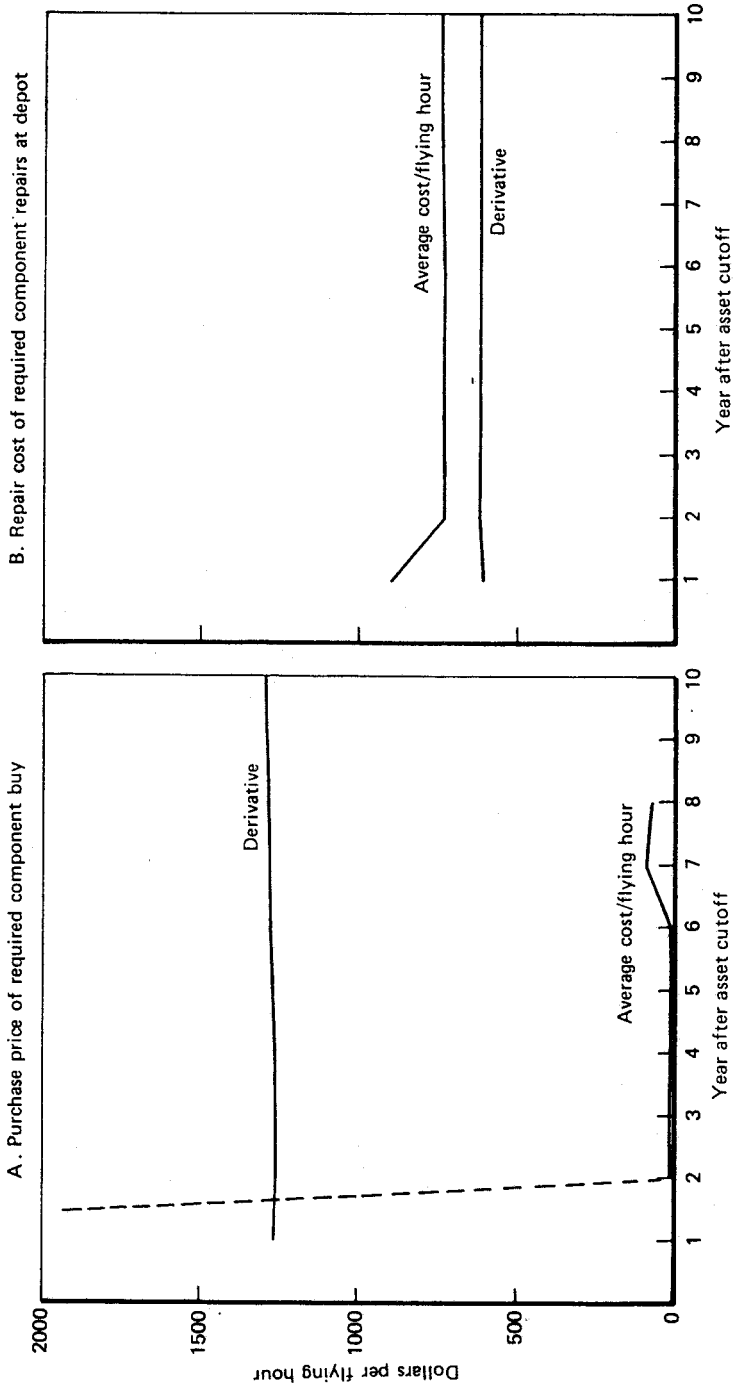

Fig. 4—Comparison of derivatives with average costs per flying hour for the F-4 aircraft

year's buy, further buys are needed only to replace condemnations, and that the average cost factors will therefore equal condemnations per flying hour as shown in Tables 1 and 2. If we now increase the flying program, we will certainly have to replace more condemnations, but we will in addition have to provide more components to occupy the base and depot pipelines, because the rate of flying has increased. As shown in Tables 1 and 2, this additional pipeline requirement (which is accounted for in the sensitivities but not in the average cost factors) is much larger than condemnations. If a weapon system's flying program is increasing from year to year, the buy requirement will include condemnations plus an allowance for increasing the pipeline contents, and the average cost factors will not disagree as badly with the sensitivities. In contrast, if a weapon system's flying program is decreasing from year to year (that is the case for the F-4), the buy requirement will consist of condemnations, reduced by components that are no longer needed in pipelines. Then the disagreement will be worse.

IV. VALIDATION OF THE AGGREGATED SENSITIVITIES

The aggregated sensitivities provide only an approximate way to reproduce in aggregate the results of a detailed, component-by-component computation. Theory guarantees that the approximation is very good for "sufficiently small" changes in program quantities, but we had to carry out a practical test to determine how large the program changes can be and still be "sufficiently small" that the approximation remains adequate. For each of the 12 end items (seven aircraft and five engines) represented in our extract of the D041 database, we considered 45 variations of the peacetime program quantities, and 27 variations of the wartime program quantities. The 45 peacetime variations consisted of all combinations of three levels for the OIM program (nominal, half nominal, and 1.5 times nominal), combined with three levels for the PDM and EOH programs (again nominal, half nominal, and 1.5 times nominal), combined with five different aircraft availability targets (expressed as a percentage of aircraft one wishes to be available, and the probability with which that target is met). We point out that changes as large as 50 percent in these programs will rarely be considered in the PPB process, at least for the major weapon systems.

The 27 wartime variations included changes in the target aircraft availability and the probability of achieving it, changes of 50 percent in attrition rates, sortie rates, and sortie lengths, and changes of 30 to 40 percent in the length of time that prepositioned war reserve materiel (PWRM) must support wartime activities before the depot can resupply the forces and in the time after the start of the wartime scenario at which repair first becomes available for selected components. The 27 variations included these changes in a variety of combinations.

