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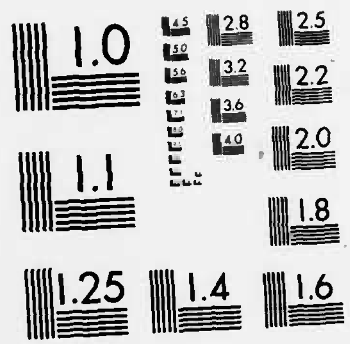

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ANALYSIS OF THE RELATIONSHIP BETWEEN LARGE TITANIUM FORGING LEAD TIMES AND F100 ENGINE PRICES

Harlan M. Brewer, 1st Lt, USAF

LSSR 50-83

DEPARTMENT OF THE AIR FORCE
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Wright-Patterson Air Force Base, Ohio

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The production phase of DOD's weapon system acquisition process provides an area for possible cost-cutting. Within the production phase, large titanium forging lead times showed a negligible relationship to engine prices. Methods used to evaluate data were primarily descriptive statistics; advanced linear regression techniques were not possible for the limited data available. Recommendations for future research efforts to clarify the research results are included.

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ANALYSIS OF THE RELATIONSHIP BETWEEN LARGE TITANIUM FORGING LEAD TIMES AND F100 ENGINE PRICES

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirement for the

Degree of Master of Science in Logistics Management

By

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CHAPTER 1

INTRODUCTION

In the United States today, many problems demand immediate solutions. For example, the U.S. must meet national defense needs, care for the elderly, and stop the declining achievements of high school graduates. The list is endless; however, one element common to each of these is their need for money.

Since the need for funding is so critical in solving national problems, our leaders conduct a continuing search for any means possible either to generate additional funds or to cut expenditures in areas already funded in the U.S. budget. Naturally, the executive branch, including the Defense Department (DOD), is always examined for possible cuts in funding to enable reallocations to more pressing national problems.

Accordingly, this chapter will first briefly discuss the budget pressures that lead to diverse attempts to control the Federal budget. Next, the defense acquisition process will be proposed as a prime section for budget-trimming. Moreover, a specific example for evaluation will be the F100-PW-100 engine; the exact problem chosen for research and analysis will also be stated. Finally, this chapter will list the research questions of interest in this study.

Budgetary Issues

Budget Pressures

Concern over control of government costs runs high in all facets of government including the Defense Department (DOD). Various government leaders have directed attention to the upward-spiraling government expenses. For example, Representative George Miller (6:80) of California expressed his concern over government cost growth by insisting, "Not just defense spending, but all spending by government has to be carefully watched and analyzed for its real value to the people." President Ronald Reagan (19:78) also expressed grave concern about government cost growth in general, and about DOD cost growth in particular, when he proposed the following during his January 25, 1983, State of the Union address:

> . . . the state of our union is strong, but our economy is troubled. . . . let me outline a four-part plan to increase growth and reduce deficits:
>
> . . . .
>
> Third, I will adjust our program to restore America's defenses by proposing 55 billion dollars in defense savings over the next five years.
>
> These are savings recommended by the Secretary of Defense, who has assured me they can be safely achieved and will not diminish our ability to negotiate arms reductions or endanger America's security.

From these quotations alone, it is clear that national leaders wish to control DOD costs when possible as a means to limit federal government spending.

Moreover, other related pressures exist in the nation. For example, the United States has other budgetary priorities which some citizens consider at least as important as military budgets. Chief among these are social welfare programs such as social security, food stamps, and federal welfare assistance. The poor and their representatives have not forgotten recent cuts in social programs. Often, therefore, these groups tend to oppose additional DOD budget growth as unfair when the poor themselves have indigent circumstances. In addition, certain citizens propose restrictions or limits on arms growth as the primary means to achieve world peace today. Although this view may be questioned, what cannot be questioned is the serious intent of these individuals to limit growth of DOD weapons. Again, a primary attempt would be through budgetary means.

Given the reality of budget cuts, the DOD must determine which areas of its budget to trim. The DOD has reemphasized the need to eliminate waste and fraud to assist in budgetary savings; however, other reductions must be sought because waste and abuse savings will yield limited savings--perhaps not enough to meet budgetary cut pressures.

Acquisition Process

Within the budget-cutting process an area which has been receiving even closer scrutiny is the DOD's weapon system acquisition process. Figure 1 is noteworthy in this regard because it indicates that the acquisition funding as a percentage of DOD budget is increasing.

