COMPARATIVE COST-EFFECTIVENESS ANALYSES AT A NAVAL AIR REWORK FACILITY

John Richard McGarrahan

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

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by

John Richard McGarrahan

Thesis Advisor: N. K. Womer

September 1973

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John Richard McGarrahan
Captain, United States Army
B.S., Wheaton College (Illinois), 1967

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the
NAVAL POSTGRADUATE SCHOOL
September 1973

ABSTRACT

The objective of this study was to compare alternative approaches to the cost-effectiveness analysis of a technological change at the Naval Air Rework Facility, North Island, San Diego, California. Previous studies were reviewed and updated. Econometric techniques were employed to develop additional methods. Each of the methods was used to predict costs for situations both before and after the technological change. These predictions were compared as to their implications concerning the cost-effectiveness of a computerized work-in-process management information system.

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I. INTRODUCTION

After changes have been made in the operating procedure of an industrial organization, the question arises, "Was the change worth the cost?" That cost may be couched in terms of effort, time, friction, inconvenience or, most likely, money. This thesis will be concerned with addressing that question, as well as one that naturally follows: "Now, how believable is the answer given?"

A. BACKGROUND

Since the beginning of calendar year 1972, the Naval Air Rework Facility, North Island (NARFNI), has been engaged in the test and use of an industrial management information system known as the Work In Progress Inventory Control System (WIPICS). As implied by its name, NARFNI is one of seven Naval Air Rework Facilities (NARF) which are responsible for reconditioning U.S. Navy and Marine Corps aircraft. Such reworking includes the overhaul, modification, modernization, preventive maintenance, and repair of a number of different kinds of aircraft and included components. It also serves a small number of aircraft and components each year from the Air Force and Coast Guard, where such aircraft match Navy models. The NARFs operate from the Navy Industrial Fund (NIF) which provides their operating capital base. Customers of the NARF services are charged against their operations and

maintenance funds (typically) for the rework services on either a cost-reimburseable or fixed price basis. The majority of the work is of the fixed price variety, a provision which is intended to promote cost-minimization at the NARF. Neither growth nor depletion of the NIF is desired, so the NARFs are expected to maintain zero profit on their operations.

The introduction of WIPICS, then, represented a technological change at NARFNI in the method of managing its in-process workload. The change was unique to NARFNI in that WIPICS was not installed in the other NARFs. WIPICS is a computerized information system which receives input data from many different control points in the rework process concerning the many different jobs being accomplished on inducted aircraft and their components. At each of a myriad of well defined disassembly, rework, repair, modification, assembly and test junctures, coded status reports are entered into the electronic files concerning each aircraft or component. Input is made via push-button telephone sets located throughout the plant complex. Information concerning the status of a specific aircraft undergoing rework can be retrieved from storage and output through the telephone by means of a limited capacity audio response unit and through teletypewriter terminals. In this way WIPICS was designed to allow many levels of the NARFNI management to be able to follow the progress of the many processes underway in the plant. The managers of the six NARFNI divisions may also

use WIPICS to plan their workloads by determining the status of antecedent operations. With such capabilities it was anticipated that WIPICS would benefit the NARFNI by:

1. allowing positive control of all work-in-process
2. reducing turn-around time for repairs
3. improving production rates [3, p. 9].

In the role of an information system, WIPICS would replace a much less responsive system known as the Uniform Automatic Data Processing System (UADPS). UADPS depended upon equipment which has rapidly become obsolete by advances in computer technology. WIPICS provided a step up to a real-time capability for information storage and retrieval. UADPS was able primarily to store and accumulate historical data which was output *en masse* by accounting equipment. Specific job information was difficult to obtain and not timely when obtained. The UADPS summary outputs proved to be too far after-the-fact to provide real assistance to management in controlling day-to-day operations. Explanation of the organizational structure into which WIPICS was inserted was given in detail in theses by Spooner, Myers and Bradley [6, 3, and 1].

B. PROBLEM ADDRESSED

Naturally, WIPICS has associated with it costs that were not incurred prior to its introduction. Certainly the added informational capability provided a benefit in itself. However, one could well argue that such a capability by itself was actually a luxury for which tax dollars need not be

spent, and other benefits, if any, would have to be demonstrated. The information, if it did help to "positively control the work-in-process," should have been valuable in dealing with schedule bottlenecks, material shortage delays, and other similar work slowdowns. Hence, this positive control ability should have been able to activate a quicker remedy at the point of concern. In looking for the answer to the question, "Is it worth the cost?," it is possible to consider the WIPICS impact on production time required for the jobs handled. If it were possible to assume that the workloads before and after WIPICS was installed were almost identical (or at least closely comparable), one might safely use averages of production time data to ascertain if any benefit had been gained. The required similarity of the workloads, however, was definitely not the case, and this forces the search for a different measure of effectiveness.

It is possible to consider changes in the workload handled by the NARFNI and ask if there was an increase in the productive capability because of the greater efficiency and "decreased turn-around time" due to WIPICS. In order to make such a comparison between the capabilities before and after WIPICS, there would have to have been a high degree of constancy in the work force and identical job mixes across the compared periods. To the contrary, the work force suffered great variation and NARFNI faced very different job mixes over the time periods involved. Hence the search for a measurement goes on.

The pattern described by the examples above was repeated often as examination was made of various ways to approach the basic question of cost effectiveness determination within a dynamic industrial operation. The problem became one of distilling the many internally changing situations and pushing forward a means of capturing before and after "snapshots" of the operation. Within these "snapshots" must be some reasonable estimates of costs which can be compared. That distillation process is not unique, as many techniques provide the opportunity for before and after comparison. Hopefully, clear-cut differences between performances in the two periods of time would be evident no matter what procedure was used.

In view of the inadequacy of the seemingly obvious indicators of benefit, the problem of how to answer the question, "Was the change worth the cost?," had to be attacked less directly. A strategy was developed to approach an answer by the following broad steps:

1. determining those models capable of representing the dynamic industrial situation and its cost flows
2. collecting data needed by the models and using the models to produce their intended "snapshots" of cost information
3. analyzing the "snapshots" for evidence of significant changes in costs
4. analyzing the models to check the validity of their outputs

5. comparing alternative models of the same structure to determine harmony of the results

6. drawing those conclusions allowable from the models, their outputs, and their intercomparisons.

C. EARLIER ANALYSES

References 1, 3, 6, 8, and 9 represent earlier attempts to proceed within the framework discussed above. Spooner [6] detailed the approach procedure and indicated models that would be applicable to this kind of economic analysis. He identified the difference between the continuous and discrete approaches to the problem. He also noted the data elements readily available for analysis and indicated methods for handling the data.

Bradley [1] undertook the development of methods for analyzing the NARF cost flow by a continuous model which made use of aggregate daily statistics that were generated from the NARF's records of individual jobs. His work also was able to estimate production functions characteristic of the time period before WIPICS was in use.

Myers [3] developed a linear programming approach to the analysis of the NARF cost flow. His model made use of data on each particular kind of job and its use of constrained resources. His work also produced an estimate of the costs of operation before WIPICS was in use.

Trafton [8] extended Bradley's work and computed cost functions based on two continuous models. His work developed

representations of the before WIPICS situation based on Cobb-Douglas and Constant Elasticity of Substitution (CES) Production functions. He also used data from the pre-WIPICS period to check the validity of the resulting cost functions.

Tye [9] investigated the validity of the Cobb-Douglas and CES production functions to determine their validity for characterizing the productive operations at NARFNI. He had available data from the period after WIPICS was installed and was able to make some initial comparisons between the before and after situations.

The five theses mentioned above, along with this thesis, are related to an on-going analysis effort undertaken by the Department of Operations Research and Administrative Sciences of the Naval Postgraduate School in conjunction with the Navy's Management Systems Development Office (MSDO). MSDO was charged with the task of developing the methodology for evaluating the management tools in use or contemplated at the seven NARFs. Specifically with regard to WIPICS, MSDO is charged with providing cost effectiveness information to be used in a decision to extend WIPICS implementation to other NARFs.

D. SCOPE OF THIS THESIS

The present work is aimed at bringing together a number of comparisons that have been started in earlier works. The linear programming model will be used to portray the after-WIPICS situation and compare it to Myers' results. Another continuous model will be introduced and evaluated. It will

be used to provide its own comparison of the before and after WIPICS periods. The results of Bradley, Trafton and Tye will be summarized and their comparisons highlighted. Then various models will be exercised, using common sets of data, to test the degree of harmony among the models. The collective results of these measuring tools will then be used to draw conclusions about the ability to perform cost-effectiveness evaluations in this kind of environment.

II. SITUATIONAL COMPARISON

As noted in Chapter I, a naive comparison of obvious performance factors was guilty of grave oversight because of changing conditions at NARFNI. This chapter will set forth some of the more important elements that underwent change as seen in comparing the before and after situations.

A. METHODS OF DATA COLLECTION

The first change and the one for which the analysis is undertaken, concerns the manner in which operational data was collected. This is, of course, the heart of the WIPICS inovation. Prior to WIPICS, information concerning the status of individual jobs undergoing processing in a given department was collected by hand-written record in departmental logs and required reports. Other status information of possible value was often collected in supervisory personnel memories. By adding the UADPS capability, the scribed reports were forwarded to centralized locations for record file updating and storage and for collective reproduction by unit record equipment. Myers [3, p. 11] provides a comparative description of UADPS and WIPICS which indicates the relatively slow and cumbersome nature of the UADPS.

WIPICS was then introduced into the shop operations to improve both the reporting and the record keeping functions. WIPICS provided the capability of direct access by the operating units to the status files of jobs in their domains.

The status updating was done instantaneously by shop personnel sending progress information from push-button telephones directly to the electronically maintained files. These same files can be queried by supervisors, departmental and divisional managers, and staff members to obtain specific reports about individual jobs, departmental workloads and interdependent operations. Further details and specific operating descriptions about WIPICS are found in Bradley [1, p. 22-26] and Spooner [6, p. 11-19]. In essence, then, the change was one of speed and availability of the information, as Myers' [3, p. 11] chart points out. This change constituted the basic impetus of the analysis effort.

B. MODIFICATION OF DATA ELEMENTS

Basic to the financial and managerial accounting effort at any industrial site is the classification of the productive inputs as to directness/indirectness of applicability to the product. Both labor and material usage contain direct and indirect elements. At NARF, material usage can be considered primarily direct because of the nature of both the material and the work to be accomplished. Determination of the number of direct manhours is, on the other hand, subject to constant reinterpretation.

The number of manhours expended (or budgeted) is often central to evaluative and planning efforts, especially in the governmental arena. Manhours directly attributable to the product are characteristically prime examples of the "variable" input. Hence the effort is expended to separate

the labor time and expenditures into the direct and indirect categories. Such separations change from time to time by management policies as new interpretations are made of the "directness" of given labor categories. Most of these categories retain their direct/indirect label over time without switching, but others vacillate over time as a result of differing judgemental factors applied and differing repair program emphases. In addition to policy changes, labor time and spending are subject to some clerical reinterpretation and error of classification. If the policy and clerical reclassification of labor were extensive, there would be considerable scepticism as to the reliability of direct labor data for measuring productive effort. Fortunately, the direct manhour determinations which are stable account for nearly all the direct labor on a percentage basis. Thus the peripheral areas which might change classification are insignificant in their impact on variable labor input information. Therefore, unless more extreme fluctuations occur, this source of change should not affect the WIPICS question. (For cost accounting procedures at NARFNI, see Ref. 4.)

C. CHANGES IN SUBPROGRAM MIX - AIRCRAFT

As indicated in the introduction, the workload of NARFNI changed in character over the time periods under scrutiny. The aircraft program reflected this change in that the mix of subprograms before WIPICS was not the same as that after WIPICS. Myers [3, p. 17] identifies twenty different aircraft upon which NARFNI performs eight different kinds of rework.

In neither the before or after case were all 160 of the possible combinations encountered. Using this background, the before and after WIPICS workload can be compared as shown in Table I. As indicated there, 20 combinations are common to both periods. These twenty common combinations will be used in a number of the comparisons of succeeding chapters. It is worthy of note that approximately 70% of the total aircraft activity is associated with the common combinations in each period. The after WIPICS period data did not include any aircraft of four models which were treated before WIPICS. No new aircraft models were introduced after WIPICS, however.

Similarly, the type of work performed changed in terms of relative importance over the periods. This can be seen in the shift to different work types for a given aircraft. Another factor which is not explicit is the reworking of aircraft for which the normal lifetime has been extended. Instead of purchasing new aircraft as had been planned, older models have been reconditioned and returned to service. Naturally, the older aircraft often required more extensive repair and Progressive Aircraft Rework (PAR). Hence, as aircraft in the after WIPICS period were generally older, the effort required for their rework increased.

Further classification of work types had been envisioned by Myers as he included a provision for recording the PAR cycle number of a job. This would have indicated how many

TABLE I

DATA SET COMPARISON AIRCRAFT

Matching Combinations				Non-matching Combinations					
Aircraft Code	Work Code	Before # Jobs	After #Jobs	Aircraft Code	Work Code	Number of Jobs	Aircraft Code	Work Code	Number of Jobs
				Before WIPICS			After WPIPCS		
10	4	3	4	11	3	25	11	2	11
21	2	48	28	21	1	1	11	6	4
21	4	21	9	22	1	2	21	5	7
21	6	1	11	22	2	16	21	7	8
22	5	16	28	22	4	23	23	2	1
22	6	7	6	23	3	1	23	4	3
25	2	22	2	25	1	2	25	4	4
25	6	9	3	26	1	3	25	5	5
27	2	4	1	26	2	9	26	4	2
27	6	8	1	26	6	2	26	5	1
33	2	2	4	27	1	1	27	5	1
34	3	45	6	31	2	4	32	6	1
35	2	5	2	32	2	3	33	3	18
42	2	11	21	35	1	1	34	1	1
43	2	27	17	41	2	7	34	2	2
48	2	7	4	41	4	1	42	6	1
48	7	16	8	42	4	4	43	4	1
48	8	3	3	44	2	1	43	6	3
49	2	1	15	45	2	2	48	6	1
49	7	1	9				49	8	8

times the aircraft had undergone "treatment" at the NARF. This would have provided a means of distinguishing between older and younger aircraft undergoing a given type of rework. However, due to the complexity of tracing this information it was not available for the after-WIPICS period. Consequently, data of the earlier period have been reclassified to ignore the cycle information. The number of required manhours (NORM) will reflect such aircraft age differences, since the NORM of an older aircraft can be expected to be larger. Though the cycle information is lacking, the NORM data should provide compensating coverage.

D. ENGINE PROGRAM

The engine program, second of the major NARF programs, was not included in WIPICS in the present implementation. Because of its exclusion from WIPICS, it might be possible to draw inferences about activity level and subprogram mix influences on overall plant activities. The engine program underwent changes in subprogram mix similar to the aircraft program. Myers [3, p. 16] also codes the engine and work types, accumulating 26 and 5 possibilities, respectively. Comparative tabulation is not included for the engine program since it will not be directly involved in the before and after WIPICS comparisons.

The exclusion of the engine program does raise a number of questions about the WIPICS impact. Some of these are:

1. Are there gaps in WIPICS aircraft program coverage due to engine program exclusion?

2. Does the exclusion hamper WIPICS scheduling cpaability?

3. Can WIPICS be extended by anology to the engine program?

Though these questions will not be addressed directly, they provide another avenue for investigation. The aircraft program examination, however, can treat these questions as independent.

III. ALTERNATIVE MODEL FORMULATIONS

In order to deal with the situational changes discussed in the last chapter, a number of alternative models have been developed to portray the economic interactions of NARFNI. Each of the models approached the problem of typifying the operational characteristics from a slightly different perspective. Nonetheless, each drew certain key information from a common data base. This data base was taken from financial records of individual rework jobs published quarterly by each of the NARFs under the title, Production Performance Report (PPR). The models and their essential variable components are discussed in this chapter.

A. VARIABLES: DEFINITION AND CHOICE

Each of the mathematical models presented relies on different subsets of the information conveyed by the following variables:

1. NORM - (Number of Required Manhours)

This is determined *a priori* by negotiation between the NARF and the Navy as an estimate of the amount of direct labor input that will be required to perform a given rework operation on a given type of aircraft, engine, or component. This variable is often included in order to provide a before-the-fact weighting of jobs of different models and rework categories. To a limited degree it provides an "index of difficulty" to characterize the rework job.

2. DMHR (Direct Manhours)

This data element is the number of direct labor hours charged against a particular job order. This *a posteriori* measure is the accumulated labor time directly associated with productive jobs. The usual accounting conventions are employed in determination of this factor, subject to the insignificant fluctuations noted previously.

3. DLB$ (Direct Labor Expenditures)

This factor is the actual dollar amount expended for input direct labor services. As such it includes both time and wage rate effects. A wide variety of skills and experience levels at the NARF can be combined in many different ways to accomplish required jobs. This item prices out the DMHR at the rate earned by each of a wide variety of skilled workers. Thus it responds to changes in the particular mix of skills used on each job. Experience levels are similarly reflected in this composite measure, and it is in this area that changes in personnel ceilings become noticeable.

4. P_L (Price of Labor) = $\frac{\text{DLB\$}}{\text{DMHR}}$

This rate is the effective wage rate for a given job or aggregation of jobs. This quotient can be used to compare distinct jobs or distinct aggregations of jobs on the basis of labor intensity. This factor also responds to the kind of labor force mix fluctuations noted above. For example, whenever a reduction of the work force occurs, those most often affected are the lower paid. Then, although a comparable number of DMHR will probably be expended for a given

job, they will be paid for at the higher rate of the remaining, more experienced workers.

5. DML$ (Material Fxpenditures)

This measure is the total cost of all direct materials used for a given job, priced on the basis of individual item costs. Adding the detailed complexity of item enumeration would be excessively superfluous, since there is such a wide variety of materials used and they are not comparable from job to job or from one time period to another.

6. DOH$ (Overhead Expenditures)

This amount is defined in the usual accounting sense and is applied to each job on the basis of the number of expended direct manhours. It includes roughly all other expenses of operating the NARF that would be paid from the NIF. This factor would be affected by overall workload changes. Any fixed operating costs would tend to keep this item high during periods of lower production while they would be spread thinner at higher levels of production.

7. NDAYS (Number of Calendar Days that Equipment Remains at NARFNI)

By implication this measures the number of days the equipment is not available for operational committment because of being in rework. It is also directly proportional to the actual number of work days required to complete the job. As the latter, it would reflect such conditions as material shortages, increased efficiency, abnormal congestion, and job complexity.

8. P_I (Penalty Cost)

This price represents the daily cost of not having a given piece of equipment operationally available. The product of this factor and NDAYS represents the "pipeline" cost associated with having a given aircraft or component in the rework system.

9. NIS (Number of Jobs)

This integer valued variable is the number of actual jobs in process in a given major program (aircraft, engines, etc.) on a given day. It was gained from knowledge of the following data items:

a. IND - Induction date

b. PD - Production date

These are, as their names suggest, the dates on which the aircraft, engine, or component entered and departed the NARF, respectively. A job was accumulated on a given date if that date fell on or between the IND and PD.

The variables described above are those found to be most useful in analyzing NARFNI activity. In his thesis, Spooner [6] described several methods for characterizing the relationships among these variables which would be of value in the analysis effort. Though he did not employ the methods, two of his contemporaries and two successors did use the methods he indicated and extensions of those methods. The remaining sections of this chapter will present the models that were developed and a discussion of each. The particular variables selected from among the foregoing take on, in addition to

their denotative definition, special surrogate roles depending on the way they are handled in each model.