For each end item, the requirements for all 45 peacetime variations and 27 wartime variations were estimated in two ways. First, the variation was used as the program input to the test version of D041, and the requirements were computed component by component and aggregated. Next, the sensitivities (calculated using the nominal program) were used to estimate the requirements, by multiplying program changes from nominal by the appropriate sensitivities. Each variation, peacetime or wartime, consisted of a complete ten-year program, and hence provided ten data points for comparison. Figures 5 through 12 show selected results of comparing the requirements calculated in the two ways. These results are typical, representing neither the best nor

the worst comparisons. But for the dollar requirements for component buys and repairs (the most important quantities to estimate well), the worst comparisons are not materially worse than the examples shown here.

Figure 5 shows the results of comparing the requirements calculated in the two ways for F100 engine parts with a one- to two-year procurement lead time. The points plotted in this figure include only those for the peacetime variations. The horizontal position of a point denotes the requirement for some year of one of the variations, as calculated using the test version of D041. The vertical position of the same point denotes the same requirement, but estimated using sensitivities. If the sensitivities replicated the test version of D041 perfectly, all the points would lie exactly on the solid line.

The agreement is obviously very good, too good, in fact, for Fig. 5 to show the size of the error. In Fig. 6, therefore, we show the error as a percentage of the requirement calculated by the test version of D041. The horizontal position of a point is the same as in Fig. 4, whereas the vertical position gives the percentage error. The largest error, an underestimate of about 1 percent, amounts to about $240,000.

Figures 7 and 8 show the F100 results for the wartime variations. Here the errors are larger, amounting in the worst case to an underestimate of about $6 million. The percentage error is limited to about 10 percent or less, except when the test version of D041 determines that little or no F100 components with one- to two-year lead times should be bought. Then the sensitivities underestimate by a large percentage. It must be kept in mind, of course, that it is a large percentage of a relatively small number.

Our second validation example shows the peacetime and wartime comparisons for the cost of repairing F-4 components at depot level. Figure 9 compares the peacetime requirements from the test version of D041 (horizontal axis) with the estimate made using sensitivities (vertical axis). Again, the error is too small to judge from this figure, so Fig. 10 shows the percentage error. The largest error, which corresponds to an overestimate of 0.4 percent, is about $400,000 dollars.

Figures 11 and 12 show the F-4 results for the wartime cases. Again, the errors are larger, amounting at worst to an overestimate of about $6 million. Observe that the overestimates are much larger in this case than the underestimates. The sensitivities do not provide an unbiased estimate of requirements.

In the above examples, the sensitivities with respect to programmed wartime quantities obviously provide poorer estimates than the peacetime sensitivities. A closer examination shows that the large errors

occur when two or more of the following wartime quantities are changed simultaneously: the number of sorties per day per aircraft; the length of the average sortie; and the attrition losses per sortie. We note that the sensitivities with respect to peacetime flying hours provide very good estimates, and we speculate that sensitivities with respect to wartime flying hours would do as well. But the relation between the above-named wartime quantities and the wartime flying hours is such that the sensitivities provide a poor approximation.

For example, if we neglect attrition, the total number of wartime flying hours in a given period is proportional to the product of the sorties per aircraft per day and the sortie length. If both of these parameters are doubled, flying hours will quadruple. But in using sensitivities, we would add the change resulting from the doubling of sorties per day (for constant sortie length) to the change resulting from doubling the sortie length (for constant sorties per day). By this rule, one would estimate that wartime flying would rise by only a factor of three, instead of a factor of four.

Thus the wartime comparisons might be greatly improved by calculating sensitivities with respect to wartime flying hours instead of to attrition, sortie length, and sorties per aircraft per day. Because the wartime flying program is not steady, it would be necessary to divide the wartime scenario into several segments and to consider flying hours in each. One might consider, for example, flying in the first five days, the next five, the next ten, and whatever period remained after day 20 until support first became available from the depot. Given these sensitivities, one could still estimate the effect of changing attrition, sortie length, or sorties per day per aircraft, by first calculating how the changes in these latter quantities affected flying hours in each of the designated periods, and then applying the sensitivities to the flying hour changes.