Although some funds under procurement will not be directly linked to weapon system acquisitions, the acquisition process still absorbs a great percentage of the DOD budget (7:80). The data also indicate a trend towards an increase in acquisition funding. A superficial interpretation would infer that the military is meeting all its weapons hardware needs; however, such is not the case. As Goldstein (9:75) says,

> An examination of defense budgets (available dollars and their use) over the past 10 years reveals a striking and disturbing pattern. Constant-dollar budgets have remained relatively stable, while purchasing ability has steadily decreased. Further, the demand for new systems (and replacement of obsolete equipment) has far outstripped available funds.

Although the acquisition process absorbs a good percentage of the DOD budget, and although it appears that the percentage of acquisition funding is rising, the military still lacks the weapons it needs to meet mission requirements.

Production Costs

Acquiring a new weapon system involves interrelated factors ranging from integrating new technology to managing resource allocation (for example, distributing money, people, and materiel). Although all portions of this

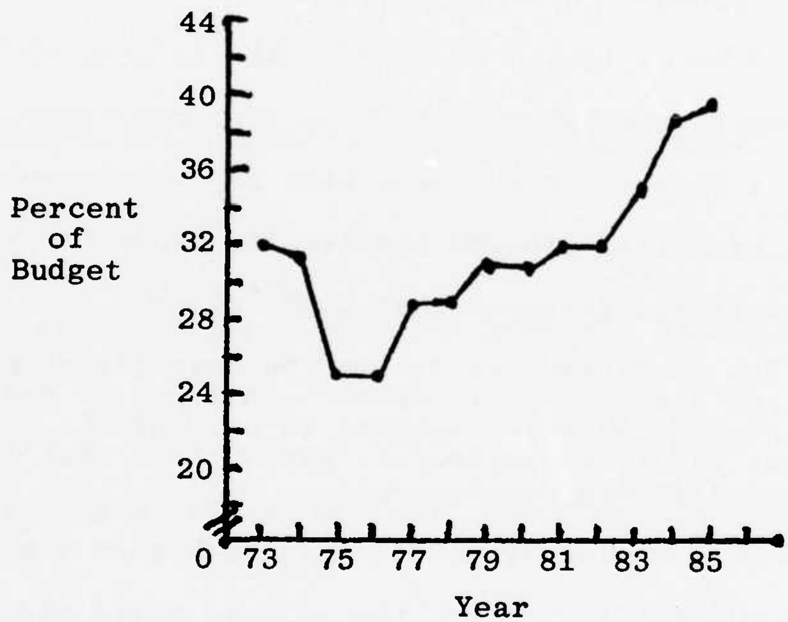

Figure 1. Acquisition Funding as Percentage of DOD Budget

(Source: Office of Management and Budget) complex process affect the DOD budget, no one factor appears definitive in the budget control problem. In an attempt to identify possible areas for reducing costs, possible areas for further study include the following phases of the acquisition process:

- Conceptual Phase
- Demonstration and Validation Phase
- Full-Scale Development Phase
- Production/Deployment Phase

These will be explained in more detail in Chapter 2. However, of greatest interest in this research study is the production phase of the acquisition process because of the significant dollar amounts involved in production. Bowers and Trimmell (3:29) agree when they say

> The production effort in the acquisition process carries a significant impact. In terms of dollars, the production phase amounts to half of the defense budget and is approximately three times what is spent in research and development.

Although this obviously conflicts with Figure 1 estimates and may well be overstated, the idea is still clear: production phase costs are significant.

Material Lead Times and Production Costs

Within the production cost issue, an important item to consider is the possible effect of changes of material lead times on weapon system prices. The concept is simple: as material lead times increase, weapon system prices may increase because the lead time increases would have an adverse affect on the schedule of the weapon production. Ultimately, any effect on the weapon production schedule would increase final costs. For example, Sullivan (21:28) speaks of possible relationships between material resource lead times and production costs by saying:

> Resource availability has been a particularly important subject because an assured materials supply is essential for the smooth operation of a highly industrialized economy such as that of the United States. Indeed, it is important to most economies. Because many production methods are basically capital intensive and require long lead times, advance planning is necessary to assure the availability of resources. To protect against interruptions in the supply of materials (and rapid price fluctuations) material inventories must be maintained. The more undependable is the supply of a particular material, the larger, and hence costlier, is the inventory.