B. DAILY PRODUCTION MODEL

1. Formulation

In his work to develop a model of NARFNI production, Bradley [1] chose to consider a depiction of the daily output of aircraft and engines expressed in terms of NORM. He used the job oriented data from the Production Performance Reports to develop a daily flow of DMHR, DLB\$, DML\$, and NIS by means of aggregation routines. With these variables he constructed this Cobb-Douglas production function [1, p. 54]

$$APH = A(APL)^{\alpha} (APD)^{\beta} (APM)^{\gamma} (NIS)^{\delta}$$

Where

APH = aggregation of prorated NORM over all jobs in process on a given day

A = constant multiplier

APL = aggregation of a prorated DMHR over all jobs in process on a given day

APD = aggregation of prorated DLB\$ over all jobs in process on a given day

APM = aggregation of prorated DML\$ over all jobs in process on a given day

NIS (as defined in Section A)

2. Assumptions

As a basis for this particular attack, Bradley assumed that NORM represented a utility both to the customer and NARFNI [1, p. 42-32]. He used that utility to express the otherwise diverse output of the NARFNI in NORM as a common

term. Hence, the daily output on a particular job was considered to be the completion of a certain percentage of that job's NORM. The sum over all jobs in the program then was taken as a measure of a day's output.

Having decided upon this output measure, Bradley chose the inputs for their contribution to the productive process. The measure of direct manhours was included to account for the "physical units of labor consumed." The total direct labor cost was also absorbed to add the impact of the varying skill levels. "It was considered that both total manhours expended and some consideration of the value of manhours expended would have separate effects on production" [1, p. 45]. DML$ was added to reflect the requirements of material usage on production. The aggregation process assumed that the expenditures of manhours (with associated labor dollars) and materials and consequent production of NORM flowed in an even daily pattern for a given job. This abstraction was used in lieu of a more realistic, but non-available, job production flow pattern. Aggregation techniques proceeded under the additional assumption that work continues seven days per week beginning on the induction date through but not including the production date. This assumption, while clearly not correct, merely has the effect of reducing the work on any given day by a proportionality factor. The variable NIS was included to account for the work flow present in the system at the time. It also was used to portray shop congestion effects. Its definition illustrates its own form of daily aggregation.

3. Procedures

Data concerning activities of a time period under scrutiny were input to the prorate program described by Spooner [6, App. B]. Output consisted of the aggregated values required by the model, representing summaries of day-by-day operations in each of the three major programs - aircraft, engines, and component repair.

In order to estimate the exponents of the three Cobb-Douglas production functions, a logarithmic transformation was performed on the basic model. This rendered:

$$\ell nAPH = \ell nA + \alpha\ell nAPL + \beta\ell nAPD + \gamma\ell nAPM + \delta\ell nNIS$$

This transformation produced a form which was linear in the coefficients, and this form was appropriate for handling by regression analysis. Bradley chose the Biomedical Stepwise Regression Program to perform the analyses [1, p. 55]. The program computed the estimates of the coefficients, associated standard errors, and other values of regression test statistics.

4. Role of Model in Cost-effectiveness Analysis

Bradley anticipated being able to capture in the production function a picture of the manner in which the NARF utilized its resources. By comparing function characteristic of the before WIPICS period with another function determined similarly for the after WIPICS period, conclusions might be drawn about the effect of WIPICS in improving the productive effort. There exists the possibility of one of the three

situations depicted for illustration by a two-input function in Figures 1 and 2. These illustrations show iso-output production functions of two inputs.

Should the results be as suggested by either case in Figure 1, a clear cut distinction between the two periods would be possible and would lead to a definite statement as to the worth of WIPICS. Results of the type suggested by Figure 2 are more likely and would cause doubt as to real distinction between the periods especially if input combinations on both sides of the intersection (z_{1_a}, z_{2_a}) were feasible. Statements about the worth of WIPICS would have to be qualified by limiting the ranges of the inputs, and such statements would have to be tentative.

Bradley's work was preliminary to establishing cost functions characteristic of the operations at NARFNI. The three production functions portrayed by him were intended for use as constraints for the problem of cost minimization. That usage was developed by two subsequent theses.

C. DAILY COST MODEL

1. Formulation

Spooner indicated in his analysis methodology that the developed production function needed to be used to determine a cost function characteristic of each time period in question. Trafton and Tye [8, 9] undertook this effort and extended Bradley's work. They viewed NARFNI as operating to minimize costs subject to the developed production function.

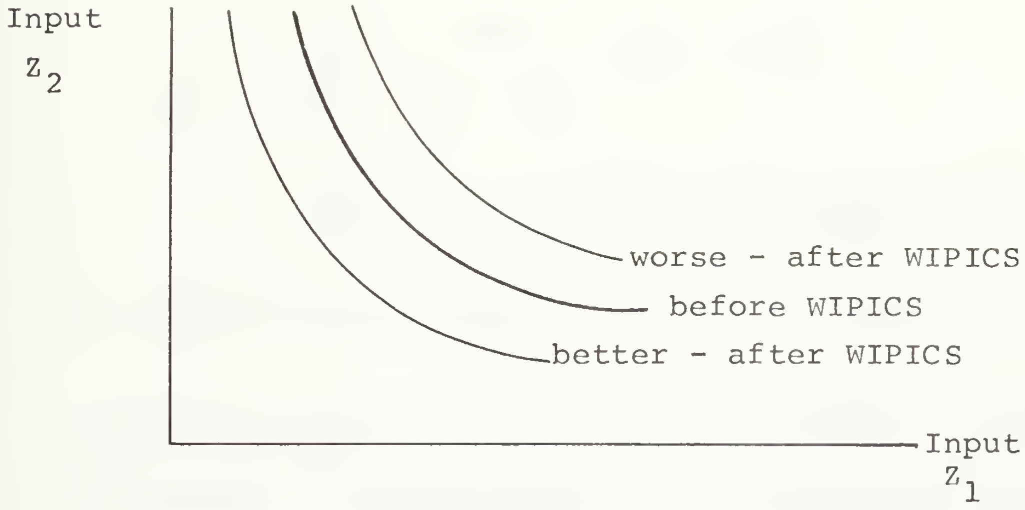

Figure 1. Production Functions, Clear Results.

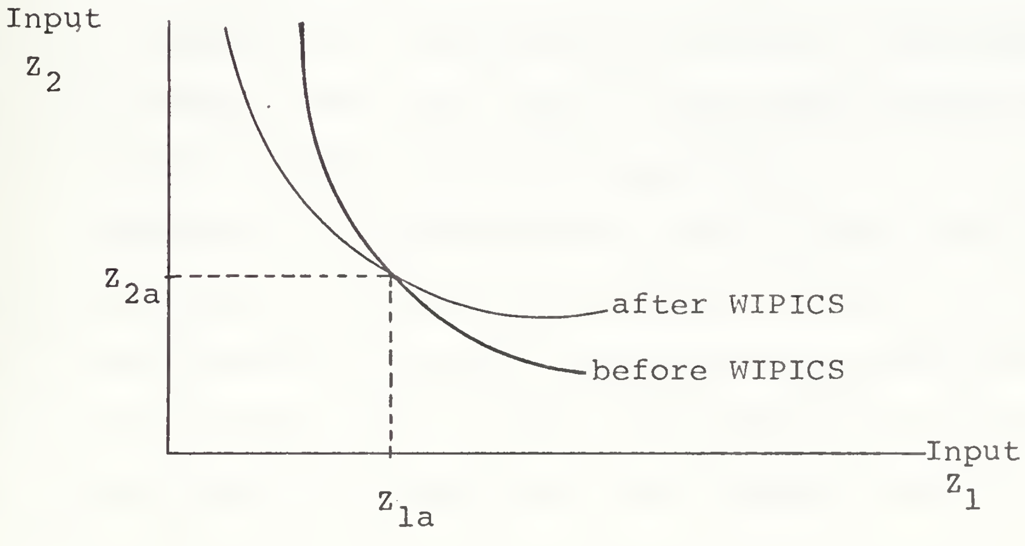

Figure 2. Production Functions, Mixed Results.

Hence they looked at two versions of that minimization problem.

$$(1)\ \text{Min } C = P_L \cdot APL + APM + AP_I$$

$$\text{s.t. : } APH = A(APL)^{\alpha}\ (APM)^{\gamma}\ (NIS)^{\beta}$$

$$(2)\ \text{Min } C' = P_L \cdot APL + AP_I$$

$$\text{s.t. : } APH = \gamma[\delta(APL)^{-\rho} + (1-\delta)(NIS)^{-\rho}]^{-\sigma/\rho}$$

where AP_I is the aggregated penalty cost over all jobs in shop.

The first version was built on the results of Bradley's work which showed the variable APD to be insignificant in explaining NORM. (Actual results on which this was based are given in Chapter IV.) The second version was developed from the more general Constant Elasticity of Substitution (CES) Production function, introduced into the analysis stream by Trafton. Both of these versions included cost contributions from both "operational" and "pipeline" sources. Thus both the actual NARFNI costs and a cost to the supply system/fleet for the awaited product have been considered.

The form of the minimization suggested the use of the Lagrange multiplier technique, per Spooner [6, p. 29]. After forming the Lagrangian function, determining the gradient, setting the gradient equal to zero, and solving for cost in terms of the inputs (for derivation see Trafton, ref. 8, p. 16-21), the respective cost functions of the two versions were determined to be, after logarithmic transformation:

$$(1)\quad \ell nC = a + \frac{1}{\alpha+\beta+\gamma}\,\ell n(APH) + \frac{\alpha}{\alpha+\beta+\gamma}\,\ell n(P_L) + \frac{\beta}{\alpha+\beta+\gamma}\,\ell n(AP_I) + \varepsilon$$

$$(2)\quad \ell nC' = \alpha' + \ell n[P_L + AP_I\,(NIS/APL)] + \beta'\ell n(APH) + \omega D + \varepsilon'$$

where

$$\alpha' = -\frac{1}{\sigma}\,\ell n\gamma$$

$$\beta' = \frac{1}{\sigma}$$

$$\omega = \frac{1}{\rho}$$

$$D = \ell n\,[(1-\delta) + \delta(NIS/APL)^{-\rho}]$$

The data required to support work on these models consisted of the performance data that served as input to Bradley's procedures plus the lists of penalty costs developed by Myers for the linear programming approach [3, p. 39, 40]. Each penalty cost was based on the "average flyaway unit procurement cost" obtained from NAVAIRSYSCOM representatives [5]. The procurement cost for each type of aircraft was prorated evenly over its expected lifetime in days. Each engine procurement cost was spread over a ten year lifetime. Because of a lack of detail in the data for the component program, Trafton and Tye restricted their work to the aircraft and engine programs.

The dependent variables used for the two versions differed due to the independent variables chosen for each. For the Cobb-Douglas version,

$$C = APD + APM + AP_I$$

The CES version used the definition,

$$C' = APD+APO + AP_I$$

where APO was the aggregation of prorated DOH$ (overhead) over all jobs in process on a given day, and AP_I was the aggregation of the penalty costs over all jobs in process on a given day.

2. Assumptions

Building on Bradley's foundation, Trafton and Tye included his assumptions in the development of the models they discussed. Basic to their advancement beyond Bradley's work was the assumption that NARFNI indeed sought to minimize costs subject to the production function constraint. That is, it was assumed that NARFNI tried to minimize the daily costs of performing required daily production, expressed in terms of NORM. This minimization was assumed to be imperfectly accomplished, which gave rise to the error term. The error terms ε and ε', were assumed to be normally distributed with mean zero and constant (but distinct) variances. Hence, the minimization would be assumed to be accomplished with respect to standard costs which are implicit and probably not definable (beyond NORM and its compensated rate). This allows both positive and negative cost variance (in the accounting sense), corresponding to super-efficiency and waste, respectively.

Another assumption stemmed from construction of the penalty costs. Here the basis for this pipeline surrogate was assumed to be the capitalized cost of the respective system. This would seem to be a minimum value to use, and

the straight line amortization probably had more validity than accelerated or usage-based rates which would have been hard to justify and determine.

3. Procedure

Both Trafton and Tye made use of the proration program, modified by Trafton to include a daily proration of the penalty costs based on the type of equipment involved. This computer program produced from the job data cards another set of data cards representing the day-by-day dollar and manhour expenditures in the appropriate categories [8, App. D and E]. From the prorated data, a cost function based on the Cobb-Douglas production function was identified for the engine program and another for the aircraft program.

In order to attack the CES formulation, a two stage technique was used. First the least-squares estimation of the following relation was performed:

$$\ell n(NIS/APL) = a + b\ell n(AP_I/P_L) + \varepsilon''$$

where

$$a = \left(\frac{1-\delta}{\delta}\right)\frac{-1}{\rho+1}$$

$$b = \frac{-1}{\rho+1}$$

The resulting estimate of NIS/APL was then substituted into version (2) for the variable D [9, p. 21]. The second stage regression was then run on the resulting relation of version (2).

Trafton dealt only with before WIPICS data and estimated relations for the Cobb-Douglas and CES cost function for that period only. He validated the resulting model using nine separate 30 day periods to compute actual versus predicted values of total costs.

Tye investigated the stability of the two models he had estimated from a slightly updated before WIPICS raw data set. Then he proceeded to estimate Cobb-Douglas and CES cost functions for engines and aircraft for the period after WIPICS was in use. Prediction intervals were calculated for each of the cost functions. Then prediced cost differentials between the periods were computed based on the models.

4. Role of the Models in Cost-effectiveness Analysis

With Tye's results, another step toward definitive conclusion was completed. The comparison of before and after WIPICS situations was the long desired goal. The cost functions developed by Trafton and Tye provided a basis for such a comparison. Exercising the model for prediction gave indication of what typical workloads would cost in each program in each time period.

Tye also pointed out some of the reservations which must accompany any statements that are conclusions to be drawn from the comparisons of the models. He noted some of the externalities which were not handled by the models. Thus he pointed out the need for independent validation of the results. Such validation is the role of the models to follow.

D. LINEAR ECONOMIC MODEL

1. Formulation

As Bradley was developing the Cobb-Douglas production function, Myers [3] prepared a linear economic model, as suggested by Spooner's methodology, to be used for validation of the continuous model results. In essence, this linear programming approach seeks the solution to the problem·

Minimize Cost = actual dollar cost of resources used to accomplish Z (a vector of job NORMS) + the corresponding penalty costs for the jobs represented by Z

Subject to: accomplishing a given total NORM level and remaining within set resource constraints with that Z.

This represents a verbal discussion of the model for which Myers provides extensive mathematical detail [3, p. 27-29]. Separate models were again formulated for engines and aircraft.

Data used in this model was not prorated by day, but was treated according to equipment type and work type. Codes were assigned for each distinct engine and aircraft model and for each type of rework undertaken on them. (The lists of codes were given as Tables I and II, p. 16, 17 of Myers' thesis.) Production activities were identified from the raw data, and a technology matrix was developed. Penalty costs, as discussed earlier, were introduced in this model. Myers emphasized that the model was not intended as a production management tool but, rather, provided only budget and penalty cost information. He did point out the possible usefulness of tradeoff information that does result [3, p. 30].

2. Assumptions

Myers listed four assumptions concerning the linear economic model:

1) The estimated processes (reworking of engine and aircraft) are linear functions and therefore these processes exhibit constant returns to scale.
2) The above linear processes may be estimated by the aggregation of a finite set of observations over some time period.
3) The NARF is not a profit maximizing organization, therefore the management objective of the NARF will be assumed to be minimization of costs subject to completion of all work demanded by the operational forces of the Navy.
4) Prices used in the model are constant and may be estimated from the production data furnished by the NARF. [3, p. 26-27]

The additional assumption concerning the penalty costs noted earlier was applicable here.

3. Procedures

For the engine program, Myers used cluster analysis to determine the alternative processes available to the NARF to accomplish various kinds of work. A series of four computer routines were used to develop distinct relationships that could be identified as "processes" [3, App. B-E]. These procedures examine vectors of input and output measures to determine any similarity among them. Here the notion of similarity was defined in terms of having approximately the same proportion of input resource usage for unit output. The clustering programs confirmed the uniqueness of the engine type/work type combination as processes.

The engine data was then further sorted by calendar quarter in which the work was done. Where possible,

additional processes were identified by quarter within the work type. Dominance relationships were sought among the centroids of the processes. A program developed for that purpose was applied repeatedly until all dominance was removed among groups having the same output (see Ref. 3, App. G). This having been accomplished, all the remaining observations were averaged to form the estimated process vector which related the output, NORM, to the input variables, DMHR, DML$, DOH$ and NDAYS.

Because of the considerably smaller number of aircraft data observations available it was decided to use the aircraft type/work types as the processes and use all data within those groupings. This resulted in a linear program that had only one choice among the processes to accomplish a particular output. Hence the linear program solution was trivial from the point of view of choosing alternative production plans. It does, however, provide a meaningful relation between workload and costs.

After the process determination was complete, the chosen processes were input into another program which prepared as output data cards in the proper format for the Mathematical Programming System/360 (MPS/360) linear programming (simplex) routine [3, App. K]. Also included in the input to the preparatory program were the penalty costs which Myers had computed,[1] the production requirements, the resource

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[1] Due to a systematic error, these costs were determined to be incorrectly calculated. Corrected factors are listed in Chapter IV, Section F, of this thesis.

constraints, and an average labor rate. The output of the preparatory program was then input to the MPS/360 program for solution.

4. Role of the Model in Cost-effectiveness Analysis

As stated earlier, it had been hoped that the linear economic model would have been able to provide validation for the results of the continuous models. Myers did expect any measurable decreases in input usage per unit of output to be evidence of an improved situation after the WIPICS installation, or the contrary. The changes could then be associated with a dollar value to determine savings or cost growth.

As only the aircraft program turned out to be of interest, the measures provided by the linear model would only be of the grossest variety due to the data limitations. The linear model solution provided the total cost computation and estimates of the process in the format of inputs per unit output. The total cost can be compared for the before and after WIPICS situations. Processes with the same output can also be compared for the two periods. Further validation can be sought from continuous analogs of the linear model, which follow immediately.

E. JOB COST MODEL

The derivation of the Daily Cost Model's relationship between cost and input factors highlighted some of the independent variables used in the present model. The formulation and development of the Linear Economic Model emphasized the

differences between the subprograms and the need to allow for those differences. A means for blending these important considerations into a continuous relationship was provided in the current model.

1. Formulation

Although the Cobb-Douglas production function form would usually be applied to physical outputs in terms of physical inputs, one could approach cost flow itself, *a priori*, as the product of input cost determinants in a similar functional form. This model considered the output to be the cost flow from a given aircraft type and work type combination. An alternate derivation of the relationship is provided in reference 2. Couched in terms of the original variables, two versions were constructed:

$$(1) \quad C_i = \alpha_i (P_L)^{\beta_1} (PD)^{\beta_2} (\overline{NIS})^{\beta_3} (NORM)^{\beta_4}$$

$$(2) \quad C_i' = \alpha_i' (P_L)^{\beta_1'} (NDAYS)^{\beta_2'} (\overline{NIS})^{\beta_3'} (NORM)^{\beta_4'}$$

where $i = 1,2,...n$ = number of aircraft type/work type combination

$\overline{NIS}$ = average number of aircraft jobs in shop over the period when jobs in category i were undergoing rework

Thus n different functions of each version are proposed: each with its unique constant but holding a common relationship among the explanatory variables. In a hybrid of matrix and standard notation, the n equations can be combined for each version in a single function:

(1) $C = (A\psi_i)(P_L)^{\beta_1}(PD)^{\beta_2}(\overline{NIS})^{\beta_3}(NORM)^{\beta_4}$

(2) $C = (A'\psi_i)(P_L)^{\beta'_1}(NDAYS)^{\beta'_2}(\overline{NIS})^{\beta'_3}(NORM)^{\beta'_4}$

where $A = (\alpha_1, \alpha_2, \ldots \alpha_n)$

$A' = (\alpha'_1, \alpha'_2, \ldots \alpha'_n)$

ψ_i = column vector with zeroes for all elements except the i^{th}, where a 1 is placed; that is, the i^{th} canonical vector.