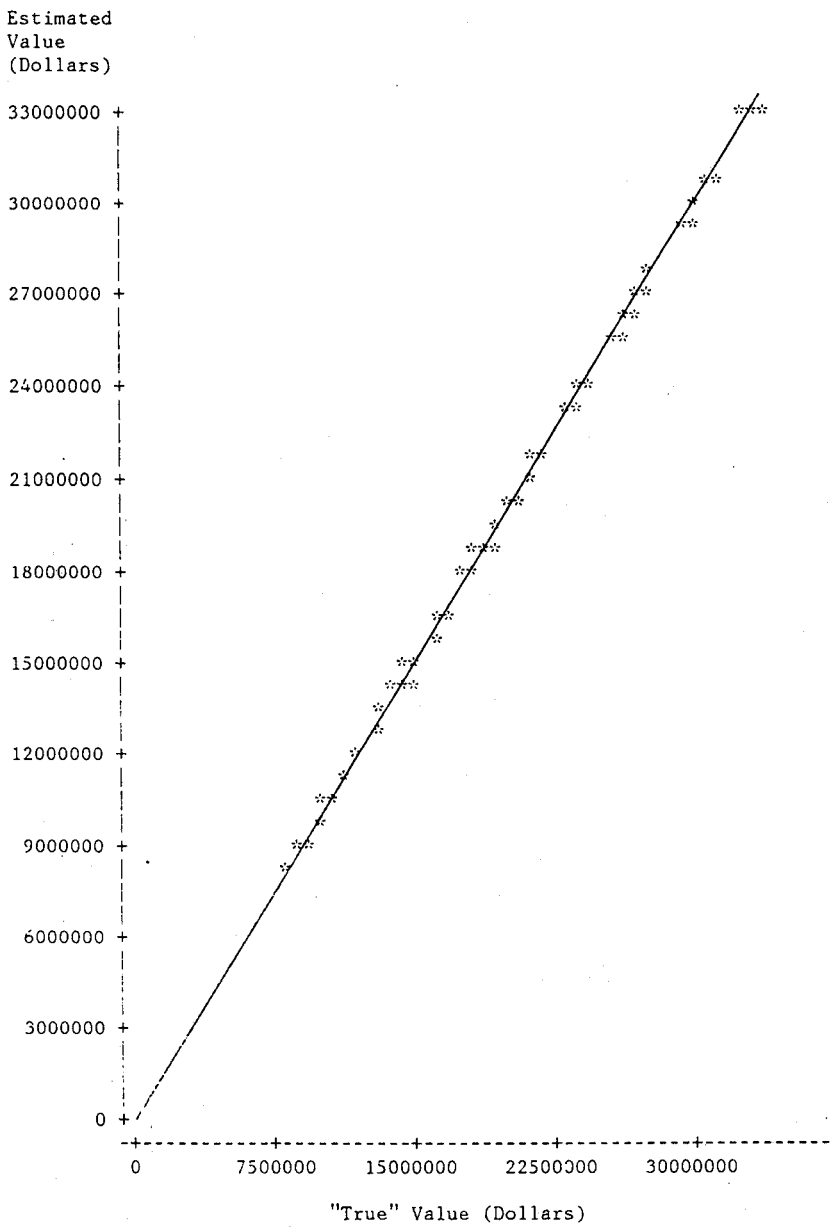

Fig. 5—Estimated vs "true" required buy of 1–2 year lead time items for the F100 engine alternative peacetime programs

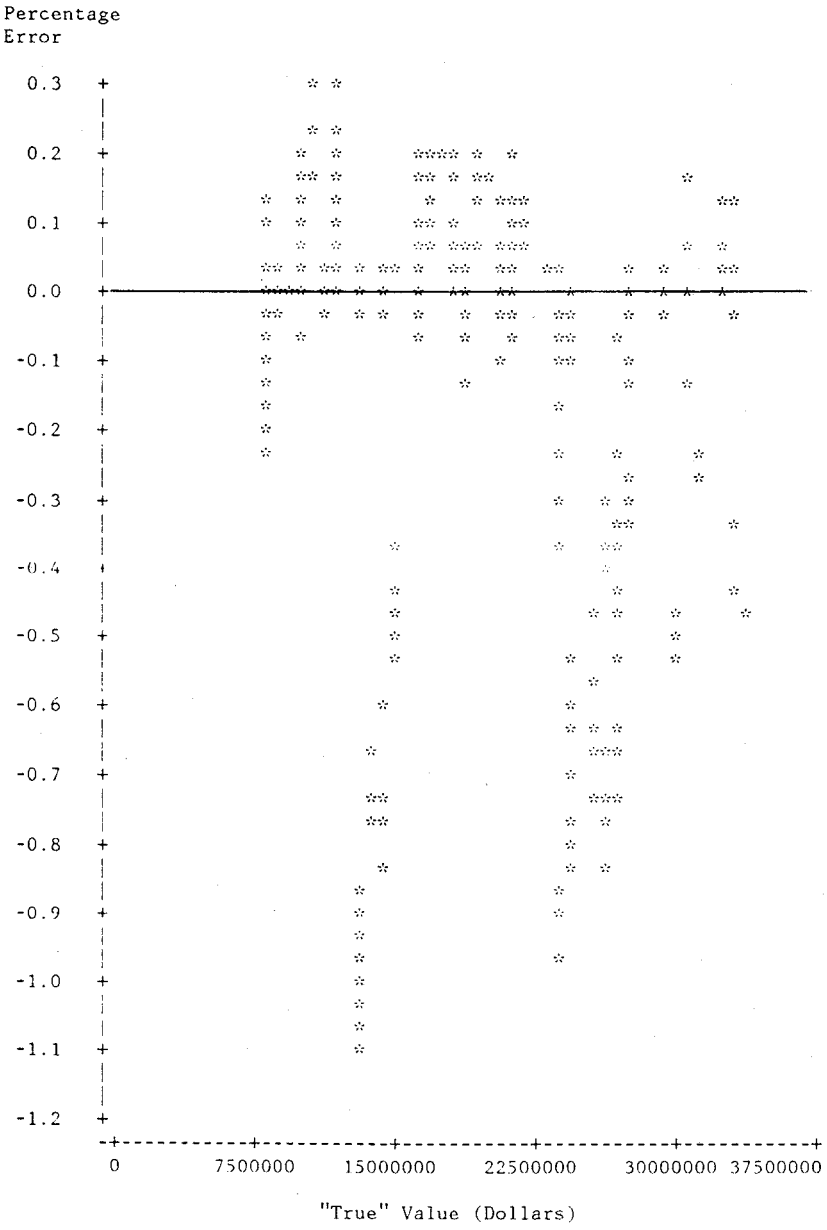

Fig. 6—Percentage error vs "true" required buy of 1–2 year lead time items for the F100 engine alternative peacetime programs