To sum up, since material lead times are so variable, and since the effects of this variability can cause dramatic production cost increases, it is important to look at a specific case evaluating such a relationship between lead times and prices.

Specific Case: F100 Engine

A better look at the effects of lead time increases on weapon system price increases comes from considering a specific case for both weapon system and material lead time. In this connection, the F100-PW-100 engine, which powers the F-15 aircraft, served as a useful weapon system for this study because of its current usage in the USAF inventory and because of its inherent advanced technology. Furthermore, the specific material resource examined as a subset of the

F100 engine analysis was the titanium large forgings. The forgings were chosen because engine lead time is delimited by the time needed to receive large titanium forgings (11:IV-17 through IV-18; 1:4-20).

Problem Statement

The problem is to determine whether or not large titanium forging lead time fluctuations affect F100-PW-100 engine price fluctuations.

If such a relationship is confirmed as significant, government planners could use the relationship to assist in control of total system costs by regulating lead time variations. Moreover, DOD budget-trimming efforts would be improved as well.

Research Questions

The following questions guided the research:

1. Do fluctuations of titanium large forging lead times relate to F100-PW-100 engine prices in the years evaluated?

2. Have years of greatest increases or decreases for lead times been followed by similar engine price changes?

3. Is there any statistical correlation between the lead times and engine prices given that lead times are independent and engine prices dependent?

CHAPTER 2

LITERATURE REVIEW

Introduction

Answering the research questions identified above requires understanding the DOD weapon acquisition process and the available models for data analysis. Understanding lead time trends will clarify the process of developing a model (as given in Chapter 3) to assist better projections of future costs. Consequently, this chapter will present and discuss literature related to the following aspects of this study:

- The DOD Acquisition Process
- Acquisition Process and Costs
- Models for Engine Cost Estimates
- Lead Time Trends

Background

DOD Acquisition Process

The chief aim of the acquisition process is to deliver at the needed time a weapon system which will meet a predetermined operational mission requirement within Congressional budget appropriations constraints. Determining the mission requirement is the object of negotiations among various levels of the DOD and among the military service organizations. For example, in the Air Force, the following organizations would cooperate in presenting unified system procurement recommendations to higher chain-of-command organizations:

- Using Commands (Tactical Air Command, for example)
- Air Force Systems Command
- Air Force Logistics Command
- Air Training Command
- Other interested groups

Moreover, DOD staffers must work with Office of Management and Budget personnel to determine which items the Executive Office will propose as part of the President's budget to Congress in a given fiscal year. In short, determining which weapon systems will be authorized and later funded is intensely negotiated within DOD and the rest of the Executive Department and between the Executive and the Congress. In this political process, the issue of costs of a proposed new system is always important to all concerned for each organization must accept trade-offs between desired programs.

In moving from idea to item, the DOD weapon system acquisition process consists of the following four phases:

- Conceptual
- Demonstration and Validation
- Full-Scale Development
- Production/Deployment

The next four paragraphs summarize the key points of each phase.

Conceptual Phase

The intent of the conceptual phase is to competitively assess alternative means to meet a predetermined mission requirement. Alternatives explored include existing military and commercial equipment as well as newly-designed alternatives. In other words, this phase considers broad alternative concepts to meet the mission requirement or deficiency. In fact, the system selected to meet the mission need could be either an off-the-shelf system or a newly-designed system; but such a specific selection is not made in this phase.

Demonstration and Validation Phase

The second phase more specifically evaluates hardware design alternatives through paper studies, hardware design development, and prototype usage. A major consideration of this phase is to find hardware alternatives which meet proposed mission needs at least possible risk and cost. This phase will usually narrow possible means for solving mission needs to as few as two or three alternatives.

Full-Scale Development Phase

A major result of the third phase is a complete weapon system which can be tested against mission requirements in an environment as close to the mission scenario as possible.

Production/Deployment Phase

The production portion of this phase delivers complete weapon systems to the Air Force via Air Force Systems Command which then transfers the systems to a user command for deployment in the operational environment. During the deployment the operational command will both operate and maintain the system until the system is retired from the active inventory.

As a result of this complex acquisition process and the need to control the U.S. budget, it is essential to take a closer look at the need to control acquisition costs themselves.