The model was used to explain three different forms of cost, analogous to the three objective functions Myers considered. For versions (1) and (2) the dependent variables chosen were:

(a) TC(Total cost) = DLB\$ + DML\$ + DOH\$ + P_INDAYS

(b) OC(Operations cost) = DLB\$ + DML\$ + DOH\$

The third form was used only with version (1) due to the respective definitions of the versions.

(c) PC(Penalty cost) = $P_I \cdot$ NDAYS

Work on both versions called for the raw data. Also required was determination of the number of all aircraft jobs in rework on each day during the periods under consideration. Finally, a listing of daily penalty costs was necessary. Only the aircraft program was considered due to the exemptions of the engine program from WIPICS implementation.

2. Assumptions

Basic to the structure of the model was the assumption that cost can be treated as a product of internal influences

and can be fit into the mathematical framework. The internal influences were portrayed, first, by P_L which took on the surrogate role of an indicator of complexity of a job. Recalling that it is defined as $\frac{DLB\$}{DMHR}$, it was thought to respond well to the effect of the use of higher skilled labor on jobs of greater complexity. $\overline{NIS}$, the average number of jobs in the shop during the rework of a given job, represented congestion within the plant. It would reflect the impact of the greater inefficiencies that result from increased congestion. It was assumed that the NARFNI would not be operating in so low a range of $\overline{NIS}$ that there were very few jobs in shop and plant size inefficiencies developed. NORM provided information concerning the sheer size of the task to be accomplished.

For version (1), PD was used to account for the trend of costs to grow over time. Included in that growth would be inflationary effects in the materials and overhead contributions and the effects of age of the aircraft which would also be seen in materials and overhead increases. NORM would probably account for any direct manhour increases that were the result of working on aging aircraft. For version (2), NDAYS would provide the alternative view of effects due to the amount of time an aircraft spent at NARFNI. The most directly affected cost would be the penalty cost, but this measure would also reinforce complexity effects in the "operational" costs.

The model, as pointed out in the previous section, assumed that production of costs was the result of common influences up to a multiplicative constant. This would be justified on the basis of the fact that, though many different subprograms are accomplished, the same departments and divisions of the plant are used across the subprogram mix. The constant factor would tend to "price" the aircraft type/work type combinations according to their relative materials and overhead mix characteristics. Within the categories, the individual jobs were considered homogeneous enough to justify the groupings.

By implication, the costs predicted by the model were not related to a particular optimization goal within the NARFNI. Rather these predicted costs serve as a type of standard cost structure for the operation. The dependent variable was measured in terms of actual costs and hence give rise to a stochastic discrepancy. Hence the two versions of the model were really assumed to be represented by

$$(1) \qquad C = (A\,\psi)(P_L)^{\beta_1}(PD)^{\beta_2}(\overline{NIS})^{\beta_3}(NORM)^{\beta_4}\,10^{\varepsilon}$$

$$(2) \qquad C' = (A'\psi)(P_L)^{\beta'_1}(PD)^{\beta'_2}(\overline{NIS})^{\beta'_3}(NORM)^{\beta'_4}\,10^{\varepsilon'}$$

The error terms (ε and ε') were assumed to arise from deviations from the "standard cost." Such deviations were assumed to be the result of greater or lesser than standard efficiencies gained from "non-standard" skill level mixes. Alternatively or additionally, any difference of DMHR from NORM would also be a basis for the existence of

the error term. Finally, the assumption of the standard linear model were applied to the logarithmic transformation of the two versions above (see Thiel, ref. 7, p. 110-111).

3. Procedures

In order to gain information concerning the number of aircraft in shop, NIS, on a given day, Trafton's version of the aircraft prorate program was used [8, App. D]. It was modified slightly to accomodate the entire three year range of data. All aircraft data cards were used to obtain the most complete historical record possible. The output deck included all the aggregated prorated variables in addition to the desired NIS. Only the last was used, however, along with the raw data, as input to the regression program.

Also calculated for input to the regression program was a revised list of penalty costs, correcting a systematic error in Myers' list. The final inputs were the raw data cards themselves separated into before and after WIPICS sets. A "buffer" time period of induction dates was excluded to aid in the distinction between the before and after data sets. The buffer was characterized by induction date before WIPICS and production date after.[2]

These inputs were prepared and assembled for use with the regression program given as Appendix A. This program produced a stepwise regression, admitting each of

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[2] Due to the long time period required for aircraft rework, a number of the jobs included in the before WIPICS set also had this feature. In these cases, the majority of the productive effort was before WIPICS.

the explanatory[3] variables in order. Inclusion of the separate categories was accomplished by creating a dummy variable for each. (See Theil, ref. 7, p. 155-156.) Structure of the model for regression then became, in general:

$$C = X\beta + \epsilon$$

where C is an $m \times 1$ vector of the logarithms of the dependent variables

$X = \begin{bmatrix} K & Z \end{bmatrix}$, is an $m \times (n+4)$ matrix of dummy variables and logarithms of the explanatory variables

K is an $m \times n$ submatrix such that each row contain one value of 1 and the rest zeros. That non-zero value falls in the column corresponding to the aircraft type/work type category.

β is an $(n+4) \times 1$ vector of coefficients

Z is an $m \times 4$ submatrix of logarithms of the explanatory variables

ϵ is an $m \times 1$ vector of disturbances

n = number of categories

m = total number of observations

Solution procedures proceed as described by Bradley [1, Chapter II, Section B]. The regression program also provides the standard statistical test values.

Regression estimates of the parameters were accomplished for both the before and after periods. The estimated relations were then used to predict cost values for two test cases drawn from the 20 categories present in both the before and after periods. The process was repeated for both of the

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[3] Explanatory is used here to distinguish between input production variables and the constants which are based on the categories, even though those category-related constants "explain," in a sense.

versions and for each dependent variable structure. Standard errors of the predicted total costs of all jobs in the test cases were computed as the mean square error.

4. Role of the Model in Cost-effectiveness Analysis

The job cost model served to provide a basis for validation of Tye's results. It was thus able to overcome some of the weakness of the linear programming formulation.

The model also provided its own characterization of the NARFNI operations in terms of cost flow. As such it provided the possibility of another view of the before and after WIPICS situation. In much the same manner as the Daily Production Model could be used to relate before and after isoproduct surfaces, this model could be used to generate isocost surfaces. As before, dominance of one surface by the other gave comparative statements a very sound base, while intersection of the surfaces introduced many reservations and limitations.

The model did add to the body of alternatives within which the cost-effectiveness question can be framed. Exercise of those alternatives in the next section unfolds that framework.

IV. RESULTS OF EXERCISING MODELS

Each of the models in the previous chapter was exercised using data supplied by NARFNI through its Production Performance Reports. General characteristics of the data base are presented here followed by the results of each model's usage. Previously reported results are presented in synopsis only. Though most of the models included a parallel structure for the engine program, only aircraft results are included in this chapter.

A. DATA BASE

A total of 837 aircraft job accounting records were included in the data available from the PPR. The elements of information were selected and transferred to computer card record as indicated in Appendix A of reference 6. The seventh field, Airframe Change Manhours, which has been ignored by all models was originally included on the cards for possible investigation. The data elements represented jobs inducted on or after Julian date 0069 (10 Mar 70) through Julian date 2332 (27 Nov 72). Production dates of these jobs extended to Julian date 3066 (7 Mar 73). For reference, WIPICS was installed during November of 1971 and was operational in December 1971.

B. DAILY PRODUCTION MODEL

Bradley used data that began with an induction on 0069 and ended with a production on 1235 to generate his aggregated

prorated statistics [1, App. A]. Near both the beginning and ending of this period, not all jobs in shop were included in the data available, and the regression was limited to the period corresponding to 0208 through 1153 during which time the job records were considered complete [1, p. 57].

Based on these derived observations of daily flow, he estimated the production relation to be [1, p. 77]:

$$APH = (57.36)(APL)^{0.38104}(APM)^{-0.23714}(NIS)^{0.88208}$$

Standard error of exponents (0.04414) (0.01879) (.04410)

Multiple Correlation Coefficient .9610

Collinearity of APD with NIS and APM precluded its inclusion in the regression [1, p. 59 ff].

Bradley attempted aggregations on weekly and monthly bases but found no improvement over the daily based result above. His work provided a basis then, for the extensions that followed and indicated which explanatory variables were most effective in NARFNI production description.

C. DAILY COST MODEL

Trafton used the data base selected by Bradley to implement his penalty cost extension and develop the CFS functions. His work, based on the Cobb-Douglas version, produced an estimated relation for total daily cost (equal to the sum of labor, material and penalty costs) with the following specification [8, p. 34]:

$$C = (2.64)(APH)^{.751}(APL)^{2.629}(AP_I)^{-.275}$$

Standard errors: (.012) (.056) (.030)

Multiple correlation coefficient squared, $R^2 = .960$

The CES cost function he introduced showed daily total cost (equal to the sum of direct labor, overhead and penalty costs) to be specified according to the following estimated relation [8, p. 30]:

$$C' = (7.870)(P_L + AP_I(\widehat{I/L}))(APH)^{.880}e^{-2.388(\hat{D})}$$

Standard errors: (.006) (.149)

where $\widehat{I/L}$ = estimate of the relation

$$I/L = a\ (P_L\ /AP_I)^b e^{\mu}$$

$$\hat{D} = [\delta + (1-\delta)(\widehat{I/L})^{-\rho}]$$

δ, ρ are estimated by simultaneous solution of

$$a = \left(\frac{\delta}{1-\delta}\right)^{\frac{-1}{\rho+1}}$$

and $b = \frac{1}{\rho+1}$

Multiple correlation coefficient, squared, $R^2 = .988$

By these estimated cost relations, Trafton had produced two methods for characterizing, in dollar terms, the cost flow of NARFNI production efforts before WIPICS was initiated. Using methods he described, a similar cost flow relationship could be derived for the after WIPICS period. As he explained, test cases could then be used to compare, in common dollar terms, two situations that were quite different if described in terms of production effort.

D. DAILY COST MODEL, EXTENDED

Using observations of jobs processed after WIPICS was installed, Tye was able to provide a characterization of that period for comparison as Trafton had proposed. He also had available additional data for the period before WIPICS to complement and advance that data set. Hence he was able to estimate an updated version of both the Cobb-Douglas and CES cost functions for that period. He also had over two hundred observations from the after WIPICS period for comparative estimation for the later period.

He estimated for the Cobb-Douglas version [9, p. 36]

$$C = (A)(APH)^{\alpha}(APH)^{\beta}(APP)^{\gamma}e^{\varepsilon}$$

	Coefficient Estimates				R^2
	$\hat{A}$	$\hat{\alpha}$	$\hat{\beta}$	$\hat{\gamma}$	
Before:	.743	.857	2.356	-.094	.949
(Standard error)		(.011)	(.090)	(.015)	
After:	.297	.745	4.222	-.487	.876
(Standard error)		(.071)	(1.234)	(.066)	

For the CES version (with a different cost composition) he estimated [9, p. 36]

$$C = B[P_L + AP_I(\widehat{I/L})](APH)^{\alpha}\ e^{\beta D+\varepsilon'}$$

	Coefficient Estimates			R^2
	$\hat{B}$	$\hat{\alpha}$	$\hat{\beta}$	
Before	20.07	.886	-10.421	.852
(Standard error)		(.019)	(.543)	
After	8.150	.881	-2.724	.980
(Standard error)		(.016)	(.293)	

He reported significance of the differences in both versions between the before and after estimates, based on the Chow test. He chose periods of time close to the changeover for use in the regression analysis. This was done to minimize the instability he noted in preliminary regressions [9, Chapter III and p. 35 ff].

He then used the before and after regression estimates to predict costs of a sample drawn from the regression construction data. He expressed the results as total cost differentials, that is, as before WIPICS cost minus after WIPICS cost, a positive value indicating a less costly after WIPICS situation as shown in Table II below [9, p. 41].

TABLE II

DIFFERENCE BETWEEN PREDICTED COSTS - AIRFRAMES

	C-D	CES
Case I	17,885	3,306
Case II	9,241	7,129

He indicated that only in the Cobb-Douglas version would the savings be significant with at least 90% confidence [9, p. 43].

It might be noted that Tye based the work on the penalty costs developed by Myers. Tye's work might be recomputed using the corrected penalty costs. Tye qualified the savings description with acknowledgement of fact that there were externalities not measured by the model which may have important explanatory capability.

Tye's work thus represents the first comparative statement about the effect WIPICS may have had on the operation of the NARFNI. It was based on the general assumption of cost minimization subject to accomplishment of a given workload. His findings presented one view of the cost flow of NARFNI and were subject to the next step of the procedure advanced by Spooner, validation.

E. LINEAR ECONOMIC MODEL

1. Myers' Results

Myers used the before WIPICS data to generate a technology matrix characteristic of that period. He used that matrix to predict the total cost, including penalty, of a projected workload. He proposed that engine and aircraft models be checked by comparing actual costs of that workload after completion. This was not completed either by Myers or since the time he finished his work. (Myers' specific results are not reported; see ref. 3, p. 41 ff for details.) The proposed comparison between predicted and actual costs has been accomplished, however, in the following extension of his work.

2. Extensions

In order to make comparisons between the two periods of interest, adjustments had to be made concerning the aircraft type/work type groupings. As stated in Chapter II, cycle information for after-WIPICS and some later before-WIPICS jobs was not available. This item was not reported among the PPR elements. It had been gained with the earlier before WIPICS data only by special research effort by MSDO personnel, who were unable to continue due to increased administrative workload. As a result the second character of the work type in the coding scheme was ignored for all data. Thus, for example, F-4 aircraft undergoing PAR for the fourth, fifth, and sixth time would be united into one process instead of three separate processes as had been established by Myers. This action reduced the number of processes of the before WIPICS period from 70 to 39. Examination was made of those individual processes which were grouped together, and they showed sufficient homogeneity of NORM that the unification did not misrepresent any one process.

The 837 data cards, each representing one aircraft job, were separated into three groups:

1. 414 jobs before WIPICS incorporating, extending and filling out Myers' base
2. 158 jobs in a buffer period
3. 265 jobs after WIPICS

The buffer period consisted largely of jobs started before and finished after WIPICS was initiated. That period included all jobs with induction dates between Julian dates 1181 and 1334 inclusive. These dates were arbitrarily chosen to allow for the long time period required for aircraft processing plus the indeterminate period while WIPICS was being initially tested. The before and after groups were also used to generate the regressions used in the job cost model.

The two groups were compared to determine the 20 matching categories listed in Chapter II. Subgroupings of matching categories were then selected, representing 70.4% (257/365) and 68.7% (182/265) of the original before and after WIPICS groups, respectively. In the interest of descriptive brevity, let

$\{B\}$ be the set of observations before WIPICS

$\{B_M\}$ be the subset of observations of $\{B\}$ that matches the categories after WIPICS

$\{A\}$ be the set of observations after WIPICS

$\{A_M\}$ be the subset of $\{A\}$ that matches the categories of $\{B_M\}$

Data sets $\{B_M\}$, $\{A_M\}$, and $\{A\}$ were used as input to Myers' Average Cost of Labor program [3, App. J], producing average labor rates of \$6.20, \$6.72, and \$6.74. This compared to \$6.17 computed for $\{B\}$ by Myers. Increases in labor rates were noted in every process although the increases were not of uniform proportion among the processes. Data sets $\{B_M\}$ and $\{A_M\}$ were aggregated using Myers' Aggregation

Program [3, App. F], to produce inputs for subsequent programs.

Prior to use of the preparatory program, the corrected penalty costs were computed. (These are given in Table III, which is placed with Tables IV through X at the end of this section.) As suggested by Trafton [8, p. 40], the activity vectors were set at the actual level of NORM corresponding to the jobs in the sample and are listed in Tables VI and VII. The labor rate, process aggregations, penalty costs, activity vector values, and non-contraining resource values were inputs to the MPS/360 Data Preparation Program [3, App. K]. This program was modified to provide for the set-up of three different problems corresponding to three different objective functions. These objective functions matched the variations of the Job Cost Model and were specified as:

1) Min: Total Cost = $[P^T T_2 + C^T T_3]Z$

2) Min: Operations Cost = $P^T T_2 Z$

3) Min: Penalty Cost = $C^T T_3 Z$

where symbols are defined as in Myers [3, p. 27 ff.].

The preparatory program provided most of the specially formatted input for the MPS/360 linear programming routines. It also produced a listing of the elements of the submatrix T_2 for comparison between periods. The T_2 listings are

given in Tables IV and V. The sledgehammer of the MPS/360 routine was then used to "execute" the "gnat" of objective function summation.

The construction of the technology matrix was such that $T_1 = I$, the identity matrix, for both the before and after situations. The T_2 and T_3 matrices, however, did take on characteristics of the two periods. In order to use the models for prediction, two test cases were run against both the before and after models. The test cases were simply the two activity vectors and the two price vectors associated with each model. Activity and price vectors run against their own models simply provide actual cost determinations, but the runs against the opposite model represent predicted costs. The costs were calculated for each of the objective function versions and the results are listed in Tables VIII, IX, and X.

The tables of comparative values are of the following format:

	Before WIPICS Model	After WIPICS Model
$\{B_M\}$	Actual Cost of $\{B_M\}$	Predicted Cost of $\{B_M\}$
$\{A_M\}$	Predicted Cost of $\{A_M\}$	Actual Cost of $\{A_M\}$

All figures represent millions of dollars. The upper right corner prediction of Table VIII, for example, is read, "If the jobs represented by $\{B_M\}$ had been accomplished during the after WIPICS period, it is predicted that the total cost would have been $51.498 million." Dollar amounts may be compared horizontally, but not verically, since the data sets are quite different in size and composition.

As the comparative results indicate, the after WIPICS period costs were estimated to be higher in each of the cost variations used. Comparison of entries in the T_2 matrices for before and after situations emphasized the increases in resources used per hour of NORM. In every process at least one coefficient was higher for the after WIPICS period, with many cases showing two and three increased coefficients. Any decreases were relatively smaller in magnitude than the increases. This model contains no inherent inflation compensation for the materials and overhead expenditures such as the DMHR price has.

Comparing the activity vectars in Tables VI and VII highlighted another potential problem. The two vectors presented radically different levels of activity in many of the processes. Such differences could greatly magnify any deviation of the linear relation from the true relationship, which is more probably non-linear. Possibly the linear estimates were pushed too far beyond their usefulness.

The linear model results provided a sharp contrast to the results of the daily cost model. Hence it did not

serve to validate that model. Neither did the linear model refute the daily cost model, but it did introduce well founded doubt. This nebulous situation would provide additional cause to seek another validation method. The following model was developed for that use.