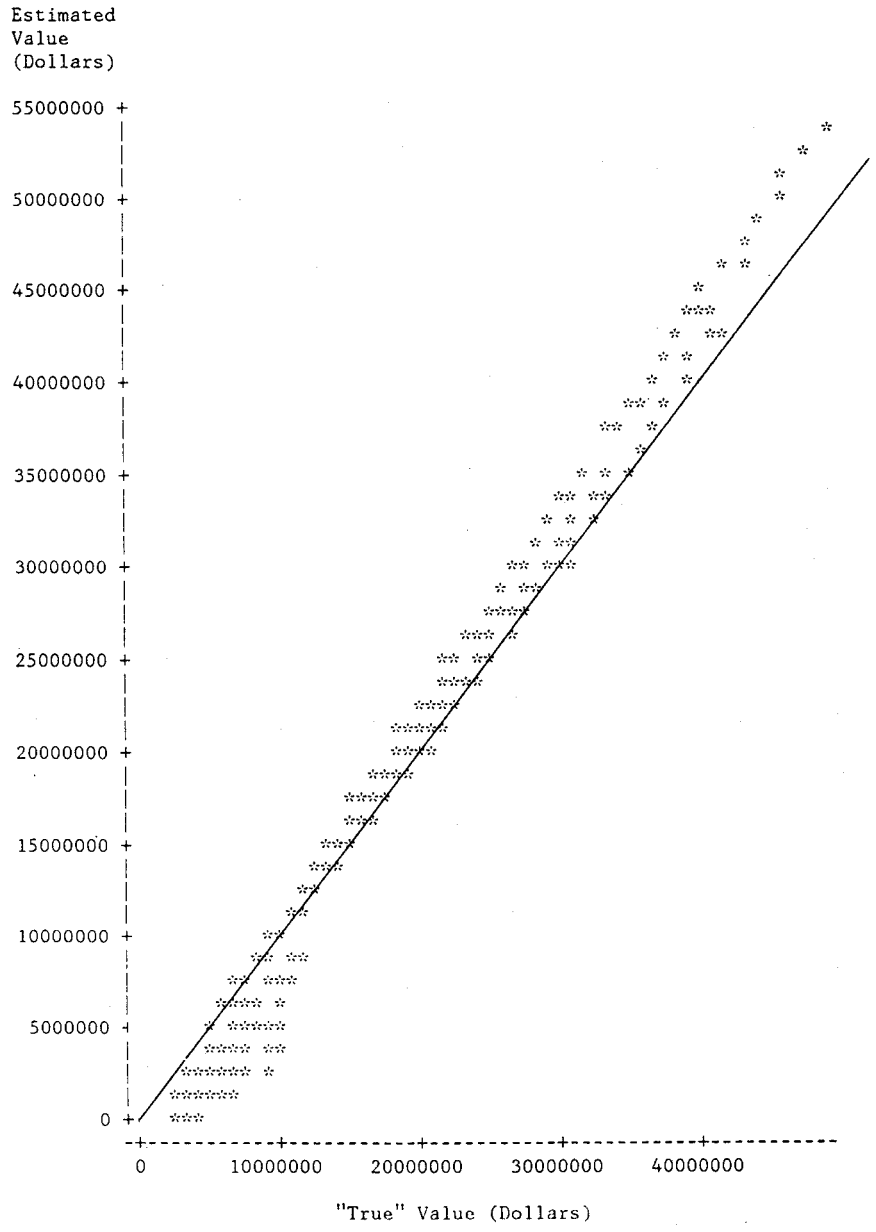

Fig. 7—Estimated vs "true" required buy of 1–2 year lead time items for the F100 engine alternative wartime programs