Acquisition Costs

Acquisition Process

The complexity of this process and the length of time involved make it such a costly endeavor that a number of writers expressed concern over controlling costs in the weapon system acquisition process. For example, Stuelpnagel (20:24) explained the underlying rationale: cost stability is essential for the U.S. government to obtain greater public support of any military buildup and to succeed in a military hardware catchup with the Soviets. Burmeister (5:59,60) had a twofold concern over rising acquisition costs. First, he explained that reasonable cost estimates reduce costs later in a program by permitting accurate resource allocation and schedule formation during the program's early phase. Second, he insisted that accurate cost estimating

> . . . is essential to the development of a new product. Based on accurate cost estimation, management can make decisions on whether to proceed, alter, or cancel a product or program.

Furthermore, Bryan and Clark (4:105) specify that "cost growth is a major problem in defense systems acquisitions." Even more strongly, Graver (10:145) explains that a manager needs accurate cost estimates to decide among alternative program approaches and to determine if <u>any</u> approach is affordable.

Production

Within the acquisition process itself, one key area for achieving cost control is the production phase. The Air Force (22:2) defines production as "the processes and procedures designed to transform a set of input elements into a specified output element." Major functions within this phase include (22:2) the following:

- Design and production engineering for producibility
- Production planning
- Production control
- Quality control
- Production demonstration and testing

- Manufacturing method development
- Fabrication
- Assembly
- Installation
- Checkout

As might be expected, such a significant element of the acquisition process as production has a subset of the various management disciplines dedicated to it, namely, production management. Production management (22:2) is "the art and science of properly and efficiently using men, money, machines, materials, and processes to economically generate goods and services" (emphasis added).

A number of writers spoke of issues related to production cost. For example, Bowers and Trimmell (3:29) identify the budgetary impact of the production phase:

> In terms of dollars, the production phase amounts to half of the defense budget and is approximately three times what is spent in research and development.

Smith (17:77) details some other production cost issues stemming from the U.S. budget process:

> Affordability issues also prevent the viewing of production rate as an isolated cost optimization problem. Affordability issues arise from an overall constraint on annual spending. This constraint, combined with large numbers of competing programs, causes production stretchouts and other adjustments.

Furthermore, Bemis (2:84) indicates that "the issue of production rates for defense systems has recently been given increased emphasis as an important element of systems affordability." Moreover, Bemis (2:93) explains that although the production rate is just one variable deserving attention in the acquisition process, it is an important one in determining unit costs of a system. Goldstein (9:75) speaks of the budget problem as related to production funding when he notes that during past efforts to balance production demands with funds availability "the approach has been to spread available funds thinly over a great number of programs" (emphasis by Goldstein). As a result of this process, none of the programs are adequately funded in a timely manner. In a related vein, White (23:1-7) suggests a relationship between production rates to acquisition costs by explaining that the relative stability of production rates and quantities "has a profound effect on acquisition cost." He also explains that "about one-third of the 129 percent growth in the cost of 47 programs" for 1980 resulted from production quantity and schedule changes. Finally, Goldstein (9:77) notes that to gain the realistic cost estimates so essential to management and budget needs, changing development and production plans must be avoided. Stability is an important element once more.

In short, the writers place a good deal of importance on control of acquisition costs in general, and the production phase costs in particular.

Models for Engine Cost Estimates

General Models

As has been stated, reasonable cost estimates enable government planners not only to decide among weapon system alternatives but also to determine if any recommended solution is economically attainable given current budget constraints. Cost estimating models exist for numerous classes of weapons including engines. Among the groups of engine costing models are the following categories:

- Parametric methods
- Engineering estimate methods
- Analogy and expert opinion methods
- Material-based methods

Each of these will now be briefly examined.

Parametric models explain costs as a function of such factors as performance, weight, fuel usage, test flying hours, etc. Usually, a linear regression relationship is established with cost as the dependent variable while the independent variables include one or more of the factors already listed.

Engineering models use estimates of required labor and material inputs as a starting basis for cost estimation. The amounts of labor and material are then priced at a predetermined rate and summed to give the system's total cost.

The third method, analogy and expert opinion, uses the idea that systems currently being produced should have similar cost estimates to those products which it resembles from past procurements. In this technique, management asks engineering and manufacturing personnel to provide the factors by which to adjust prior cost estimates to yield current estimates for the proposed new engine.

Finally, material-based methods assume the material content of an engine reflects the level of technology of the engine. Cost estimates for an engine are then calculated by using standard material prices and standard labor prices. One specific model from these material-based models deserves further consideration, the Maurer Factor.