TABLE III

CORRECTED PENALTY COSTS

Aircraft Program

Type Aircraft	Unit Cost	Service Life (months)	Penalty Costs ($/day in shop)
C-2A	$10,742,000	105	3410.15
E-2B	10,742,000	105	3410.15
F-4B	2,756,000	80	1148.33
RF-4B	2,699,000	96	937.15
F-4J	2,492,000	80	1038.23
RF-8G	1,300,000	75	577.72
F-8H	1,352,000	54	834.48
F-8J	1,302,000	54	803.62
RF-3A	1,508,000	80	628.27
SH-3A	1,278,000	80	532.45
SH-3D	1,064,000	80	443.29
CH-46A	1,083,000	80	451.20
UH-46A	834,000	80	347.47
CH-46D	1,083,000	80	451.20
UH-46D	834,000	80	347.47
CH-46F	1,083,000	80	451.20
CH-53A	1,453,000	96	504.46
CH-53D	1,453,000	96	504.46

TABLE IV

BEFORE WIPICS LINEAR MODEL MATRIX VALUES

PROCESS	OBJ FCN TOTAL COST	R1 ROW	R2 ROW	R3 ROW
1	50.8837	1.0033	2.6083	6.1787
2	25.3226	1.0658	2.7924	6.9814
3	23.7328	1.0233	1.4353	6.4288
4	23.4082	1.0375	2.1636	6.4856
5	24.7885	1.0476	1.9794	6.4993
6	26.2025	1.0709	2.3736	6.5446
7	23.8285	1.0117	2.5836	6.4357
8	25.5976	1.0907	2.9067	6.5343
9	19.9475	1.0135	1.6247	6.6520
10	23.5180	1.1885	2.5320	7.1241
11	19.6264	0.8198	2.1192	5.5877
12	20.7446	0.9599	2.1615	6.0713
13	20.4524	0.9621	2.3180	6.4492
14	22.0935	1.0129	3.2470	6.3631
15	20.1110	0.8567	3.0531	5.6263
16	26.0542	1.0788	4.8596	7.5501
17	21.7725	0.9254	5.3453	6.2415
18	22.9244	1.0350	4.5450	6.1227
19	19.9200	0.9633	3.1309	5.9558
20	20.5787	1.0183	3.1359	6.6616

R1,R2,R3 ROWS ARE ROWS OF T_2

R1 VALUES - EXPENDED MANHOURS PER HOUR OF NORM

R2 VALUES - EXPENDED MATERIAL \$ PER HOUR OF NORM

R3 VALUES - EXPENDED OVERHEAD \$ PER HOUR OF NORM

ONLY THE OBJECTIVE FUNCTION ROW VECTOR CHANGES FOR OPERATIONS AND PENALTY COST MODELS, AS SHOWN BELOW.

OBJ FCN OPERATIONS COST		OBJ FCN PENALTY COST
15.0000	1	35.8700
16.3800	2	8.9400
14.2000	3	9.5200
15.0800	4	8.3200
14.9700	5	9.8100
15.5500	6	10.6400
15.2900	7	8.5300
16.2000	8	9.3900
14.5600	9	5.3800
17.0200	10	6.4900
12.7800	11	6.8300
14.1800	12	6.5600
14.7300	13	5.7200
15.8900	14	6.2000
13.9900	15	6.1200
19.0900	16	6.9500
17.3200	17	4.4400
17.0800	18	5.8300
15.0500	19	4.8600
16.1100	20	4.4600

TABLE V

AFTER WIPICS LINEAR MODEL MATRIX VALUES

PROCESS	OBJ FCN TOTAL COST	R1 ROW	R2 ROW	R3 ROW
1	54.0431	0.9347	3.7940	6.8082
2	27.2283	1.1166	2.1298	7.7364
3	27.6738	1.0950	1.9956	7.9110
4	24.2239	1.0250	2.2246	7.2431
5	29.1293	1.1292	2.1919	7.9766
6	30.2740	1.1186	2.3613	7.7940
7	29.3154	1.0234	4.1372	7.3677
8	24.4796	0.9739	2.6037	6.8329
9	16.1529	0.6425	1.3869	4.4964
10	19.5713	0.9129	1.9015	6.4321
11	26.1976	1.0280	4.3485	7.5144
12	24.4091	0.9033	5.3909	6.3861
13	28.6139	1.0921	6.4555	7.2433
14	27.8638	1.1078	4.8085	8.1890
15	28.3191	1.1423	4.2452	8.0286
16	26.1638	1.0177	5.2367	7.6349
17	25.5025	1.0644	4.7748	7.1854
18	22.8347	0.8822	4.8571	6.4737
19	22.9092	0.9539	3.9050	6.9969
20	23.7676	0.9147	4.9925	6.9606

R1,R2,R3 ROWS ARE ROWS OF T_2

R1 VALUES - EXPENDED MANHOURS PER HOUR OF NORM

R2 VALUES - EXPENDED MATERIAL $ PER HOUR OF NORM

R3 VALUES - EXPENDED OVERHEAD $ PER HOUR OF NORM

ONLY THE OBJECTIVE FUNCTION ROW VECTOR CHANGES FOR OPERATIONS AND PENALTY COST MODELS, AS SHOWN BELOW.

OBJ FCN OPERATIONS COST		OBJ FCN PENALTY COST
16.8800	1	37.1500
17.3600	2	9.8500
17.2600	3	10.4000
16.3500	4	7.8600
17.7500	5	11.3700
17.6700	6	12.6000
18.3800	7	10.9300
15.9800	8	8.4900
10.2000	9	5.9500
14.4600	10	5.1000
18.7700	11	7.4200
17.8400	12	6.5600
21.0300	13	7.5700
20.4400	14	7.4200
19.9500	15	8.3600
19.7100	16	6.4500
19.1100	17	6.3800
17.2500	18	5.5700
17.3100	19	5.5900
18.1000	20	5.6600

TABLE VI

BEFORE WIPICS ACTIVITY VECTOR

(BEFORE WIPICS)

PROCESS	ACTIVITY LEVEL
1	26900.00
2	374990.00
3	260440.00
4	10600.00
5	278240.00
6	84900.00
7	149300.00
8	71600.00
9	31100.00
10	62100.00
11	8800.00
12	223100.00
13	21000.00
14	44000.00
15	99300.00
16	34300.00
17	118500.00
18	16500.00
19	5500.00
20	7000.00

TABLE VII

AFTER WIPICS ACTIVITY VECTOR

(AFTER WIPICS)

PROCESS	ACTIVITY LEVEL
1	50200.00
2	251400.00
3	121100.00
4	106100.00
5	489300.00
6	89300.00
7	17200.00
8	31300.00
9	9900.00
10	12000.00
11	19500.00
12	35700.00
13	8600.00
14	95610.00
15	56600.00
16	22200.00
17	48000.00
18	17100.00
19	87600.00
20	57500.00

TABLE VIII

LINEAR MODEL RESULTS - TOTAL COST

Base Cases	Before WIPICS Model	After WIPICS Model
$\{B_M\}$	46.192	51.498
$\{A_M\}$	40.799	45.565

(millions of dollars)

TABLE IX

LINEAR MODEL RESULTS - OPERATIONS COST

Base Cases	Before WIPICS Model	After WIPICS Model
$\{B_M\}$	29.708	33.043
$\{A_M\}$	25.882	28.972

(millions of dollars)

TABLE X

LINEAR MODEL RESULTS - PENALTY COST

Base Cases	Before WIPICS	After WIPICS
$\{B_M\}$	16.484	18.455
$\{A_M\}$	14.917	16.693

(millions of dollars)

F. JOB COST MODEL

1. Preparation

Trafton's proration program was modified to accommodate a time span of 1100 days and was used to produce a card record that included NIS data. The complete set of 837 data cards was used to provide as complete a record as possible of the variable NIS. The usual "tails" appeared and decision was made to define the usable period as that period between the first and last occurrence of 60 jobs in shop. This provided cutoff dates of 0187 and 2272 respectively. For the regressions, any jobs falling outside of that interval were ignored. Data sets {B} and {A} were assembled as described previously to be used for the regressions. The corrected penalty costs were used in this model, as listed in Table III. These inputs were then run with the regression program given in Appendix A. The program provided simultaneous regression and prediction results, but these have been separated in what follows for the purposes of discussion.

2. Regression

The program used for regression analysis calculated the estimates using logarithms of base 10. The program established dummy variables for each different category encountered. In the models based on the before WIPICS situation 36 dummy variables were generated compared to 37 for the after WIPICS situation. As noted in Chapter II, there were 20 categories common to the two periods and all twenty entered the regression base. The possibility existed that a

the variation in their dependent variables. The standard errors of the dependent variables were also consistently low which indicated that the functions provided a good fit to the actual data.

Between the two versions on the comparable cost definitions, the estimated relationships of version 2 showed better measures of variation accountability and fit than did the counterparts in version 1, except in the after WIPICS operations cost functions, where there was almost parity. Recall the version 2 models use NDAYS in lieu of PD in the explanatory structure. Such was not unexpected since the duration of time spent in rework would be more likely to explain cost than a trend - _ceteris paribus_, as they were in this comparison.

Another measure of model accuracy included in the tables is analogous to what Tye referred to as "percent error in cost" [9, p. 29]. This measure is the standard error to mean ratio (SE/M) and is defined:

$$SE/M = \frac{\sqrt[2]{\dfrac{\sum_{i=1}^{m} [C_i - \hat{C}_i]^2}{m}}}{\sqrt{m}} \cdot \frac{1}{\Sigma C_i / m}$$

$$= \frac{\sqrt[2]{\sum_{i=1}^{m} [C_i - \hat{C}_i]^2}}{\Sigma C_i}$$

where $\hat{C}_i$ = predicted cost of job i.

The models of Penalty Cost separated out this imputed measure and suggested some possible explanations. In both

before and after WIPICS situations, the $\overline{NIS}$ variables entered with negative exponents as was true in the other cost variations of version 1. Recall that Trafton and Tye reported similar results for the companion AP_I. Rather than indicating purely congestive effects this variable probably portrayed the effects of job flow pressure. A job inducted and reworked during a period of lower density (lower $\overline{NIS}$) was probably not expedited to the degree those of higher density times were. Hence its overall stay at NARFNI may have lengthened, increasing the penalty cost. The management adage, "Work expands to fill the time allotted," may also apply to this particular industrial operation.

Between the two penalty cost models there was also a shift of explanatory power of the variables. The before WIPICS model showed the influence of the trend factor PD, while its coefficient in the after WIPICS model is not significantly different from zero. An examination of the sequential values of NIS, recorded by the prorate program, confirmed a distinct upward trend in NIS over the period before WIPICS was installed and a level pattern during the after WIPICS period. The results were then consistent; as the workload increased to the after WIPICS level, the PD had no trend to indicate and $\overline{NIS}$ reflected that the "pressures" had more relative impact on cost. Further, the Operations Cost functions of version 1 show that both before and after WIPICS estimates of the $\overline{NIS}$ coefficient are not significantly different from zero. Hence, from the operational viewpoint, $\overline{NIS}$ did not seem to reflect congestive effects, either.

In the Total Cost models of version 1, there was a dramatic shift in the importance of the explanatory variables. The before WIPICS model indicated greater diversity among the job categories as demonstrated by the values of the dummy variable coefficients. In the after WIPICS model, the explanatory variables took a greater role and indicated more commonality of the job categories as shown by smaller variations in the dummy coefficients. The influence of $\overline{\text{NIS}}$ on penalty cost contributed to its entry into this model; whereas $\overline{\text{NIS}}$ did not enter the before WIPICS model.

Concerning the models of version 2, comparison of the Operations Cost to Total Cost showed the relative changes in role between NORM and NDAYS for both time periods. The Operations Cost was more NORM-dependent while the Total Cost showed the effect of adding the penalty by the increased relative importance there of NDAYS. The difference in the definitions of the alternatives provided that expected result.

More dramatic and not expected was the change across time periods in the sign of the coefficients of $\overline{\text{NIS}}$. While this happened in both Total and Operations Cost models it was most pronounced in the latter. In these models the combination of NDAYS and $\overline{\text{NIS}}$ should actually provide a measure of congestion. One possible explanation was considered: If WIPICS had been effective there would be reason to believe that congestion would no longer influence the productive processes and costs generated there. The estimated

equation for the after WIPICS period did not include a significant coefficient for NDAYS, which would render $\overline{NIS}$ more indicative of pressure than congestion.

3. Prediction

a. General

The base cases $\{B_M\}$ and $\{A_M\}$ used in the linear models were also used to predict costs in each of the 10 models. The base cases contained observations which had only the elements necessary for specifying three of the four explanatory variables: NORM (directly), P_L (DML\$/DMHR), and PD (directly) or NDAYS (PD-IND). The appropriate value of $\overline{NIS}$ was generated by the program if the observation met the criteria used for the regression observations. However, those falling partly or wholly in the "tail" periods were assigned an $\overline{NIS}$ value equal to the overall average value of the complete before or after period from which they were taken. The average number in shop for the before WIPICS period, 0187 through 1364, was 87 jobs. For the after WIPICS period of 1335 through 2272 this average was 97 jobs.[4] This procedure, while improper for regression, is not an undue extrapolation for prediction and was done to insure that all observations of $\{B_M\}$ and $\{A_M\}$ were included. Better comparability with the linear model was expected under such rules.

---

[4] The time period overlap was intentional. This was done to include the effect of those few before WIPICS jobs of great length that were still in process until the year end.

TABLE XI

```
           VERSION 1 BEFORE WIPICS   TOTAL COST

SUM OF DEPENDENT VARIABLE VALUES IS  0.7979D 08

SUM OF PREDICTED DEPENDENT VARIABLES IS  0.7925D 08

STANDARD ERROR TO MEAN RATIO IS  0.1402D-01
MEAN IS 0.2254D 06

                      ANALYSIS OF VARIANCE
SOURCE    SUM OF SQUARES    DF     MEAN SQUARE  F STATISTIC

  TSS       0.9842D 04     354   0.2780D 02

  RDM       0.9815D 04       1   0.9815D 04     **********

  TSSA      0.2666D 02     353   0.7553D-01

  RDB       0.9841D 04      40   0.2460D 03     **********

  RDBA      0.2599D 02      39   0.6663D 00       309.2749

 ERROR      0.6765D 00     314   0.2154D-02

RSQR IS   0.9746D 00  RSQR ADJUSTED IS  0.9715D 00

THE STANDARD ERROR OF THE DEPENDENT VARIABLE IS  0.4642D-01


VARIABLE  COEFFICIENT    STD ERROR    T STATISTIC

    1       0.1326D 00   0.7646D-01    0.1734D 01
    2       0.2003D 00   0.3151D-01    0.6355D 01
    3      -0.3728D 00   0.3395D 00   -0.1098D 01
    4       0.3557D 00   0.2256D-01    0.1576D 02
```

On Tables XI through XX, asterisks indicate an F statistic value greater than 100,000.

TABLE XII

```
            VERSION 1  AFTER WIPICS   TOTAL COST

SUM OF DEPENDENT VARIABLE VALUES IS  0.4516D 08

SUM OF PREDICTED DEPENDENT VARIABLES IS  0.4504D 08

STANDARD ERROR TO MEAN RATIO IS  0.1415D-01
MEAN IS 0.2340D 06

                         ANALYSIS OF VARIANCE
SOURCE     SUM OF SQUARES     DF     MEAN SQUARE  F STATISTIC
  TSS        0.5431D 04      193   0.2814D 02

  RDM        0.5420D 04        1   0.5420D 04     **********

  TSSA       0.1125D 02      192   0.5859D-01

  RDB        0.5431D 04       41   0.1325D 03     98676.8894

  RDBA       0.1105D 02       40   0.2761D 00       205.6978

 ERROR       0.2040D 00      152   0.1342D-02

RSQR IS    0.9819D 00  RSQR ADJUSTED IS  0.9771D 00

THE STANDARD ERROR OF THE DEPENDENT VARIABLE IS  0.3664D-01


VARIABLE  COEFFICIENT   STD ERROR   T STATISTIC

    1       0.3567D 00  0.5177D-01   0.6891D 01
    2       0.2804D 00  0.1614D 00   0.1737D 01
    3      -0.5996D 00  0.2321D 00  -0.2584D 01
    4       0.8653D 00  0.6932D-01   0.1248D 02
```

TABLE XIII

```
              VERSION 1 BEFORE WIPICS    OPNS COST

SUM OF DEPENDENT VARIABLE VALUES IS  0.4689D 08

SUM OF PREDICTED DEPENDENT VARIABLES IS  0.4659D 08

STANDARD ERRCR TO MEAN RATIO IS  0.1249D-01
MEAN IS 0.1325D 06

                        ANALYSIS OF VARIANCE
SOURCE     SUM OF SQUARES     DF     MEAN SQUARE  F STATISTIC

  TSS        0.9099D 04     354    0.2570D 02

  RDM        0.9081D 04       1    0.9081D 04     *********

  TSSA       0.1827D 02     353    0.5176D-01

  RDB        0.9098D 04      40    0.2275D 03    98728.8696

  RDBA       0.1755D 02      39    0.4499D 00      195.2932

 ERROR       0.7234D 00     314    0.2304D-02

RSCR IS    0.9604D 00  RSQR ADJUSTED IS  0.9555D 00

THE STANDARD ERROR OF THE DEPENDENT VARIABLE IS  0.4800D-01


VARIABLE  CCEFFICIENT    STD ERROR    T STATISTIC

    1       0.2345D 00   0.7907D-01    0.2966D 01
    2       0.1743D 00   0.3258D-01    0.5350D 01
    3      -0.1546D 00   0.3510D 00   -0.4403D 00
    4       0.3919D 00   0.2333D-01    0.1680D 02
```

TABLF XIV

```
              VERSION 1   AFTER WIPICS    OPNS COST

SUM OF DEPENDENT VARIABLE VALUES IS  0.2752D 08

SUM CF PREDICTED DEPENDENT VARIABLES IS  0.2744D 08

STANDARD ERROR TO MEAN RATIO IS  0.1146D-01
MEAN IS 0.1426D 06

                      ANALYSIS OF VARIANCE
SOURCE     SUM OF SQUARES     DF      MEAN SQUARE   F STATISTIC

  TSS        0.5050D 04     193    0.2617D 02

  RDM        0.5043D 04       1    0.5043D 04     **********

  TSSA       0.7207D 01     192    0.3754D-01

  RDB        0.5050D 04      41    0.1232D 03     76238.7354

  RDBA       0.6962D 01      40    0.1740D 00        107.7305

 ERRCR       0.2456D CO     152    0.1616D-02

RSQR IS    0.9659D 00   RSQR ADJUSTED IS  0.9570D 00

THE STANDARD ERROR OF THE DEPENDENT VARIABLE IS  0.4C19D-01


VARIABLE  COEFFICIENT    STD ERROR    T STATISTIC

    1       0.5886D 00   0.5679D-01    0.1036D 02
    2       C.3569D 00   0.1771D 00    0.2015D 01
    3      -0.3963D 00   0.2546D 00   -0.1557D 01
    4       0.1010D 01   0.7604D-01    0.1328D 02
```

TABLE XV

```
          VERSION 1 BEFORE WIPICS PENALTY COST

SUM OF DEPENDENT VARIABLE VALUES IS  0.3290D 08

SUM CF PRECICTED DEPENDENT VARIABLES IS  0.3251D 08

STANDARC ERROR TO MEAN RATIO IS  0.2182D-01
MEAN IS 0.9293D 05

                     ANALYSIS OF VARIANCE
SOURCE    SUM OF SQUARES    DF    MEAN SQUARE  F STATISTIC

  TSS       0.8223D 04     354   0.2323D 02

  RDM       0.8178D 04       1   0.8178D 04    *********

  TSSA      0.4563D 02     353   0.1293D 00

  RDB       0.8222D 04      40   0.2056D 03    51418.0761

  RDBA      0.4438D 02      39   0.1138D 01      284.6449

 ERROR      0.1255D 01     314   0.3998D-02

RSQR IS   0.9725D 00  RSQR ADJUSTED IS  0.9691D 00

THE STANDARD ERROR OF THE DEPENDENT VARIABLE IS  0.6323D-01


VARIABLE  CCEFFICIENT   STD ERROR   T STATISTIC

    1     -0.2420D-01   0.1042D 00  -0.2323D 00
    2      0.2419D 00   0.4292D-01   0.5635D 01
    3     -0.9253D 00   0.4624D 00  -0.2001D 01
    4      0.2919D 00   0.3073D-01   0.9496D 01
```