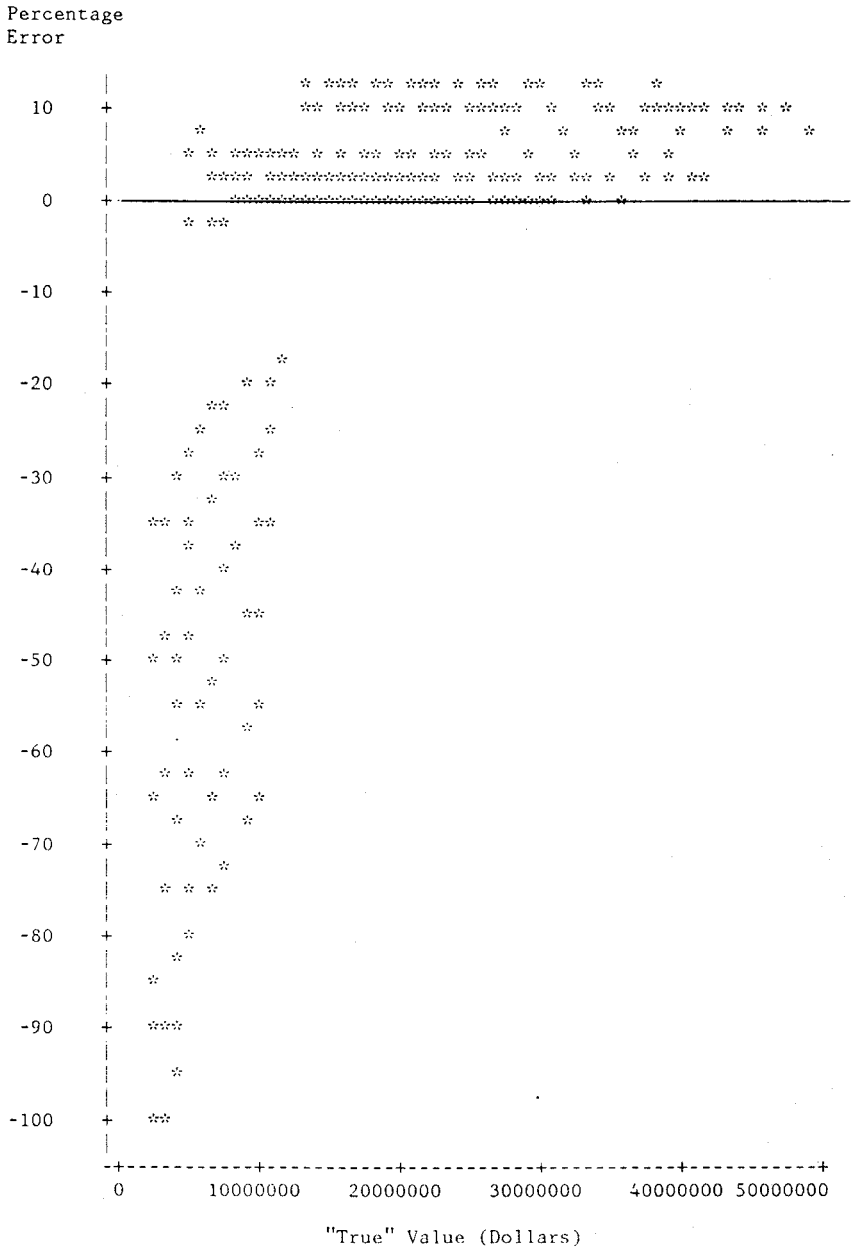

Fig. 8—Percentage error vs "true" required buy of 1–2 year lead time items for the F100 engine alternative wartime programs

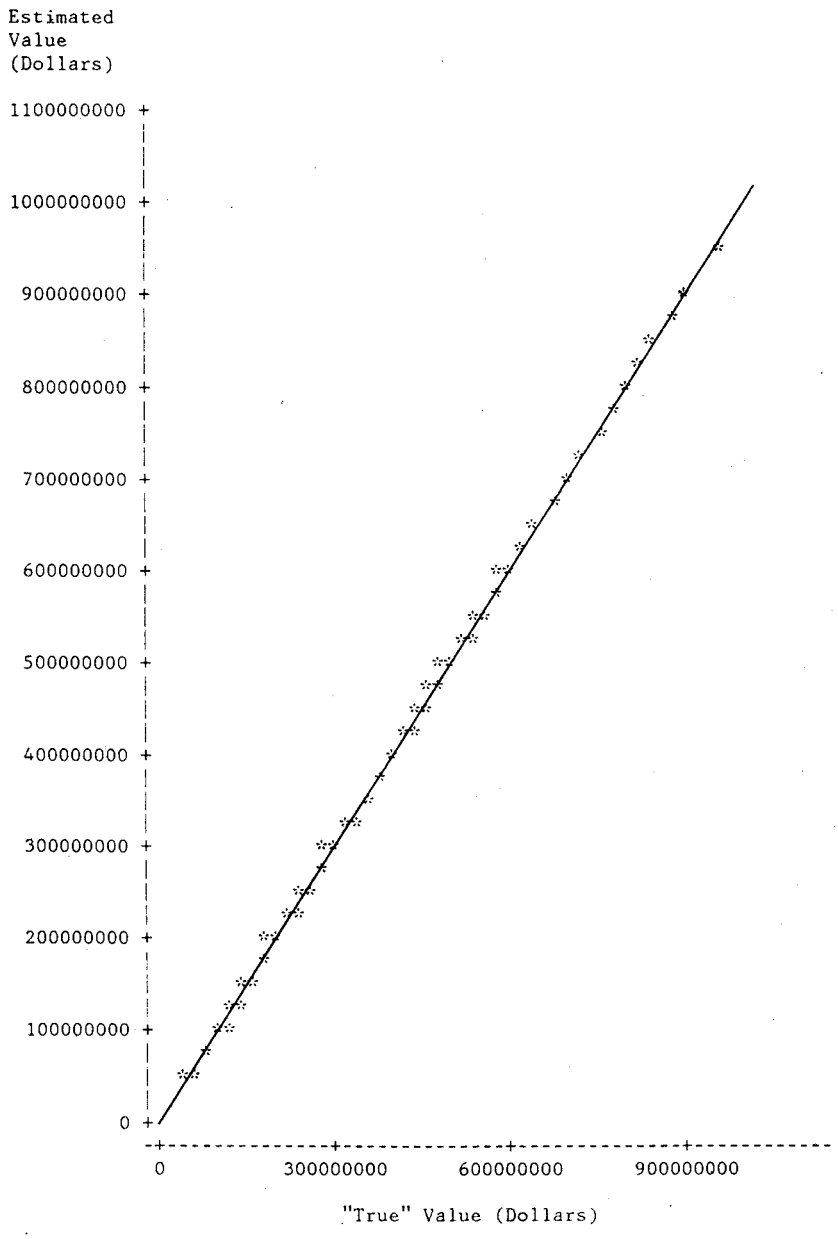

Fig. 9—Estimated vs "true" actual depot repairs (valued at repair cost) for the F-4 aircraft alternative peacetime programs

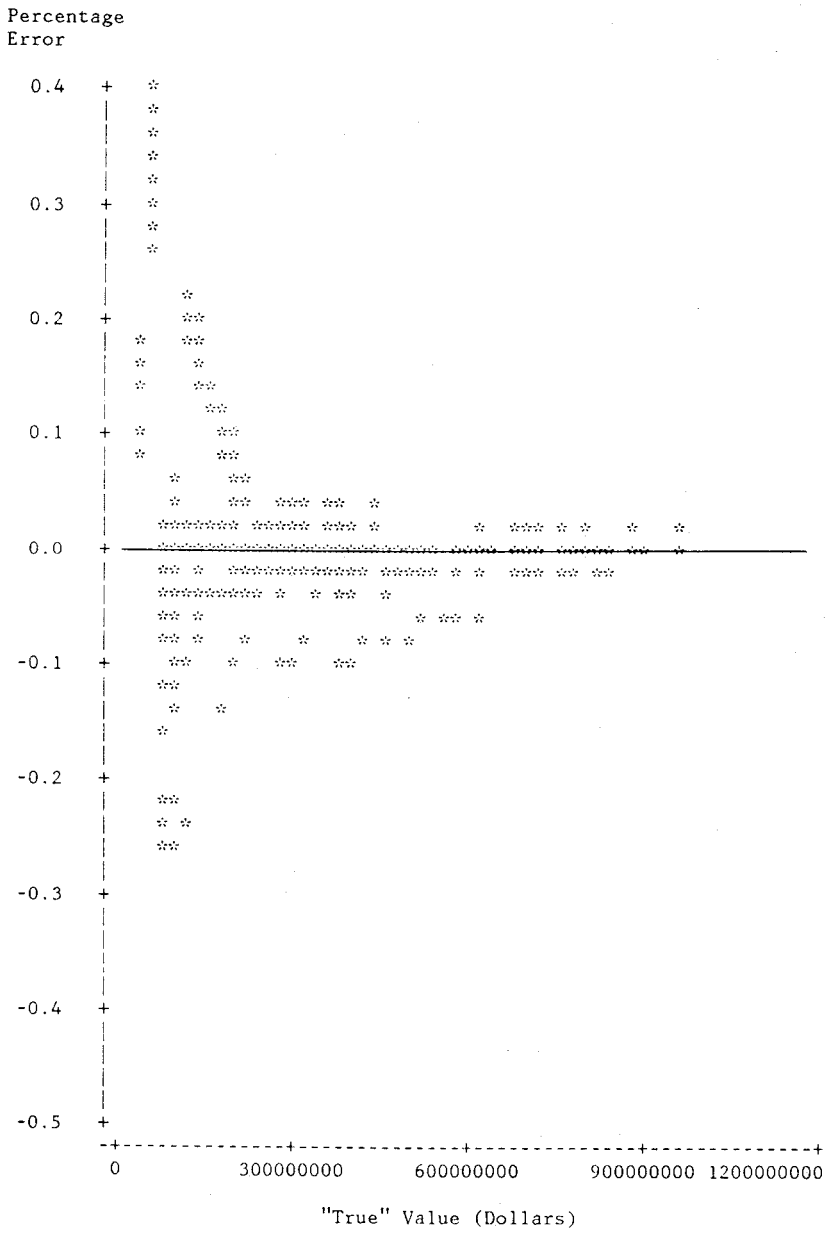

Fig. 10—Percentage error vs "true" actual depot repairs (valued at repair cost) for the F-4 aircraft alternative peacetime programs

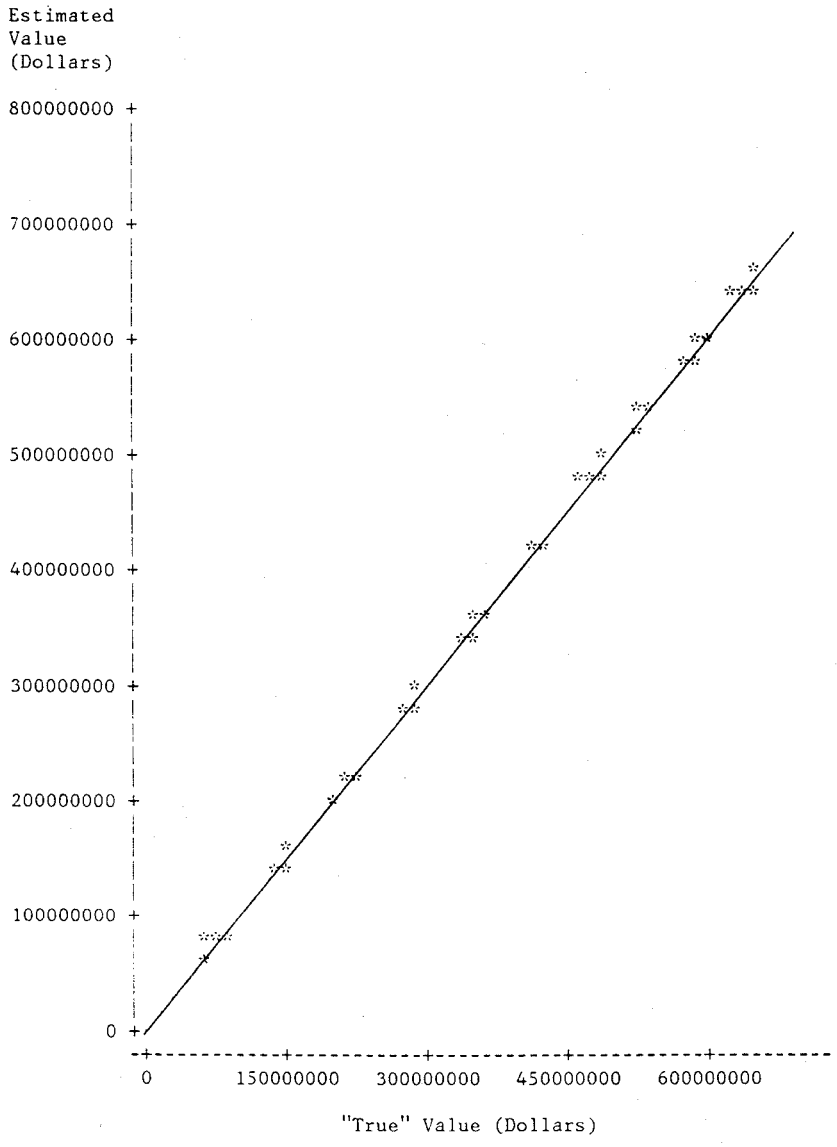

Fig. 11—Estimated vs "true" actual depot repairs (valued at repair cost) for the F-4 aircraft alternative wartime programs