TABLE XVI

```
              VERSION 1  AFTER WIPICS PENALTY COST

SUM OF DEPENDENT VARIABLE VALUES IS  0.1764D 08

SUM OF PREDICTED DEPENDENT VARIABLES IS  0.1751D 08

STANDARD ERROR TO MEAN RATIO IS  0.2884D-01
MEAN IS 0.9142D 05

                     ANALYSIS OF VARIANCE
SOURCE    SUM OF SQUARES     DF     MEAN SQUARE   F STATISTIC

  TSS       0.4494D 04      193    0.2329D 02

  RDM       0.4473D 04        1    0.4473D 04     *********

  TSSA      0.2181D 02      192    0.1136D 00

  RDB       0.4494D 04       41    0.1096D 03     31821.1321

  RDBA      0.2129D 02       40    0.5322D 00       154.5197

 ERROR      0.5236D 00      152    0.3444D-02

RSQR IS    0.9760D 00  RSQR ADJUSTED IS  0.9697D 00

THE STANDARD ERROR OF THE DEPENDENT VARIABLE IS  0.5869D-01


VARIABLE  COEFFICIENT    STD ERROR    T STATISTIC

    1     -0.8250D-01   0.8292D-01   -0.9950D 00
    2     -0.1018D 00   0.2586D 00   -0.3938D 00
    3     -0.1459D 01   0.3717D 00   -0.3924D 01
    4      0.5933D 00   0.1110D 00    0.5343D 01
```

TABLE XVII

```
            VERSION 2 BEFORE WIPICS   TOTAL COST

SUM CF DEPENDENT VARIABLE VALUES IS  0.7979C 08

SUM CF PREDICTED DEPENDENT VARIABLES IS  0.7961D 08

STANDARD ERRCR TO MEAN RATIO IS  0.6544D-02
MEAN IS 0.2254D 06

                      ANALYSIS OF VARIANCE
SOURCE    SUM OF SQUARES    DF     MEAN SQUARE  F STATISTIC
  TSS       C.9842D 04    354    0.2780D 02
  RDM       C.9815D C4      1    0.9815D 04     **********
  TSSA      0.2666D 02    353    0.7553D-01
  RDB       0.9842D 04     40    0.2460D 03     **********
  RDBA      0.2639D 02     39    C.6767D 0C       785.6C38
 ERRCR      0.2705D 00    314    0.8614D-03
RSQR IS   0.9899D 00  RSQR ADJUSTED IS  0.9886D 00
THE STANCARD ERROR OF THE DEPENDENT VARIABLE IS  0.2935D-01


VARIABLE  COEFFICIENT   STD ERROR    T STATISTIC

    1      0.1571D 00   0.4822D-01   0.3257C 01
    2      0.5972D 0C   0.2496D-01   0.2392D 02
    3      0.6067D 00   0.1529D 00   0.3968D 01
    4      C.1922D 00   0.1613D-01   0.1192C 02
```

TABLE XVIII

```
           VERSION 2  AFTER WIPICS   TOTAL COST

SUM OF DEPENDENT VARIABLE VALUES IS  0.4516D 08

SUM OF PREDICTED DEPENDENT VARIABLES IS  0.4509D 08

STANDARD ERROR TO MEAN RATIO IS  0.9098D-02
MEAN IS 0.2340D 06

                    ANALYSIS OF VARIANCE
SOURCE    SUM OF SQUARES     DF     MEAN SQUARE  F STATISTIC
  TSS       0.5431D 04     193    0.2814D 02

  RDM       0.5420D 04       1    0.5420D 04     **********

  TSSA      0.1125D 02     192    0.5859D-01

  RDB       0.5431D 04      41    0.1325D 03     **********

  RDBA      0.1111D 02      40    0.2777D 00       296.2373

 ERROR      0.1425D 00     152    0.9373D-03

RSQR IS   0.9873D 00  RSQR ADJUSTED IS  0.9840D 00

THE STANDARD ERROR OF THE DEPENDENT VARIABLE IS  0.3062D-01


VARIABLE  COEFFICIENT   STD ERROR   T STATISTIC

    1       0.4004D 00   0.4297D-01   0.9317D 01
    2       0.3539D 00   0.4229D-01   0.8367D 01
    3      -0.4402D 00   0.1331D 00  -0.3307D 01
    4       0.6656D 00   0.6292D-01   0.1058D 02
```

TABLE XIX

```
          VERSION 2 BEFORE WIPICS    OPNS COST

SUM CF DEPENDENT VARIABLE VALUES IS  0.4689D C8

SUM OF PREDICTED DEPENDENT VARIABLES IS  0.4667D 08

STANCARC ERRCR TO MEAN RATIO IS  0.1077D-C1
MEAN IS C.1325D 06

                        ANALYSIS OF VARIANCE
SOURCE    SUM OF SQUARES     CF    MEAN SQUARE  F STATISTIC
  TSS       0.9099D 04     354   0.2570D 02
  RDM       0.9081D 04       1   0.9081D 04    **********
  TSSA      C.1827D C2     353   C.5176D-01
  RDB       0.9098D 04      40   0.2275D 03    **********
  RDBA      0.1767D 02      39   0.4530D 00      236.0674
 ERROR      0.6026D 00     314   0.1919D-02
RSQR IS   0.9670D 00  RSQR ADJUSTED IS  0.9629D 00
THE STANDARD ERROR OF THE DEPENDENT VARIABLE IS  0.4381D-01


VARIABLE  CCEFFICIENT   STD ERROR   T STATISTIC

    1       0.2588D 00   0.7197D-01   0.3595D 01
    2       0.3676D 00   0.3726D-01   0.9865D 01
    3       C.8390D 0C   0.2282D 00   C.3677D C1
    4       0.3013D 00   0.2407D-01   0.1252D 02
```

TABLE XX

```
            VERSION 2  AFTER WIPICS    OPNS COST

SUM OF DEPENDENT VARIABLE VALUES IS  0.2752D 08

SUM OF PREDICTED DEPENDENT VARIABLES IS  0.2744D 08

STANDARD ERROR TO MEAN RATIO IS  0.1150D-01
MEAN IS 0.1426D 06

                       ANALYSIS OF  VARIANCE
SOURCE    SUM OF SQUARES     DF     MEAN SQUARE  F STATISTIC
  TSS       0.5050D 04     193   0.2617D 02

  RDM       0.5043D 04       1   0.5043D 04     **********

  TSSA      0.7207D 01     192   0.3754D-01

  RDB       0.5050D 04      41   0.1232D 03     74357.6377

  RDBA      0.6956D 01      40   0.1739D 00       104.9788

 ERROR      0.2518D 00     152   0.1656D-02

RSQR IS   0.9651D 00  RSQR ADJUSTED IS  0.9559D 00

THE STANDARD ERROR OF THE DEPENDENT VARIABLE IS  0.4070D-01


VARIABLE  COEFFICIENT   STD ERROR    T STATISTIC

    1       0.6072D 00   0.5713D-01   0.1063D 02
    2       0.2585D-01   0.5622D-01   0.4597D 00
    3      -0.7639D 00   0.1769D 00  -0.4317D 01
    4       0.1006D 01   0.8364D-01   0.1203D 02
```

The program produced predicted costs for each job, and then these costs were summed over the entire base cases. Each of the 10 separate models predicted two costs, one for $\{B_M\}$ and another for $\{A_M\}$. The results are given in Tables XXI through XXV. Costs are in millions of dollars, arranged according to Figure 3 below.

Base Case:	Before WIPICS Model	After WIPICS Model	Actual Cost
$\{B_M\}$	Predicted $\{B_M\}$ Cost (Standard Error)	Predicted $\{B_M\}$ Cost (Standard Error)	Aggregate Cost of the jobs in base case $\{B_M\}$
$\{A_M\}$	Predicted $\{A_M\}$ Cost (Standard Error)	Predicted $\{A_M\}$ Cost (Standard Error)	Aggregate Cost of the jobs in base case $\{A_M\}$

Figure 3. Model Predictions.

Standard errors reported are the standard errors of estimates of the mean of the aggregated base case costs in dollar terms as opposed to that which could be computed based on the logarithmic form of the data. That is, the standard error was defined as:

$$SE = \sqrt{\frac{\Sigma [C_i - \hat{C}_i]^2}{m}}$$

The tables are read, taking the upper right corner of Table XXI for example, "If jobs $\{B_M\}$ had been reworked during the after WIPICS period the aggregate cost would have been $41.25 million."

It appeared that the version 2 models did do a better job of predicting the actual costs of the base cases

corresponding to the periods from which the models were estimated than their counterparts in version 1.

b. Version 1

As shown in Table XXI, the before WIPICS Total Cost was predicted to be higher for both cases. Predictions for case $\{A_M\}$ are not significantly different. In Table XXII, the case $\{B_M\}$ was again predicted to be higher in Operations Cost in the before WIPICS environment, while case $\{A_M\}$ showed the opposite result. Table XXIII depicting the Penalty Cost, reversed the pattern of the Operations Cost comparisons. If the Penalty Cost and Operations Cost tables were added, they would show parity for case $\{A_M\}$ and higher after WIPICS predictions for $\{B_M\}$.

c. Version 2

In Tables XXIV and XXV both Total and Operations Cost predictions for the base case $\{B_M\}$ indicated less cost in the before WIPICS period. However, the base case $\{A_M\}$ showed the opposite result for both Total and Operations Cost, predicting that the after WIPICS period would be less costly. If the actual penalty costs for each base case were added to the predicted Operations Costs, the Total Cost results would be repeated as expected due to the computation of the penalty cost.

TABLE XXI

VERSION 1, TOTAL COST, COMPARISONS

Base Case	Before WIPICS Model	After WIPICS Model	Actual Cost
$\{B_M\}$	44.91 (.0248)	41.25 (.0362)	46.19
$\{A_M\}$	43.72 (.0546)	43.66 (.0475)	45.58

(millions of dollars)

TABLE XXII

VERSION 1, OPERATIONS COST, COMPARISONS

Base Case	Before WIPICS Model	After WIPICS Model	Actual Cost
$\{B_M\}$	28.95 (.0156)	23.68 (.0316)	29.71
$\{A_M\}$	27.81 (.0243)	28.17 (.0166)	28.88

(millions of dolars)

TABLE XXIII

VERSION 1, PENALTY COST, COMPARISONS

Base Case	Before WIPICS Model	After Wipics Model	Actual Cost
$\{B_M\}$	15.87 (.0130)	24.55 (.0374)	16.48
$\{A_M\}$	15.49 (.0425)	15.22 (.0463)	16.70

(millions of dollars)

TABLE XXIV

VERSION 2, TOTAL COST, COMPARISONS

Base Case	Before WIPICS Model	After WIPICS Model	Actual Cost
$\{B_M\}$	46.13 (.0112)	50.62 (.0256)	46.19
$\{A_M\}$	45.97 (.0271)	44.12 (.0299)	45.58

(millions of dollars)

TABLE XXV

VERSION 2, OPERATIONS COST, COMPARISONS

Base Case	Before WIPICS Model	After WIPICS Model	Actual Cost
$\{B_M\}$	29.59 (.0111)	34.87 (.0274)	29.71
$\{A_M\}$	28.98 (.0246)	27.82 (.0189)	28.88

(millions of dollars)

V. COMPARATIVE USEFULNESS OF THE MODELS IN COST-EFFECTIVENESS ANALYSIS

A. MODEL LIMITATIONS

Each model chronicled in this thesis provides its own unique perspective on the question of cost-effectiveness. Comparisons among the models pointed out some of the limitations of each, and also provided insight into possible remedies of those limitations.

1. Linear Economic Models

As a tool for validation, these models seemed to provide no definite answer. Using the same case data, they gave singly directed results compared to their continuous analogs, in Job Cost Models, which provided highly mixed results. The limitations of linearity for extrapolation became readily apparent when the models were tested using cases drawn from ranges quite different from those used to construct the model. Increased data to allow more homogeneous selection of base cases would tend to minimize this problem. The linear models used were not able to deal with inflation, in a manner such as version 1 of the Job Cost Models could. Expression of the resource coefficients for material and overhead in real monetary units would lessen this problem. Changing work type requirements could not be handled well by the aircraft linear model. However, the process Myers outlined for the engine program would be better able to make the accommodations

for some of these time related changes by defining new processes for each quarter. As Myers pointed out, the clustering method would require more data to be meaningful.

2. Daily Cost Models

Tye noted the major limitations for both models he examined [9, Chap. V]. These were the effects of: price changes for overhead and material cost, NORM redefinition, and changes in work required in terms of subprogram mix. He felt that these were not treated effectively by the models. He also noted the computational problem of the first stage regression of the CES function and the subsequent accuracy limitations.

3. Job Cost Models

Both versions of the Job Cost Model were subject to unstable treatment of congection effects. The alternate explanation of pressure effects cast doubt over the exact nature of the measurement. Possibly by forming the product of $\overline{\text{NIS}}$ and NDAYS, a variable would be created which indeed would measure congestion. This product would be a job density over the period of rework for the particular job considered. Substituting this composite measure for $\overline{\text{NIS}}$ in version 1 might provide more satisfactory results.

B. INTERPRETATIONS OF MODEL HARMONY OR DISCORD

In developing cost-effectiveness criteria it was necessary to propose what was to be expected if indeed WIPICS had provided a cost savings for NARFNI. In other words, what conditions would be indicative of improvement in the facility's

cost flow or work flow? An extensive list of single items could be made, attacking a ceteris paribus condition to each. Such ceteris paribus conditions were clearly not likely, and hence the models attempted to take on the job of accounting for more than one changing condition at a time. It was clear that if all of the different models that were used distinctly proclaimed the after WIPICS situation better by their own measures, there was firm ground for declaring WIPICS cost-effective. Only those known frailities of the models would have to be appended to the pronouncement as warnings.

But what sort of second best situation might apply? Surely, if most models had indicated superiority of the after WIPICS situation and the others had indicated parity, a similar cost-effective declaration would have been in order subject to minor reservations. Even an element of opposite indications could have been tolerated if an explanation of the opposite effects better than that provided by WIPICS could be demonstrated. Naturally, these arguments apply equally well reversed for indications of a more costly or less productive after-WIPICS situation.

But what of models that stood opposed to each other, firmly based? One might porpose a democratic, "majority wins," approach, but the answer would better lie in a thorough examination of model accuracy by measures of fit and variability accounting. The conflicting models would have to be checked for the assumptions on which they were

based, also. Further, any limitations of the models explanatory abilities would also have to be weighed. Those factors not considered at all by each respective model would have to be evaluated. For fit and variance explanation, the measures of standard error and the coefficient of determination (R^2,R_a^2) could be compared. Realism would provide a guage for the assumptions. Limitations and omissions would require judgments based on operational experience.

Another possible situation can be constructed. This would be the situation where there existed not only inter-model conflict, but intra-model disagreement as well. This situation would seem to be the best characterization of the results reported in this thesis. Far from being a discordant presentation of meaningless contradiction, however, the situation provided increased reason to believe that there were other factors to consider which had been omitted and that these factors were of some importance. At the same time some factors may be present that faithfully mask all attempts at isolating others that would be important and indicative. Some of the factors omitted and masking have been discussed above as limitations - such as inflation and better measures of congestion. Thus it would be appropriate to reconsider some of the structures used in the model development.

An alternative explanation of the discord is possible. In an effort to maintain strict comparability between the linear model and the job cost model, the base cases used were

chosen to match by aircraft type/work type and to include as many observations in those cases as possible for more meaningful estimations. It is possible that in doing so, the respective base cases were so atypical that they forced unlikely results. Some indications, notably by comparison of the production vectors expressed in terms of NORM, would provide good reason to hold this view. This could be checked by adding observations from another quarter and repeating the procedures.

Returning to a situation in which WIPICS would have been deemed cost-effective on the basis of the models presented, it would be a natural extension to inquire about extending the use of WIPICS at other NARFs. The analyses would provide a valuable basis for considering such an extension, but the methodology would be even more valuable in checking the desirability of such an extension. The methodology has provided a means for estimating the production and cost flows of a facility and could be used to determine if there was sufficient similarity at the proposed location to make extension appropriate. If a model characterized the proposed activity as not being presently subject to congestive slowdowns, this portion of the WIPICS "cure" would probably be lost. The models also provide a tool for planning. If, in the face of budget reductions, it was anticipated that NARF activities would be scaled down, this situation could be analyzed to determine whether the benefits of WIPICS would still be realized. This could be accomplished by using planned data as a base case for the models.

C. IMPACT OF OTHER FACTORS

Tye's thesis and the present work used data to represent the after WIPICS period that began with observations very near the initiation of WIPICS. As Tye points out in his concluding chapter, WIPICS was not truly fully operational until October of 1972 [9, p. 47]. Even if it had been operational at the beginning of 1972, there would be sufficient reason to delay any denotation of an after-WIPICS period until after a long enough interval of time had passed that the system became routinely operational. The WIPICS related equipment required a learning period as would any mechanical device. Hence real effects would probably not be expected immediately. Ignoring work before, say, 1 July 1972 would decrease the learning period effect. To accomplish any meaningful results would again require additional later data. Each of the models would probably show clearer results from this extension.

Each of the cost models primarily dealt with the total cost figure for the basis of the analysis. Unfortunately the WIPICS effect, if any, might have been buried in doing so. It would probably be beneficial to eliminate from the cost accumulations, on both daily and job bases, the direct labor and material costs. By accounting definition and usage there would be little, if any, expected impact of WIPICS on these costs which constitute the largest share of the cost burden. WIPICS would have the largest impact on the

the overhead and penalty costs. Eliminating labor and material costs would also eliminate many of the additional problems and complications of explaining them.

VI. CONCLUSIONS AND AREAS FOR FUTURE STUDY

A. CONCLUSIONS

Previously described cost models of the NARFNI and their results concerning before and after WIPICS time periods were reviewed. Linear Economic Models were updated with more recent data to provide before and after WIPICS comparisons. Job Cost Models using dummy variables to account for differing work types were introduced and exercised on before and after data. Comparisons of the models indicated extensive inter-models and intra-model conflict. It was concluded that this conflict indicated either missing explanatory factors or excessive extraneous detail of the models. Limitations and possible remedies were suggested for the models presented.

The following table summarizes the conflict within and between the models. In this table the cost differentials have been computed as the before-WIPICS predicted cost minus the after-WIPICS predicted cost. Hence a positive value would indicate cost reduction predicted for the after-WIPICS situation, and a negative value a cost increase. Tye's comparisons for the Daily Cost Models are added for further comparison.

B. AREAS FOR FUTURE STUDY

1. Myers provided a method for using clustering analysis to indentify processes that aided in structuring the engine program model. It would be possible to consider the work

TABLE XXVI

COST DIFFERENTIAL COMPARISONS

Model	Cost Construction	$\{B_M\}$	$\{A_M\}$
Linear	Total Cost	-5.31	-4.77
	Operations Cost	-3.64	-3.09
	Penalty Cost	-1.97	-1.78
Job, Version 1	Total Cost	+3.66	+0.06
	Operations Cost	+5.27	-0.36
	Penalty Cost	-8.68	+0.27
Job, Version 2	Total Cost	-4.49	+1.85
	Operations Cost	-5.28	+1.16
		(Before WIPICS Data)	(After WIPICS Data)
Daily, Cobb-Douglas		+17,885	+9,241
Daily, CES		+ 3,306	+7,129

Values are millions of dollars for the Linear and Job models and dollars per day in the daily models.

types alone rather than the aircraft type and work type together to develop fewer categories and possibly produce more than one process among those work types. There appeared to be some indication of similarity among aircraft, especially where they differ only by model or special configuration. This might provide additional information concerning alternative resource utilizations and allow sensitivity analysis of the aircraft program effort.