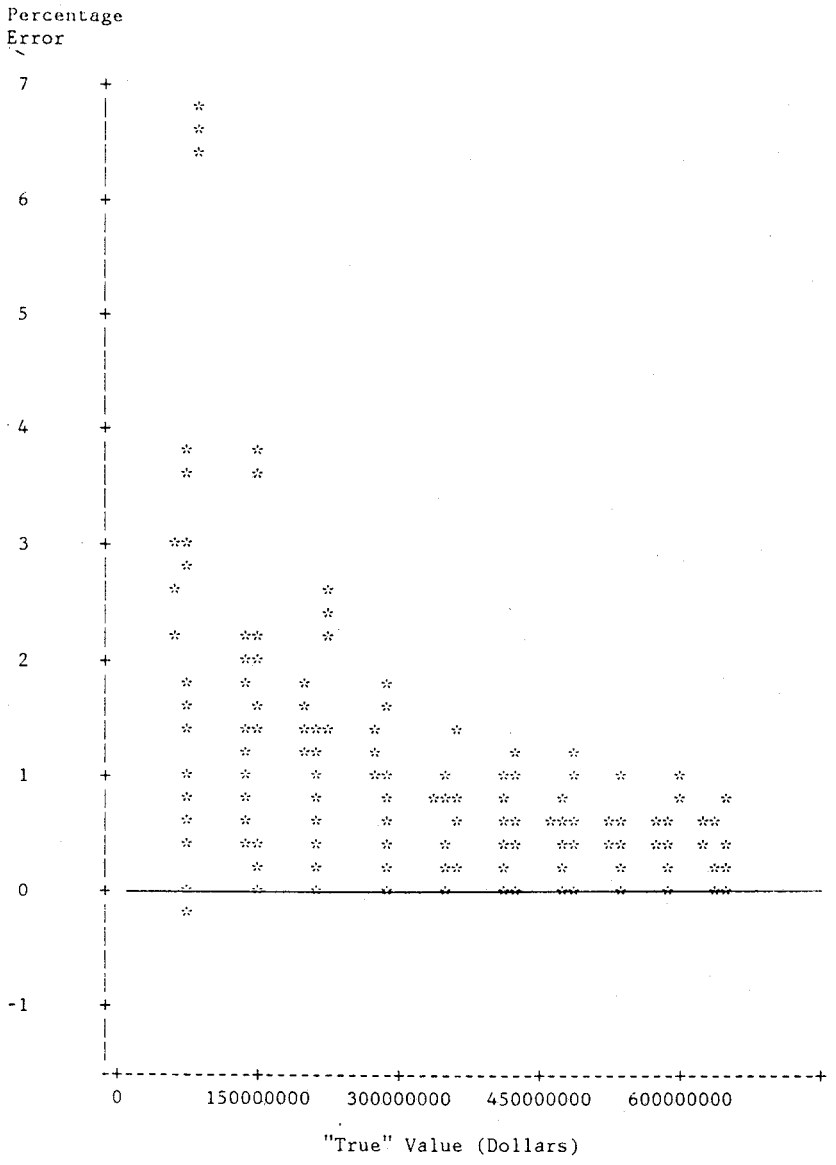

Fig. 12—Percentage error vs "true" actual depot repairs (valued at repair cost) for the F-4 aircraft alternative wartime programs

V. ORACLE IN A LARGER CONTEXT

The ORACLE methodology was developed primarily to help the PPB process better plan and justify the dollars spent on buying and repairing recoverable aircraft components. But ORACLE does not address all the problems inherent in this task. In this section, we discuss two of the most important remaining problems—forecasting, and the tracking and control of execution.

THE FORECASTING PROBLEM

The ORACLE database provides a method for reproducing the aggregate dollar requirements projected by D041 or LEVELS/STRAT for component buys and repairs, without requiring those systems to be exercised repeatedly. But neither D041 nor LEVELS/STRAT was designed for forecasting. Rather, they were intended only to estimate current requirements. Because ORACLE builds its database in such a way as to reproduce the aggregate results of these systems, the ORACLE database also fails to address the forecasting problem.

Forecasting is a problem because of the delay between the start of the PPB process and the eventual results of execution. The funding justified today in the PPB process will not be available for execution to spend for another two years, and components bought with those funds will not be delivered for yet another two years. In that time, demand rates, depot repair percentages, condemnation percentages, etc., will change for many components. Modification programs will design new components to replace old ones. Flying programs anticipated when the funds are planned and justified will have been altered by the time the funds are spent and the components delivered.

Some of these changes may be known in advance, and the item manager may capture them by entering forecast values for the demand rates and other parameters of the components he manages. But this is not a true forecasting capability of D041. It places a tremendous burden on the item manager to correctly forecast future events at a detailed, component-by-component level. But over time, many changes will occur that cannot be predicted in detail. The recent CORONA REQUIRE study [7] identified many recent examples. Because requirements must be estimated (and justified) at such a detailed level, those requirements not yet well described—e.g., a modification program still being engineered—will not be included. Thus, D041 will

tend systematically to underestimate future requirements, and the size of the underestimate will be worse the further into the future D041 attempts to forecast. This explains part of the huge spike that Fig. 3 shows in the first year of the buy requirement.