2. The engine program since it was not affected by WIPICS implimentation provides a standard for control. The engine

program job mix would probably fluctuate in a manner similar to the aircraft program. The effects of the level of activity on production rates could be investigated. The impact of growth in NORM could be examined for effects on the ability to predict a valid functional relationship. Although the two programs have been treated as independent to date, any interface between aircraft and engine programs might be investigated. This interface could especially be checked for interference with WIPICS. Conclusions drawn about changes in engine program productive factors might shed light on similar factors within the aircraft program which are changing wholly outside of WIPICS influence. The aircraft program might be then reexamined with the highlighted factors diminished or deleted.

APPENDIX A

JOB COST MODEL REGRESSION AND PREDICTION PROGRAM

A. PURPOSE

This program provides regression equation coefficients and statistics for a log-linear model of the job cost flow at NARFNI using as a basis the actual observations of job financial records. Data used is that contained in the Production Performance Reports issued quarterly by NARFNI. The program continues beyond the regression, if desired, to predict values of various cost constructions based on the equation estimated by the regression procedure. Additional data sets of actual data may be used for the prediction, in which case comparison may be made between actual and predicted values. Alternatively, hypothetical or planning data may be used for the prediction, in which case the predicted cost values would serve a budgeting function.

B. INPUTS

A header card, five control cards, and two data sets are required for the regression procedures. Additional sets of data may be included as desired for prediction. In the descriptions that follow, "CC" indicates card column on a computer punch card.

1. Header Card:

CC 1-40	Any alphanumeric title of heading for the model

CC 41-42 The number of additional sets of data to be used for prediction, ≤ 99, right justified in the field. Zero or blank indicates no prediction.

2. Control Cards

first: CC 1-4 The number of explanatory variables to be used in the regression. ("LI")

CC 8 Zero (blank) or one for exclusion or inclusion, respectively, of the penalty cost computation from the desired cost construction ("NOGO")

CC 9-12 The number (< 1600) of data cards for the regression plus one. ("NSTOP")

CC 13-16 The value, separately computed, to be used in prediction for those jobs lying in "tail" periods to indicate average number in shop. ("NIS") May be blank if prediction is not desired.

second: The twenty two-digit aircraft type codes, in numerical order, without spaces between. ("IMATR")

third, fourth, fifth cards: penalty costs per day for the aircraft types identified in the second control card above, in the same order. ("PMATR") Third and fourth card contain eight nine-digit fields, one place of which may be a decimal point. The fifth card contains the remaining four nine-digit fields.

3. Aggregated Prorated Data Deck

The output from the Aircraft Prorate Program [ref. 8, App. D] from Julian date 0069 through the highest production date. Add one blank card, if there is a non-zero number in shop on the last day.

4. Regression Data

Raw data cards in the format given by Myers [8, App. A]. Cards are in order by aircraft type and, within aircraft type, by work type. Exactly NSTOP-1 cards must be entered.

5. Prediction Data

> As many additional decks as indicated on the header card may be included. Repeat the set of control cards, adjusting the first card to match the prediction data set in number of cards and NIS value. The Aggregated data is <u>not</u> repeated.

C. OUTPUTS

Statistical results and a list of computed estimates for the dummy and explanatory variables are printed for the regression procedures. Each step of the stepwise procedure is printed. For the prediction procedures, the predicted values of the input jobs are accumulated and the total is printed along with the total actual value and statistical parameters.

D. SPECIAL NOTES

Construction of the particular cost dependent variable is done in the Read subroutine, where one of the two given statements is chosen depending on the construction desired. Changes between versions are made by interchanging the card "X(J,2)=..." in the same subroutine. Expansion of the program for increased number of explanatory variables and data cards can be accomplished by increasing appropriate DIMENSION values. The subroutine LOC is also required from the IBM Scientific Subroutine Package.

The author wishes to thank Assistant Professor Norman K. Womer, formerly of the Naval Postgraduate School for contributing the computer program appearing in this Appendix.

```
C.....................................................................C
C                                                                     C
C   JOB COST MODEL REGRESSION & PREDICTICN PROGRAM                    C
C                                                                     C
C.....................................................................C
      IMPLICIT REAL*8 (A-H,O-Y)
      REAL*8 P(60),R(60,4)/240*0.0D0/,Y(1600),X(1600,4),XI(4,4)/16*C.0D0
     1/,XY(60)/60*0.0D0/,BI(60),B(4),XX(60,60),RPIR(4,4),TR(60,4),TXI(4
     2,4),W(1100)/1100*0.0D0/,HEAD(5)
      INTEGER*4 IJ(60)
      KEY = 0
      READ(5,94) HEAD, MSTOP
   94 FCRMAT(5A8, I2)
      CALL READ(P,R,Y,X,XI,M,N,XY,IJ,LL,W,KEY)
      DO 10 LI=1,LL
      DC 20 I=1,LI
      DO 30 J=1,LI
 30   TXI(I,J)=XI(I,J)
      DC 20 J=1,M
 20   TR(J,I)=R(J,I)
      DC 40 J=1,M
 40   P(J)=DFLCAT(IJ(J))
      CALL COMB(P,TR,Y,X,TXI,XY,M,N,XX,RPIR,BI,B,LI)
      WRITE(6,95) HEAD
   95 FORMAT('1',////,27X,5A8,//)
      CALL ANOVA(X,Y,IJ,BI,B,M,S,LI)
      CALL TSTAT(XX,RPIR,S,BI,B,M,LI)
 10   CCNTINUE
      IF(MSTOP) 4,4,9
    9 KEY = 1
      DO 70 MIX = 1, MSTOP
      CALL READ(P,R,Y,X,XI,MT,N,XY,IJ,LL,W,KEY)
      IF(MT.EC.M) GO TO 50
      WRITE(6,100) MT, M
  100 FCRMAT('    ERROR IN NUMBER OF DUMMIES..', I4,' VICE',I4)
      GO TO 4
   50 CALL ANOVA(X,Y,IJ,BI,B,M,S,LL)
      LI = 0
      CALL TSTAT(XX,RPIR,S,BI,B,M,LI)
   70 CCNTINUE
    4 STOP
      END
```

```
      SLBROUTINE READ(P,R,Y,X,XI,M,N,XY,IJ,LI,W,KEY)
C
C.......................................................................C
C                                                                       C
C   THIS SUBROUTINE READS IN REGRESSION AND PREDICTION DATA            C
C                                                                       C
C.......................................................................C
      IMPLICIT REAL*8 (A-H,O-Y)
      DIMENSICN P(60),R(60,4),Y(1600),X(1600,4),XI(4,4),XY(60),IJ(6C),
     1W(1100),IMATR(20),PMATR(20)
      M=1
      J=1
      K=0
      L=0
      N=0
      JK=1
      WRITE(6,100)
      READ(5,101) LI, NOGO, NSTOP, NIS
  101 FORMAT(4I4)
      READ(5, 1101) IMATR
 1101 FCRMAT(20I2)
      READ(5, 12C1) PMATR
 1201 FORMAT(8F9.2/8F9.2/4F9.2)
      IF(KEY.EQ.1) GO TC 12
      CALL SREAD(W,ND)
   12 READ(5,110) K1, L1,I1,I2,AN,AL,ALS,AMS,AOS
  110 FCRMAT(I2,8X,I2,1X,2I5,F6.0,6X,F6.0,3F7.0)
      IF(I1.NE.0.AND.I2.NE.0) GO TO 71
C
C  FORM ZERO ROW FOR UNUSED A/C & W/T CCMBO
C
      Y(J) = 0.0D0
      DO 68 IP = 1, LI
   68 X(J,IP) = 0.0D0
      GO TO 21
   71 CALL COML(W,I1,I2,AI,LL)
      IF(LL.EC.1) GO TO 73
      IF (KEY.EQ.0) GO TC 40
      AI = DFLOAT(NIS)
   73 PD=DFLOAT(I2)
      DA = DFLOAT(I2-I1)
      PCCST = 0.0D0
      IF(NOGO.EQ.0) GO TO 14
      DO 47 IDX = 1, 20
      IF(IMATR(IDX).NE.K1) GO TO 47
      PCOST = PMATR(IDX)*DA
      GO TO 14
   47 CCNTINUE
```

```
C    CONSTRUCT DEPENDENT, INDEPENDENT VARIABLE VALUES
C
C    FOR TOTAL OR OPERATICNS CCST FUNCTICNS DEPENCENT VARIABLE
C          USE
   14 Y(J) = DLOG10(ALS+AMS+ACS+PCOST)
C
C    FOR VERSION 1 PENALTY COST FUNCTIONS, DEPENDENT VARIABLE
C          USE
   14 Y(J) = DLOG10(PCOST)
      X(J,1) = DLOG10(ALS/AL)
C
C    FOR VERSICN 1
C          USE
      X(J,2) = DLOG10(PD)
C
C    FOR VERSICN 2
C          USE
      X(J,2) = DLOG10(DA)
      X(J,3) = DLOG10(AI)
      X(J,4) = DLOG10(AN)
 21   IF(K.EQ.K1) GO TO 10
      IF(K.EQ.0) GO TO 13
 11   P(M)=DFLCAT(N)
      IJ(M)=N
      WRITE(6,102)K,L,M,N
      IF(K1.EQ.0) GO TO 20
      M=M+1
      N=0
      K=K1
      L=L1
      GC TO 13
 10   IF(L.NE.L1) GO TO 11
 13   K=K1
      L=L1
      N=N+1
      IF(I2.EQ.0) N = 0
      IF(KEY.EQ.1) GO TO 39
      XY(M)=XY(M)+Y(J)
      DC 22 I=1,LI
      R(M,I)=R(M,I)+X(J,I)
      DO 22 JJ=1,LI
 22   XI(I,JJ)=XI(I,JJ)+X(J,I)*X(J,JJ)
   39 J = J + 1
 40   JK=JK+1
      IF(JK.EQ.NSTOP) GO TO 30
      GC TO 12
 30   K1=0
      GC TO 11
```

```
 20   N=J-1
      RETURN
 100  FORMAT('1     TYPE    WORK    CAT    NUMBER')
 102  FORMAT(' ',4I7)
C
C N IS NUMBER OF OBS, M IS NUMBER OF DUMMIES
C X'X IS PARTITIONED INTO P,R,R', AND XI
C
      END
```

```
      SLBROUTINE COMB(P,R,Y,X,XI,XY,M,N,XX,RPIR,EI,B,LI)
C
C.......................................................................C
C                                                                       C
C    THIS SUBRCUTINE COMPUTES THE ESTIMATED COEFFICIENT VECTOR          C
C                                                                       C
C.......................................................................C
      IMPLICIT REAL*8 (A-H,O-Y)
      DIMENSION P(60),R(240),Y(1600),X(1600,4),XI(4,4),PIR(60,4),RPIR(4,
     14),XX(3600),PIRT(4,60),XJ(4)         ,XK(4),XY(60),B(4),BI(60),W(60)
      INTEGER*4 Z1(4),Z2(4)
      DO 10 I=1,M
 10   P(I)=P(I)**(-1)
      CALL ARRAY(2,LI,LI,4,4,XI,XI)
      CALL ARRAY(2,M,LI,60,4,R,R)
      CALL MPRD(P,R,PIR,M,M,2,0,LI)
      CALL GTPRD(R,PIR,RPIR,M,LI,LI)
      CALL GMSUB(XI,RPIR,RPIR,LI,LI)
      CALL DMINV(RPIR,LI,C,Z1,Z2)
      CALL GMPRD(PIR,RPIR,R,M,LI,LI)
      CALL GMTRA(PIR,PIRT,M,LI)
      CALL GMPRD(R,PIRT,XX,M,LI,M)
      DO 20 I=1,M
      CALL LOC(I,I,IR,M,M,0)
      XX(IR)=P(I)+XX(IR)
      DO 20 J=1,LI
      CALL LCC(I,J,IR,M,LI,0)
 20   R(IR)=-R(IR)
C
C X'X**-1 IS PARTITIONED INTO XX, R, AND RPIR
C
      CALL GMPRD(XX,XY,W,M,M,1)
      DC 60 I=1,LI
 60   XJ(I)=0.0D0
      DO 40 I=1,N
      DC 40 J=1,LI
 40   XJ(J)=XJ(J)+X(I,J)*Y(I)
      CALL GMPRD(R,XJ,BI,M,LI,1)
      DC 30 I=1,M
 30   BI(I)=BI(I)+W(I)
      CALL GMPRD(RPIR,XJ,B,LI,LI,1)
      CALL GTPRD(R,XY,XJ,M,LI,1)
      DO 50 J=1,LI
 50   B(J)=B(J)+XJ(J)
C
C BI AUGMENTED BY B IS THE ESTIMATED COEFFICIENT VECTOR
      RETURN
      END
```

```
      SUBROUTINE SREAD(W,I)
C
C.......................................................................C
C                                                                       C
C   THIS SUBROUTINE READS DATA FOR COMPUTING AVERAGE NUMBER IN SHOP     C
C                                                                       C
C.......................................................................C
      IMPLICIT REAL*8(A-H,O-Y)
      DIMENSION W(1100)
      I = 1
 10   READ(5,100)W(I)
      IF(W(I).EQ.0) GO TO 20
      I=I+1
      GO TO 10
 20   RETURN
  100 FORMAT(67X,F5.1)
      END
```

```
      SUBROUTINE COML(W,I1,I2,A,J)
C
C..................................................................C
C                                                                  C
C   THIS SUBROUTINE COMPUTES AVERAGE NUMBER IN SHOP FOR EACH JOB   C
C                                                                  C
C..................................................................C
      IMPLICIT REAL*8(A-H,O-Y)
      DIMENSION W(1100), JULN(5)
      JULN(1) = 68
      JULN(2) = 635
      JULN(3) = 635
      JULN(4) = 634
      JULN(5) = 635
      IT1 = (I1/1000) + 1
      IT2 = (I2/1000) + 1
      DO 7 JLN = 1, IT2
      I2 = I2 - JULN(JLN)
    7 CONTINUE
    8 DO 9 JLM = 1, IT1
      I1 = I1 - JULN(JLM)
    9 CONTINUE
   12 CONTINUE
      IF(I1.LE.118) GO TO 30
      IF(I2.GT.934) GO TO 30
      A=0.0
      DO 13 I=I1,I2
 13   A=A+W(I)
      B=I2-I1
      A=A/B
      J=1
      GO TO 40
 30   J=0
 40   RETURN
      END
```

```
      SUBROUTINE ANOVA(X,Y,IJ,BI,B,M,S,LI)
C
C......................................................................C
C                                                                      C
C   ANALYSIS OF VARIANCE SUBROUTINE                                    C
C                                                                      C
C......................................................................C
      IMPLICIT REAL*8 (A-H,O-Y)
      DIMENSION X(1600,4),Y(1600),IJ(60),BI(60),B(4)
      REAL*8 MS
C
C CALCULATE SUMS OF SQUARES
      S=0.0D0
      YIY=0.0D0
      SE=0.0D0
      SYH = 0.0D0
      J=0
      YY=0.0D0
      YJY=0.0D0
      DO 10 K=1,M
      L=IJ(K)
      IF(L) 30,30,35
   30 J = J + 1
      GO TO 10
   35 DO 10 KK=1,L
      J=J+1
      YH=BI(K)
      DO 20 I=1,LI
 20   YH=YH+B(I)*X(J,I)
      SYH = SYH + 10.0D0**YH
      R=Y(J)-YH
      RE=(10.0D0**(Y(J))-10.0D0**(YH))
      YIY=YIY+10.0D0**(Y(J))
      SE=SE+RE**2
      S=S+R**2
      YJY=YJY+Y(J)
 10   YY=YY+Y(J)**2
      D=DFLOAT(J)
      SE=2*DSQRT(SE)/YIY
      WRITE (6,109) YIY
  109 FORMAT(16X,'SUM OF DEPENDENT VARIABLE VALUES IS ',D11.4/)
      WRITE(6,110) SYH
  110 FORMAT(16X,'SUM OF PREDICTED DEPENDENT VARIABLES IS ',D11.4/)
      YIY=YIY/D
      WRITE(6,108)SE,YIY
  108 FORMAT(16X,'STANDARD ERROR TO MEAN RATIO IS ',D11.4/,16X,'MEAN IS'
     1,D11.4/)
      E=DFLOAT(M+LI)
```

```
      E=M+LI
      MS=YY/D
      WRITE(6,100)
      WRITE(6,101)YY,J,MS
      YJY=(YJY**2)/D
      SS=S
      S=S/(D-E)
      K=1
      F=YJY/S
      WRITE(6,102)YJY,K,YJY,F
      YAY=YY-YJY
      K=J-1
      MS=YAY/(D-1.0D0)
      WRITE(6,103)YAY,K,MS
      RDB=YY-SS
      MS=RDB/E
      F=MS/S
      K=M+LI
      WRITE(6,104)RDB,K,MS,F
      RDBA=RDB-YJY
      K=K-1
      E=DFLOAT(K)
      MS=RDBA/E
      F=MS/S
      WRITE(6,105)RDBA,K,MS,F
      K=J-M-LI
      WRITE(6,106)SS,K,S
      RS=1.0D0-SS/YAY
      D=DFLOAT(J-1)
      RSA=1.0D0-S*D/YAY
      WRITE(6,107)RS,RSA
      RETURN
  100 FORMAT('0',35X,'ANALYSIS OF VARIANCE',/,16X,'SOURCE',4X,'SUM OF SQ
     1UARES',4X,'DF',4X,'MEAN SQUARE',2X,'F STATISTIC')
  101 FORMAT('0',17X,'TSS',6X,E11.4,3X,I4,2X,E11.4)
  102 FORMAT('0',17X,'RDM',6X,E11.4,3X,I4,2X,E11.4,4X,F10.4)
  103 FORMAT('0',17X,'TSSA',5X,E11.4,3X,I4,2X,E11.4)
  104 FORMAT('0',17X,'RDB',6X,E11.4,3X,I4,2X,E11.4,4X,F10.4)
  105 FORMAT('0',17X,'RDBA',5X,E11.4,3X,I4,2X,E11.4,4X,F10.4)
  106 FORMAT('0',16X,'ERROR',5X,E11.4,3X,I4,2X,E11.4)
  107 FORMAT('0',15X,'RSQR IS  ',E11.4,'  RSQR ADJUSTED IS ',E11.4)
      END
```

```
      SLBROUTINE TSTAT(XX,RPIR,S,BI,B,M,LI)
C
C.....................................................................C
C                                                                     C
C   THIS SUBROUTINE COMPUTES RATIO OF COEFFICIENT TC STANDARD ERRCR   C
C                                                                     C
C       FOR COMPARISON TO STUDENT'S T STATISTICAL VALUES              C
C                                                                     C
C.....................................................................C
      IMPLICIT REAL*8 (A-H,O-Y)
      DIMENSICN XX(3600),RPIR(16),BI(60),B(4)
      SD=DSQRT(S)
      WRITE(6,100)SD
      IF(LI.EQ.0) RETURN
      WRITE(7,101)
      WRITE(6,104)
      DC 10 I=1,M
      CALL LOC(I,I,IR,M,M,0)
      SB=DSQRT(S*XX(IR))
      T=BI(I)/SB
 10   WRITE(7,102) I,BI(I),SB,T
      DC 20 K=1,LI
      CALL LOC(K,K,I,LI,LI,0)
      SB=DSORT(S*RPIR(I))
      T=B(K)/SB
 20   WRITE(6,102)K,B(K),SB,T
      RETURN
 100  FCRMAT('0',15X,'THE STANDARD ERROR OF THE DEPENDENT VARIABLE IS ',
     1E11.4//)
 101  FCRMAT(' CATEGORY',2X,'COEFFICIENT',3X,'STD ERROR',3X,'T STATISTIC
     1')
 102  FORMAT(18X,I3,5X,E11.4,2X,E11.4,2X,E11.4)
  104 FCRMAT('0',15X,'VARIABLE',2X,'COEFFICIENT',3X,'STD ERROR',3X,'T ST
     1ATISTIC',/)
      END
```

```
C.....................................................................C
C                                                                     C
C                                                                     C
C                                                                     C
C   THE FOLLOWING SUBROUTINES ARE MODIFIED VERSIONS OF THE STANDARD   C
C                                                                     C
C      IBM SCIENTIFIC SUBROUTINE PACKAGE MATRIX ALGEBRA SUBROUTINES   C
C                                                                     C
C                                                                     C
C                                                                     C
C                                                                     C
C.....................................................................C
      SUBROUTINE ARRAY (MODE,I,J,N,M,S,D)
      DIMENSION S(1),D(1)
      DOUBLE PRECISION S,D
C
      NI=N-I
C
C        TEST TYPE OF CONVERSION
C
      IF(MODE-1) 100, 100, 120
C
C        CONVERT FROM SINGLE TO DOUBLE DIMENSION
C
  100 IJ=I*J+1
      NM=N*J+1
      DO 110 K=1,J
      NM=NM-NI
      DO 110 L=1,I
      IJ=IJ-1
      NM=NM-1
  110 D(NM)=S(IJ)
      GO TO 140
C
C        CONVERT FROM DOUBLE TO SINGLE DIMENSION
C
  120 IJ=0
      NM=0
      DO 130 K=1,J
      DO 125 L=1,I
      IJ=IJ+1
      NM=NM+1
  125 S(IJ)=D(NM)
  130 NM=NM+NI
C
  140 RETURN
      END
```

```
      SUBROUTINE MPRD(A,B,R,N,M,MSA,MSB,L)                              MPRD 520
      DIMENSION A(1),B(1),R(1)                                          MPRD 530
      DOUBLE PRECISION A,B,R
C                                                                       MPRD 540
C        SPECIAL CASE FOR DIAGONAL BY DIAGONAL                          MPRD 550
C                                                                       MPRD 560
      MS=MSA*10+MSB                                                     MPRD 570
      IF(MS-22) 30,10,30                                                MPRD 580
   10 DO 20 I=1,N                                                       MPRD 590
   20 R(I)=A(I)*B(I)                                                    MPRD 600
      RETURN                                                            MPRD 610
C                                                                       MPRD 620
C        ALL OTHER CASES                                                MPRD 630
C                                                                       MPRD 640
   30 IR=1                                                              MPRD 650
      DO 90 K=1,L                                                       MPRD 660
      DO 90 J=1,N                                                       MPRD 670
      R(IR)=0                                                           MPRD 680
      DO 80 I=1,M                                                       MPRD 690
      IF(MS) 40,60,40                                                   MPRD 700
   40 CALL LOC(J,I,IA,N,M,MSA)                                          MPRD 710
      CALL LOC(I,K,IB,M,L,MSB)                                          MPRD 720
      IF(IA) 50,80,50                                                   MPRD 730
   50 IF(IB) 70,80,70                                                   MPRD 740
   60 IA=N*(I-1)+J                                                      MPRD 750
      IB=M*(K-1)+I                                                      MPRD 760
   70 R(IR)=R(IR)+A(IA)*B(IB)                                           MPRD 770
   80 CONTINUE                                                          MPRD 780
   90 IR=IR+1                                                           MPRD 790
      RETURN                                                            MPRD 800
      END                                                               MPRD 810
```

```
      SUBROUTINE GTPRD(A,B,R,N,M,L)                                     GTPR 360
      DIMENSICN A(1),B(1),R(1)                                          GTPR 370
      DOUBLE PRECISION A,B,R
C                                                                       GTPR 380
      IR=0                                                              GTPR 390
      IK=-N                                                             GTPR 400
      DC 10 K=1,L                                                       GTPR 410
      IJ=C                                                              GTPR 420
      IK=IK+N                                                           GTPR 430
      DC 10 J=1,M                                                       GTPR 440
      IB=IK                                                             GTPR 450
      IR=IR+1                                                           GTPR 460
      R(IR)=0                                                           GTPR 470
      DO 10 I=1,N                                                       GTPR 480
      IJ=IJ+1                                                           GTPR 490
      IB=IB+1                                                           GTPR 500
   10 R(IR)=R(IR)+A(IJ)*B(IB)                                           GTPR 510
      RETURN                                                            GTPR 520
      END                                                               GTPR 530
```

```
      SUBROUTINE GMSUB(A,B,R,N,M)                                       GMSU 320
      DIMENSION A(1),B(1),R(1)                                          GMSU 330
      DOUBLE PRECISION A,B,R
C                                                                       GMSU 340
C        CALCULATE NUMBER OF ELEMENTS                                   GMSU 350
C                                                                       GMSU 360
      NM=N*M                                                            GMSU 370
C                                                                       GMSU 380
C        SUBTRACT MATRICES                                              GMSU 390
C                                                                       GMSU 400
      DC 10 I=1,NM                                                      GMSU 410
   10 R(I)=A(I)-B(I)                                                    GMSU 420
      RETURN                                                            GMSU 430
      END                                                               GMSU 440
```

```
      SUBROUTINE GMPRD(A,B,R,N,M,L)                                     GMPR 370
      DIMENSION A(1),B(1),R(1)                                          GMPR 380
      DOUBLE PRECISION A,B,R
C                                                                       GMPR 390
      IR=0                                                              GMPR 400
      IK=-M                                                             GMPR 410
      DO 10 K=1,L                                                       GMPR 420
      IK=IK+M                                                           GMPR 430
      DO 10 J=1,N                                                       GMPR 440
      IR=IR+1                                                           GMPR 450
      JI=J-N                                                            GMPR 460
      IB=IK                                                             GMPR 470
      R(IR)=0                                                           GMPR 480
      DO 10 I=1,M                                                       GMPR 490
      JI=JI+N                                                           GMPR 500
      IB=IB+1                                                           GMPR 510
   10 R(IR)=R(IR)+A(JI)*B(IB)                                           GMPR 520
      RETURN                                                            GMPR 530
      END                                                               GMPR 540
```

```
      SUBROUTINE GMTRA(A,R,N,M)                                         GMTR 300
      DIMENSION A(1),R(1)                                               GMTR 310
      DOUBLE PRECISION A,R
C                                                                       GMTR 320
      IR=0                                                              GMTR 330
      DO 10 I=1,N                                                       GMTR 340
      IJ=I-N                                                            GMTR 350
      DO 10 J=1,M                                                       GMTR 360
      IJ=IJ+N                                                           GMTR 370
      IR=IR+1                                                           GMTR 380
   10 R(IR)=A(IJ)                                                       GMTR 390
      RETURN                                                            GMTR 400
      END                                                               GMTR 410
```

APPENDIX B

JOB COST MODEL DUMMY VARIABLE COEFFICIENTS

1. Job Cost Model categories are identified below.

2. All values are given in scientific notation, i.e., 0.4345D01 means 0.4345 times 10 raised to the 1st power or 4.345.

BEFORE WIPICS CATEGORY IDENTIFICATION

TYPE	WORK	CAT	NUMBER
10	4	1	3
11	3	2	22
21	2	3	49
21	4	4	16
21	5	5	3
21	6	6	2
22	1	7	1
22	2	8	14
22	4	9	24
22	5	10	22
22	6	11	7
23	3	12	1
23	4	13	5
25	2	14	19
25	6	15	9
26	2	16	7
26	6	17	1
27	2	18	4
27	6	19	8
31	2	20	3
32	2	21	3
33	2	22	1
33	9	23	1
34	3	24	52
35	2	25	2
41	2	26	7
42	2	27	12
42	4	28	2
43	2	29	24
44	2	30	1
45	2	31	2
48	2	32	7
48	7	33	13
48	8	34	5
49	2	35	1
49	7	36	1

AFTER WIPICS CATEGORY IDENTIFICATION

TYPE	WORK	CAT	NUMBER
10	4	1	3
11	2	2	9
11	6	3	2
21	2	4	24
21	4	5	8
21	5	6	4
21	6	7	9
21	7	8	4
22	5	9	15
22	6	10	3
23	2	11	1
23	4	12	3
25	2	13	1
25	4	14	2
25	5	15	2
25	6	16	2
26	4	17	1
26	5	18	1
27	2	19	1
27	6	20	1
33	2	21	4
33	3	22	18
34	1	23	1
34	2	24	2
34	3	25	6
35	2	26	2
42	2	27	9
43	2	28	16
43	4	29	1
43	6	30	3
48	2	31	4
48	6	32	1
48	7	33	5
48	8	34	3
49	2	35	15
49	7	36	3
49	8	37	4

VERSION 1 BEFORE WIPICS TOTAL COST

CORRESPONDING TO THE MODELS OF THE SAME TITLE IN CHAPTER IV, THE COEFFICIENTS OF THE DUMMY VARIABLES AND THEIR RELATED STATISTICS ARE GIVEN BELOW. THE CATEGORY NUMBERS REFER TO AIRCRAFT TYPE-WORK TYPE COMBINATIONS GIVEN ON THE FIRST PAGE OF THIS APPENDIX.

CATEGORY	COEFFICIENT	STD ERROR	T STATISTIC
1	0.4345D 01	0.6187D 00	0.7022D 01
2	0.4399D 01	0.6190D 00	0.7107D 01
3	0.4010D 01	0.6199D 00	0.6468D 01
4	0.4111D 01	0.6192D 00	0.6640D 01
5	0.4037D 01	0.6213D 00	0.6497D 01
6	0.4054D 01	0.6208D 00	0.6530D 01
7	0.4287D 01	0.6215D 00	0.6898D 01
8	0.4107D 01	0.6188D 00	0.6638D 01
9	0.4180D 01	0.6187D 00	0.6757D 01
10	0.4244D 01	0.6196D 00	0.6850D 01
11	0.4137D 01	0.6191D 00	0.6682D 01
12	0.4057D 01	0.6213D 00	0.6530D 01
13	0.4195D 01	0.6250D 00	0.6711D 01
14	0.3948D 01	0.6184D 00	0.6383D 01
15	0.4023D 01	0.6189D 00	0.6501D 01
16	0.3951D 01	0.6189D 00	0.6385D 01
17	0.4054D 01	0.6199D 00	0.6540D 01
18	0.3936D 01	0.6184D 00	0.6365D 01
19	0.3977D 01	0.6201D 00	0.6414D 01
20	0.3848D 01	0.6183D 00	0.6224D 01
21	0.3882D 01	0.6185D 00	0.6276D 01
22	0.3729D 01	0.6195D 00	0.6020D 01
23	0.4013D 01	0.6280D 00	0.6391D 01
24	0.3807D 01	0.6175D 00	0.6164D 01
25	0.3774D 01	0.6211D 00	0.6076D 01
26	0.3785D 01	0.6185D 00	0.6119D 01
27	0.3763D 01	0.6179D 00	0.6089D 01
28	0.3823D 01	0.6218D 00	0.6149D 01
29	0.3724D 01	0.6189D 00	0.6017D 01
30	0.3768D 01	0.6258D 00	0.6021D 01
31	0.3770D 01	0.6217D 00	0.6064D 01
32	0.3922D 01	0.6171D 00	0.6355D 01
33	0.3936D 01	0.6191D 00	0.6357D 01
34	0.3844D 01	0.6164D 00	0.6236D 01
35	0.3798D 01	0.6219D 00	0.6107D 01
36	0.3864D 01	0.6182D 00	0.6250D 01

VERSION 1 AFTER WIPICS TOTAL COST

CORRESPONDING TO THE MODELS OF THE SAME TITLE IN CHAPTER IV, THE COEFFICIENTS OF THE DUMMY VARIABLES AND THEIR RELATED STATISTICS ARE GIVEN BELOW. THE CATEGORY NUMBERS REFER TO AIRCRAFT TYPE-WORK TYPE COMBINATIONS GIVEN ON THE FIRST PAGE OF THIS APPENDIX.

CATEGORY	COEFFICIENT	STD ERROR	T STATISTIC
1	0.2264D 01	0.9019D 00	0.2510D 01
2	0.2346D 01	0.9002D 00	0.2605D 01
3	0.2284D 01	0.9013D 00	0.2534D 01
4	0.2039D 01	0.8989D 00	0.2268D 01
5	0.2060D 01	0.9032D 00	0.2281D 01
6	0.2031D 01	0.9030D 00	0.2250D 01
7	0.1998D 01	0.8994D 00	0.2221D 01
8	0.2015D 01	0.9002D 00	0.2239D 01
9	0.2083D 01	0.9051D 00	0.2301D 01
10	0.2078D 01	0.9048D 00	0.2296D 01
11	0.2024D 01	0.9039D 00	0.2239D 01
12	0.2007D 01	0.8996D 00	0.2231D 01
13	0.2079D 01	0.8963D 00	0.2319D 01
14	0.2012D 01	0.9008D 00	0.2233D 01
15	0.2029D 01	0.9021D 00	0.2250D 01
16	0.1997D 01	0.9009D 00	0.2216D 01
17	0.2001D 01	0.8989D 00	0.2226D 01
18	0.2018D 01	0.9032D 00	0.2234D 01
19	0.1855D 01	0.8973D 00	0.2067D 01
20	0.1921D 01	0.9014D 00	0.2131D 01
21	0.1994D 01	0.8956D 00	0.2227D 01
22	0.1966D 01	0.8938D 00	0.2200D 01
23	0.2097D 01	0.9011D 00	0.2327D 01
24	0.2063D 01	0.9057D 00	0.2278D 01
25	0.1982D 01	0.8957D 00	0.2212D 01
26	0.2013D 01	0.8964D 00	0.2246D 01
27	0.1980D 01	0.8951D 00	0.2213D 01
28	0.2009D 01	0.8924D 00	0.2252D 01
29	0.1964D 01	0.8858D 00	0.2217D 01
30	0.1987D 01	0.8944D 00	0.2221D 01
31	0.2030D 01	0.8920D 00	0.2275D 01
32	0.2042D 01	0.8984D 00	0.2273D 01
33	0.1979D 01	0.8979D 00	0.2204D 01
34	0.1951D 01	0.8955D 00	0.2179D 01
35	0.1975D 01	0.8941D 00	0.2209D 01
36	0.1945D 01	0.8968D 00	0.2169D 01
37	0.1983D 01	0.8967D 00	0.2212D 01

VERSION 1 BEFORE WIPICS   OPNS COST

CORRESPONDING TO THE MODELS OF THE SAME TITLE IN CHAPTER IV, THE COEFFICIENTS OF THE DUMMY VARIABLES AND THEIR RELATED STATISTICS ARE GIVEN BELOW. THE CATEGORY NUMBERS REFER TO AIRCRAFT TYPE-WORK TYPE COMBINATIONS GIVEN ON THE FIRST PAGE OF THIS APPENDIX.

```
CATEGORY  COEFFICIENT   STD ERROR    T STATISTIC
    1     0.3233D 01   0.6398D 00    0.5053D 01
    2     0.3345D 01   0.6401D 00    0.5226D 01
    3     0.3245D 01   0.6411D 00    0.5063D 01
    4     0.3308D 01   0.6403D 00    0.5167D 01
    5     0.3278D 01   0.6425D 00    0.5102D 01
    6     0.3263D 01   0.6419D 00    0.5084D 01
    7     0.3393D 01   0.6427D 00    0.5279D 01
    8     0.3305D 01   0.6399D 00    0.5165D 01
    9     0.3375D 01   0.6398D 00    0.5275D 01
   10     0.3427D 01   0.6407D 00    0.5349D 01
   11     0.3331D 01   0.6402D 00    0.5203D 01
   12     0.3287D 01   0.6425D 00    0.5116D 01
   13     0.3377D 01   0.6463D 00    0.5225D 01
   14     0.3183D 01   0.6395D 00    0.4977D 01
   15     0.3246D 01   0.6400D 00    0.5072D 01
   16     0.3187D 01   0.6400D 00    0.4980D 01
   17     0.3301D 01   0.6410D 00    0.5150D 01
   18     0.3220D 01   0.6394D 00    0.5035D 01
   19     0.3259D 01   0.6412D 00    0.5083D 01
   20     0.3131D 01   0.6394D 00    0.4897D 01
   21     0.3139D 01   0.6396D 00    0.4908D 01
   22     0.2957D 01   0.6406D 00    0.4615D 01
   23     0.3252D 01   0.6494D 00    0.5008D 01
   24     0.3069D 01   0.6386D 00    0.4806D 01
   25     0.3058D 01   0.6423D 00    0.4762D 01
   26     0.3072D 01   0.6396D 00    0.4803D 01
   27     0.3052D 01   0.6390D 00    0.4776D 01
   28     0.3116D 01   0.6430D 00    0.4847D 01
   29     0.2997D 01   0.6400D 00    0.4683D 01
   30     0.3091D 01   0.6472D 00    0.4776D 01
   31     0.3075D 01   0.6429D 00    0.4783D 01
   32     0.3213D 01   0.6382D 00    0.5035D 01
   33     0.3253D 01   0.6403D 00    0.5080D 01
   34     0.3153D 01   0.6374D 00    0.4946D 01
   35     0.3103D 01   0.6431D 00    0.4825D 01
   36     0.3184D 01   0.6393D 00    0.4981D 01
```

VERSION 1 AFTER WIPICS CPNS COST

CORRESPONDING TO THE MODELS OF THE SAME TITLE IN CHAPTER IV, THE COEFFICIENTS OF THE DUMMY VARIABLES AND THEIR RELATED STATISTICS ARE GIVEN BELOW. THE CATEGORY NUMBERS REFER TO AIRCRAFT TYPE-WORK TYPE COMBINATIONS GIVEN ON THE FIRST PAGE OF THIS APPENDIX.

```
CATEGORY  COEFFICIENT    STD ERROR    T STATISTIC
    1      0.4240D 00    0.9894D 00    0.4285D 00
    2      0.4804D 00    0.9876D 00    0.4864D 00
    3      0.4186D 00    0.9887D 00    0.4234D 00
    4      0.4612D 00    0.9861D 00    0.4677D 00
    5      0.4374D 00    0.9908D 00    0.4415D 00
    6      0.4203D 00    0.9906D 00    0.4243D 00
    7      0.4294D 00    0.9867D 00    0.4352D 00
    8      0.4389D 00    0.9875D 00    0.4445D 00
    9      0.4342D 00    0.9929D 00    0.4373D 00
   10      0.4198D 00    0.9926D 00    0.4229D 00
   11      0.4449D 00    0.9916D 00    0.4487D 00
   12      0.4164D 00    0.9869D 00    0.4219D 00
   13      0.4923D 00    0.9833D 00    0.5007D 00
   14      0.4109D 00    0.9882D 00    0.4158D 00
   15      0.4099D 00    0.9897D 00    0.4142D 00
   16      0.4133D 00    0.9883D 00    0.4182D 00
   17      0.3977D 00    0.9861D 00    0.4033D 00
   18      0.4054D 00    0.9908D 00    0.4091D 00
   19      0.2571D 00    0.9843D 00    0.2612D 00
   20      0.3777D 00    0.9888D 00    0.3820D 00
   21      0.4936D 00    0.9824D 00    0.5024D 00
   22      0.4519D 00    0.9805D 00    0.4609D 00
   23      0.4957D 00    0.9885D 00    0.5015D 00
   24      0.4295D 00    0.9935D 00    0.4323D 00
   25      0.4768D 00    0.9826D 00    0.4853D 00
   26      0.5329D 00    0.9834D 00    0.5419D 00
   27      0.4968D 00    0.9819D 00    0.5059D 00
   28      0.5215D 00    0.9790D 00    0.5326D 00
   29      0.4644D 00    0.9717D 00    0.4779D 00
   30      0.4796D 00    0.9812D 00    0.4888D 00
   31      0.5454D 00    0.9785D 00    0.5573D 00
   32      0.5291D 00    0.9856D 00    0.5369D 00
   33      0.4942D 00    0.9851D 00    0.5017D 00
   34      0.4642D 00    0.9824D 00    0.4725D 00
   35      0.4854D 00    0.9809D 00    0.4948D 00
   36      0.4599D 00    0.9838D 00    0.4675D 00
   37      0.4940D 00    0.9836D 00    0.5022D 00
```