Unanticipated requirements do not explain the entire spike. Part of it consists of requirements left unfunded in prior years and hence carried over. Historically, this has been the fate of much of the PWRM requirement, and virtually all of the Other War Reserve Materiel (OWRM) requirement. This part of the spike does not represent a forecasting problem, since the requirement has been identified and since it is known that the requirement will persist until funded. But the failure to forecast one requirement may cause money to be reprogrammed once the requirement emerges, leaving a second requirement that has been identified—and funded—without funds after all. Thus, poor forecasting can exacerbate carryovers.

AFLC and Hq USAF attempt to deal with this problem by incrementing the D041 projection with additives. But the additives are still estimated and justified for particular, well-defined programs. All they do, therefore, is allow the effect of a modification program, for example, to be reflected in the requirements statement a bit earlier than would be the case if one waited until D041 were given visibility of the program. But this attempt at forecasting still does not provide its information early enough.

If the forecasting problem is to be solved, it is probably necessary to permit a contingency allowance to be shown as a substantial part of the requirement in future years. This allowance would cover the requirements that cannot be anticipated in detail but which experience has demonstrated will nevertheless emerge. Six or seven years in the future, the allowance might constitute as much as a third or a half of the total requirement. But as a given year approached, more and more of its requirements would emerge, and more and more of the allowance would be allocated to specific uses. By the time that year's budget was submitted to Congress, relatively little of the allowance would remain unallocated.

One approach to determining how large the contingency allowance should be involves studying how the D041 database evolves over time. What magnitude of demand rate fluctuations should one expect of different types of components? How long is a component likely to remain active in the inventory? Under what conditions will it be retired in favor of a newly designed component? And finally, what do these factors imply for future dollar requirements? These questions might be answered by an examination of a sequence of D041 databases from the

past, and from the answers one might devise a forecasting methodology for component requirements.

EXECUTION TRACKING AND CONTROL

Even if one were permitted to incorporate a contingency allowance in future year programmed resources, there would remain an uncertainty in the requirement for that year. In one year, the largest Air Force programs might all go smoothly; in another year, problems requiring unprogrammed expenditures might arise. The size of the uncertainty will be exacerbated by the fact that the buy requirement for components is the difference between a total gross requirement and total assets, both of which are much larger than the difference between them. Thus, a small percentage error in estimating either the total gross requirement or total assets can result in a relatively large percentage error in the estimate of the buy requirement.

This uncertainty guarantees that in some years, enough requirements will emerge to outstrip funding, and this shortage in funding will manifest itself, eventually, as shortages in some components. In addition, the difficulty in forecasting demands for individual components will guarantee that, even when total funding is ample, some components will be underbought and others overbought. Thus, it is certain that the execution system will face shortages of individual components.

Day-to-day managers have a number of policy levers at their command to cope with these uncertainties. For example, they can redistribute stock among flight lines, or from wholesale to other echelons. By providing for dynamic, real-time redistribution, they can reduce the need for safety stock; the portion of safety stock that becomes "excess" can now be used to fill pipelines. Redistributions beyond the safety levels cut into WRM stocks and reduce wartime capability in favor of peacetime activity.

Or they can affect key factors that influence component availability, such as transportation or repair times, by assigning high priority to the components that are short. The processing of components through supply and maintenance organizations is expedited; they can travel by air instead of ship, train, or truck. These measures reduce the time a component spends in the pipelines and hence reduce the number of components in the pipelines. Base maintenance personnel may work overtime to expedite the repair of critically short items. Pilots, knowing that an item cannot be replaced, may fly an aircraft with that item working poorly or not at all, thus reducing the item's apparent failure rate. However, close attention can be given to only a limited number

of components. Thus it is important to single out the components in critically short supply and devote special management attention to them.

Managers need an execution tracking and control system to help determine which components are in critically short supply and to suggest methods to work around critical shortages. To do this, a tool is needed that relates aircraft availability in peacetime and wartime to parameters that describe components, such as the assets on hand, repair times, demand rates, etc. Such a tool is Dyna-METRIC [8], a model developed at Rand.

The Air Force has contracted for the development of the "Combat Analysis Capability (CAC)" system. Under CAC, weapon system managers will be given access to Dyna-METRIC, and the databases needed by Dyna-METRIC will be assembled and kept current. As a tool for day-to-day management, it can provide the kinds of information needed to pursue the stated goals of wartime operational capability. Instead of supply-oriented information related to the current, peacetime situation (how many widgets are currently backordered?), Dyna-METRIC provides measures of the wartime capability of the operating forces (how many aircraft can I expect to have available after a week of war?); and Dyna-METRIC also provides measures of how badly a component shortage hurts (if I lose two more widgets, how many more aircraft can I expect to be grounded?).

We think that by itself, ORACLE should have significant value for resource planning. In conjunction with an improved forecasting capability and an execution tracking and control system, ORACLE's value can only be enhanced.

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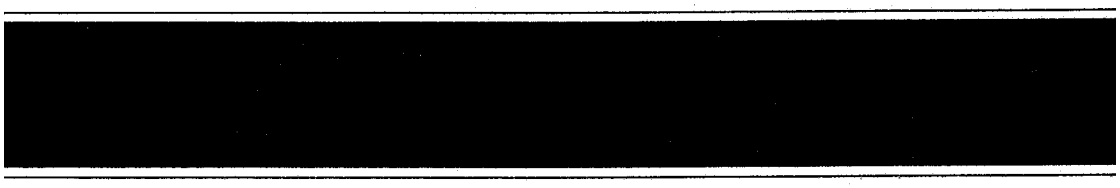
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