VERSION 1 BEFORE WIPICS PENALTY COST

CORRESPONDING TO THE MODELS OF THE SAME TITLE IN CHAPTER IV, THE COEFFICIENTS OF THE DUMMY VARIABLES AND THEIR RELATED STATISTICS ARE GIVEN BELOW. THE CATEGORY NUMBERS REFER TO AIRCRAFT TYPE-WORK TYPE COMBINATIONS GIVEN ON THE FIRST PAGE OF THIS APPENDIX.

```
CATEGORY   COEFFICIENT    STD ERROR    T STATISTIC
    1      0.5533D 01    0.8428D 00    0.6565D 01
    2      0.5565D 01    0.8431D 00    0.6600D 01
    3      0.4886D 01    0.8445D 00    0.5786D 01
    4      0.5051D 01    0.8434D 00    0.5989D 01
    5      0.4903D 01    0.8463D 00    0.5793D 01
    6      0.4979D 01    0.8456D 00    0.5889D 01
    7      0.5359D 01    0.8467D 00    0.6330D 01
    8      0.5048D 01    0.8429D 00    0.5989D 01
    9      0.5125D 01    0.8427D 00    0.6082D 01
   10      0.5209D 01    0.8440D 00    0.6172D 01
   11      0.5083D 01    0.8433D 00    0.6027D 01
   12      0.4942D 01    0.8463D 00    0.5840D 01
   13      0.5166D 01    0.8514D 00    0.6068D 01
   14      0.4825D 01    0.8424D 00    0.5727D 01
   15      0.4918D 01    0.8430D 00    0.5834D 01
   16      0.4827D 01    0.8431D 00    0.5726D 01
   17      0.4911D 01    0.8444D 00    0.5816D 01
   18      0.4703D 01    0.8423D 00    0.5583D 01
   19      0.4752D 01    0.8446D 00    0.5626D 01
   20      0.4625D 01    0.8423D 00    0.5491D 01
   21      0.4719D 01    0.8426D 00    0.5601D 01
   22      0.4624D 01    0.8438D 00    0.5480D 01
   23      0.4889D 01    0.8554D 00    0.5716D 01
   24      0.4633D 01    0.8412D 00    0.5508D 01
   25      0.4552D 01    0.8461D 00    0.5380D 01
   26      0.4554D 01    0.8426D 00    0.5405D 01
   27      0.4528D 01    0.8417D 00    0.5379D 01
   28      0.4572D 01    0.8470D 00    0.5398D 01
   29      0.4524D 01    0.8430D 00    0.5366D 01
   30      0.4416D 01    0.8525D 00    0.5180D 01
   31      0.4486D 01    0.8469D 00    0.5297D 01
   32      0.4674D 01    0.8406D 00    0.5560D 01
   33      0.4599D 01    0.8434D 00    0.5453D 01
   34      0.4555D 01    0.8397D 00    0.5425D 01
   35      0.4514D 01    0.8472D 00    0.5329D 01
   36      0.4531D 01    0.8421D 00    0.5381D 01
```

VERSION 1 AFTER WIPICS PENALTY COST

CORRESPONDING TO THE MODELS OF THE SAME TITLE IN CHAPTER IV, THE COEFFICIENTS OF THE DUMMY VARIABLES AND THEIR RELATED STATISTICS ARE GIVEN BELOW. THE CATEGORY NUMBERS REFER TO AIRCRAFT TYPE-WORK TYPE COMBINATIONS GIVEN ON THE FIRST PAGE OF THIS APPENDIX.

```
CATEGORY   COEFFICIENT    STD ERROR    T STATISTIC
    1      0.6341D 01    0.1445D 01    0.4389D 01
    2      0.6457D 01    0.1442D 01    0.4478D 01
    3      0.6410D 01    0.1444D 01    0.4440D 01
    4      0.5851D 01    0.1440D 01    0.4064D 01
    5      0.5956D 01    0.1447D 01    0.4117D 01
    6      0.5908D 01    0.1446D 01    0.4084D 01
    7      0.5790D 01    0.1441D 01    0.4019D 01
    8      0.5824D 01    0.1442D 01    0.4039D 01
    9      0.6023D 01    0.1450D 01    0.4154D 01
   10      0.6032D 01    0.1449D 01    0.4162D 01
   11      0.5837D 01    0.1448D 01    0.4031D 01
   12      0.5841D 01    0.1441D 01    0.4054D 01
   13      0.5903D 01    0.1436D 01    0.4112D 01
   14      0.5869D 01    0.1443D 01    0.4067D 01
   15      0.5922D 01    0.1445D 01    0.4098D 01
   16      0.5821D 01    0.1443D 01    0.4034D 01
   17      0.5857D 01    0.1440D 01    0.4068D 01
   18      0.5896D 01    0.1447D 01    0.4075D 01
   19      0.5701D 01    0.1437D 01    0.3966D 01
   20      0.5643D 01    0.1444D 01    0.3908D 01
   21      0.5650D 01    0.1435D 01    0.3939D 01
   22      0.5649D 01    0.1432D 01    0.3945D 01
   23      0.5954D 01    0.1443D 01    0.4125D 01
   24      0.5979D 01    0.1451D 01    0.4121D 01
   25      0.5637D 01    0.1435D 01    0.3929D 01
   26      0.5622D 01    0.1436D 01    0.3915D 01
   27      0.5593D 01    0.1434D 01    0.3901D 01
   28      0.5638D 01    0.1430D 01    0.3944D 01
   29      0.5613D 01    0.1419D 01    0.3956D 01
   30      0.5665D 01    0.1433D 01    0.3954D 01
   31      0.5626D 01    0.1429D 01    0.3937D 01
   32      0.5724D 01    0.1439D 01    0.3977D 01
   33      0.5574D 01    0.1438D 01    0.3875D 01
   34      0.5555D 01    0.1434D 01    0.3873D 01
   35      0.5583D 01    0.1432D 01    0.3898D 01
   36      0.5534D 01    0.1437D 01    0.3852D 01
   37      0.5600D 01    0.1436D 01    0.3899D 01
```

VERSION 2 BEFORE WIPICS   TOTAL COST

CORRESPONDING TO THE MODELS OF THE SAME TITLE IN CHAPTER IV, THE COEFFICIENTS OF THE DUMMY VARIABLES AND THEIR RELATED STATISTICS ARE GIVEN BELOW. THE CATEGORY NUMBERS REFER TO AIRCRAFT TYPE-WORK TYPE COMBINATIONS GIVEN ON THE FIRST PAGE OF THIS APPENDIX.

CATEGORY	COEFFICIENT	STD ERROR	T STATISTIC
1	0.2418D 01	0.2924D 00	0.8268D 01
2	0.2451D 01	0.2918D 00	0.8398D 01
3	0.2156D 01	0.2925D 00	0.7372D 01
4	0.2159D 01	0.2914D 00	0.7409D 01
5	0.2175D 01	0.2943D 00	0.7393D 01
6	0.2149D 01	0.2942D 00	0.7304D 01
7	0.2181D 01	0.2938D 00	0.7422D 01
8	0.2184D 01	0.2914D 00	0.7495D 01
9	0.2212D 01	0.2914D 00	0.7590D 01
10	0.2227D 01	0.2923D 00	0.7618D 01
11	0.2195D 01	0.2922D 00	0.7512D 01
12	0.2138D 01	0.2918D 00	0.7328D 01
13	0.2147D 01	0.2960D 00	0.7255D 01
14	0.2066D 01	0.2916D 00	0.7085D 01
15	0.2087D 01	0.2920D 00	0.7146D 01
16	0.2073D 01	0.2904D 00	0.7139D 01
17	0.2135D 01	0.2938D 00	0.7264D 01
18	0.2039D 01	0.2907D 00	0.7015D 01
19	0.2054D 01	0.2928D 00	0.7014D 01
20	0.1979D 01	0.2912D 00	0.6794D 01
21	0.1998D 01	0.2910D 00	0.6865D 01
22	0.1865D 01	0.2939D 00	0.6347D 01
23	0.1983D 01	0.2979D 00	0.6656D 01
24	0.1936D 01	0.2918D 00	0.6634D 01
25	0.1897D 01	0.2927D 00	0.6482D 01
26	0.1918D 01	0.2926D 00	0.6555D 01
27	0.1913D 01	0.2926D 00	0.6537D 01
28	0.1936D 01	0.2923D 00	0.6623D 01
29	0.1871D 01	0.2917D 00	0.6413D 01
30	0.1908D 01	0.2963D 00	0.6438D 01
31	0.1868D 01	0.2927D 00	0.6383D 01
32	0.2009D 01	0.2900D 00	0.6925D 01
33	0.2066D 01	0.2915D 00	0.7087D 01
34	0.2011D 01	0.2927D 00	0.6872D 01
35	0.1983D 01	0.2955D 00	0.6710D 01
36	0.2045D 01	0.2941D 00	0.6953D 01

VERSION 2 AFTER WIPICS TOTAL COST

CORRESPONDING TO THE MODELS OF THE SAME TITLE IN CHAPTER IV, THE COEFFICIENTS OF THE DUMMY VARIABLES AND THEIR RELATED STATISTICS ARE GIVEN BELOW. THE CATEGORY NUMBERS REFER TO AIRCRAFT TYPE-WORK TYPE COMBINATIONS GIVEN ON THE FIRST PAGE OF THIS APPENDIX.

CATEGORY	COEFFICIENT	STD ERROR	T STATISTIC
1	0.2858D 01	0.3453D 00	0.8278D 01
2	0.2894D 01	0.3476D 00	0.8325D 01
3	0.2850D 01	0.3489D 00	0.8167D 01
4	0.2620D 01	0.3432D 00	0.7635D 01
5	0.2608D 01	0.3497D 00	0.7457D 01
6	0.2593D 01	0.3507D 00	0.7394D 01
7	0.2601D 01	0.3428D 00	0.7588D 01
8	0.2611D 01	0.3414D 00	0.7647D 01
9	0.2621D 01	0.3541D 00	0.7402D 01
10	0.2614D 01	0.3527D 00	0.7410D 01
11	0.2600D 01	0.3485D 00	0.7460D 01
12	0.2569D 01	0.3508D 00	0.7323D 01
13	0.2593D 01	0.3478D 00	0.7457D 01
14	0.2550D 01	0.3459D 00	0.7372D 01
15	0.2547D 01	0.3504D 00	0.7270D 01
16	0.2549D 01	0.3478D 00	0.7330D 01
17	0.2546D 01	0.3454D 00	0.7369D 01
18	0.2556D 01	0.3474D 00	0.7357D 01
19	0.2391D 01	0.3483D 00	0.6863D 01
20	0.2484D 01	0.3491D 00	0.7117D 01
21	0.2548D 01	0.3343D 00	0.7624D 01
22	0.2513D 01	0.3383D 00	0.7426D 01
23	0.2542D 01	0.3502D 00	0.7256D 01
24	0.2506D 01	0.3531D 00	0.7097D 01
25	0.2537D 01	0.3374D 00	0.7518D 01
26	0.2554D 01	0.3323D 00	0.7685D 01
27	0.2529D 01	0.3335D 00	0.7584D 01
28	0.2543D 01	0.3293D 00	0.7721D 01
29	0.2486D 01	0.3338D 00	0.7447D 01
30	0.2514D 01	0.3300D 00	0.7617D 01
31	0.2572D 01	0.3376D 00	0.7620D 01
32	0.2560D 01	0.3423D 00	0.7477D 01
33	0.2554D 01	0.3359D 00	0.7604D 01
34	0.2527D 01	0.3363D 00	0.7515D 01
35	0.2537D 01	0.3379D 00	0.7507D 01
36	0.2531D 01	0.3360D 00	0.7533D 01
37	0.2549D 01	0.3341D 00	0.7630D 01

VERSION 2 BEFORE WIPICS   OPNS COST

CORRESPONDING TO THE MODELS OF THE SAME TITLE IN CHAPTER IV, THE COEFFICIENTS OF THE DUMMY VARIABLES AND THEIR RELATED STATISTICS ARE GIVEN BELOW. THE CATEGORY NUMBERS REFER TO AIRCRAFT TYPE-WORK TYPE COMBINATIONS GIVEN ON THE FIRST PAGE OF THIS APPENDIX.

```
CATEGORY  COEFFICIENT   STD ERROR   T STATISTIC
    1      0.1376D 01   0.4364D 00   0.3153D 01
    2      0.1473D 01   0.4356D 00   0.3382D 01
    3      0.1430D 01   0.4365D 00   0.3276D 01
    4      0.1432D 01   0.4350D 00   0.3293D 01
    5      0.1460D 01   0.4392D 00   0.3324D 01
    6      0.1420D 01   0.4391D 00   0.3234D 01
    7      0.1425D 01   0.4385D 00   0.3249D 01
    8      0.1447D 01   0.4349D 00   0.3328D 01
    9      0.1490D 01   0.4349D 00   0.3426D 01
   10      0.1514D 01   0.4363D 00   0.3469D 01
   11      0.1464D 01   0.4361D 00   0.3357D 01
   12      0.1427D 01   0.4355D 00   0.3276D 01
   13      0.1442D 01   0.4418D 00   0.3265D 01
   14      0.1353D 01   0.4353D 00   0.3107D 01
   15      0.1382D 01   0.4358D 00   0.3171D 01
   16      0.1353D 01   0.4334D 00   0.3122D 01
   17      0.1451D 01   0.4386D 00   0.3308D 01
   18      0.1377D 01   0.4339D 00   0.3174D 01
   19      0.1403D 01   0.4371D 00   0.3209D 01
   20      0.1307D 01   0.4347D 00   0.3006D 01
   21      0.1304D 01   0.4343D 00   0.3003D 01
   22      0.1140D 01   0.4386D 00   0.2600D 01
   23      0.1326D 01   0.4447D 00   0.2982D 01
   24      0.1247D 01   0.4356D 00   0.2864D 01
   25      0.1227D 01   0.4369D 00   0.2808D 01
   26      0.1253D 01   0.4367D 00   0.2868D 01
   27      0.1245D 01   0.4368D 00   0.2850D 01
   28      0.1276D 01   0.4363D 00   0.2924D 01
   29      0.1183D 01   0.4354D 00   0.2717D 01
   30      0.1269D 01   0.4423D 00   0.2868D 01
   31      0.1227D 01   0.4369D 00   0.2808D 01
   32      0.1362D 01   0.4329D 00   0.3146D 01
   33      0.1427D 01   0.4351D 00   0.3279D 01
   34      0.1360D 01   0.4369D 00   0.3112D 01
   35      0.1315D 01   0.4411D 00   0.2982D 01
   36      0.1399D 01   0.4390D 00   0.3187D 01
```

VERSION 2 AFTER WIPICS OPNS COST

CORRESPONDING TO THE MODELS OF THE SAME TITLE IN CHAPTER IV, THE COEFFICIENTS OF THE DUMMY VARIABLES AND THEIR RELATED STATISTICS ARE GIVEN BELOW. THE CATEGORY NUMBERS REFER TO AIRCRAFT TYPE-WORK TYPE COMBINATIONS GIVEN ON THE FIRST PAGE OF THIS APPENDIX.

```
CATEGORY   COEFFICIENT    STD ERROR    T STATISTIC
    1      0.2156D 01    0.4590D 00    0.4696D 01
    2      0.2204D 01    0.4621D 00    0.4769D 01
    3      0.2143D 01    0.4638D 00    0.4621D 01
    4      0.2188D 01    0.4562D 00    0.4796D 01
    5      0.2165D 01    0.4649D 00    0.4657D 01
    6      0.2146D 01    0.4662D 00    0.4604D 01
    7      0.2159D 01    0.4557D 00    0.4737D 01
    8      0.2172D 01    0.4538D 00    0.4785D 01
    9      0.2160D 01    0.4707D 00    0.4590D 01
   10      0.2147D 01    0.4689D 00    0.4578D 01
   11      0.2177D 01    0.4633D 00    0.4698D 01
   12      0.2134D 01    0.4664D 00    0.4576D 01
   13      0.2205D 01    0.4623D 00    0.4769D 01
   14      0.2138D 01    0.4599D 00    0.4648D 01
   15      0.2133D 01    0.4658D 00    0.4580D 01
   16      0.2138D 01    0.4623D 00    0.4625D 01
   17      0.2120D 01    0.4592D 00    0.4618D 01
   18      0.2136D 01    0.4619D 00    0.4624D 01
   19      0.1972D 01    0.4631D 00    0.4258D 01
   20      0.2102D 01    0.4641D 00    0.4530D 01
   21      0.2223D 01    0.4443D 00    0.5003D 01
   22      0.2172D 01    0.4498D 00    0.4828D 01
   23      0.2215D 01    0.4656D 00    0.4758D 01
   24      0.2156D 01    0.4694D 00    0.4593D 01
   25      0.2203D 01    0.4486D 00    0.4910D 01
   26      0.2267D 01    0.4418D 00    0.5131D 01
   27      0.2226D 01    0.4433D 00    0.5021D 01
   28      0.2249D 01    0.4377D 00    0.5139D 01
   29      0.2170D 01    0.4437D 00    0.4891D 01
   30      0.2211D 01    0.4387D 00    0.5040D 01
   31      0.2262D 01    0.4488D 00    0.5040D 01
   32      0.2254D 01    0.4551D 00    0.4953D 01
   33      0.2228D 01    0.4465D 00    0.4990D 01
   34      0.2192D 01    0.4470D 00    0.4903D 01
   35      0.2207D 01    0.4491D 00    0.4914D 01
   36      0.2191D 01    0.4467D 00    0.4905D 01
   37      0.2227D 01    0.4441D 00    0.5014D 01
```

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7. AUTHOR(s) John Richard McGarrahan; CPT, U.S. Army	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940	12. REPORT DATE September 1973 13. NUMBER OF PAGES 128
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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cost Effectiveness Analysis
Cost Flow Models
Constrained Cost Minimization
Naval Air Rework Facility

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

The objective of this study was to compare alternative approaches to the cost-effectiveness analysis of a technological change at the Naval Air Rework Facility, North Island, San Diego, California. Previous studies were reviewed and updated. Econometric techniques were employed to develop additional methods. Each of the methods was used to predict

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
(Page 1) S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

costs for situations both before and after the technological change. These predictions were compared as to their implications concerning the cost-effectiveness of a computerized work-in-process management information system.

Thesis 146490
M18824 McGarrahan
c.1 Comparative cost-effectiveness analyses at a Naval Air Rework Facility.