Maurer Factor

The Naval Air Systems Command constructed a material-based model under the leadership of Brennan and Maurer. Brennan conducted a study which showed a high relationship of both physical and metallurgical properties with engine costs; engine costs, therefore, would depend in large measure upon the type and weight of raw materials used to make the engine. Schuman (16:36) quotes Brennan's explanation as follows:

> This rationale assumes that most of the physical and thermodynamic technology areas associated with engines--compressor stage loading, maximum turbine temperatures, specific weights, etc.--are closely interrelated with the metallurgical technologies. This assumption is probably more true of the aircraft engine industry than any other aerospace industry because of the severe stress and temperature environment experienced by a jet engine.

In related work, Maurer derived a production cost estimator using materials content factors as independent variables and cost as the dependent variable (16:36). The Maurer Factor, as well as all materials approaches, takes into account the use of new superalloys and the attendant manufacturing changes based on the increased use of superalloys, both of which have led to engine cost increases. Furthermore, such superalloys use scarce metals like titanium and cobalt. When such metals are already scarce, military requirements drive demand for these metals even higher, thus further increasing prices of these metals (and related engine costs). In brief, this summary of Schuman's (16:35-49) explanation considers the Maurer Factor as the key material-based method of engine production cost estimation. Schuman (16:49) suggests that the Maurer Factor is accepted among Navy personnel with some confidence; however, the Air Force lacks sufficient data bases to directly modify the Maurer Factor to estimate its engine production costs.

Model of Interest and the Maurer Factor

Following the pattern used in the Maurer Factor, the model developed in this research considers large titanium forging lead times as the independent variable with engine production unit costs the dependent variable. This research employs a model similar to the material-based models because it takes into account the effect of a specific material--the key metal titanium--on the estimated production costs of an engine. Similarly the increased titanium usage would affect manufacturing techniques needed to process titanium as part of engine superalloys. Engine costs would rise once again as in the Maurer model. Finally, since titanium is a relatively scarce metal, increasing military requirements for this metal would cause a rise in overall titanium demand with a resultant rise in engine production unit cost.

Lead Times

Lead Times Defined

Lead time is the period of time between the placing of an order for unprocessed titanium and the time the unprocessed titanium reaches the company which will produce the titanium forgings. Note that the definition does not include forging production time. In other words, this model assumes the time to produce titanium forgings is constant. This assumption could be made for two reasons. First, over long periods of time the effects of a learning curve would ultimately make direct labor hours approach an approximately constant value. Thus the only time left to be considered as part of lead time would be the time between order placement and order receipt for the raw titanium. In a second manner, production time could be nearly constant because the actual manufacturing process does not significantly change and because the titanium forging manufacturers would wish to move all titanium raw materials through their plant as quickly as possible to minimize inventory holding costs for titanium. Once again, the result would be a nearly constant value for production time. In either case, this lead time definition assumes the value for forging production time is constant and not a part of the overall lead time concept.

Lead Time Trends

Aviation Week and Space Technology (13:64-73; 14:38-40; 18:53-57) reported lead time trends for various aerospace industry-required metals in an early 1982 series of issues. This section summarizes those reports.

Material lead times increased by nearly double from 1977-1980. Titanium was among these. In fact, Wyman-Gordon, a leading large titanium forging producer, reported 100 week lead times for titanium during this period. The two leading causes of this dramatic lead time increase were limited titanium availability, and greatly increased commercial and military requirements for titanium forgings or other titanium-related products. Furthermore, these initial production surges caused some panic buying or hedge buying of titanium and other resources vital to aerospace manufacturers. As a result, the availability of titanium became even more restricted and lead times either increased or remained artificially high until some dramatic market changes occurred.

In 1981 and 1982, the dramatic market change did occur. First of all, the recession caused a number of the major airlines to restrict their new orders for aircraft and engines. In turn, the manufacturers of these products required less material, including titanium. This change eased the titanium shortage somewhat. Secondly, increasing fuel costs and deregulation also led to lower demand for aircraft and engines, again easing the titanium shortage. Finally, military programs were being stretched out so that the demands for titanium by military requirements were also being spread over future years. Again, shorter lead times resulted.

Were the future trend for lead times to remain low, manufacturers of aerospace items would have no concern. However, some industry leaders are concerned that the impending production of the Air Force's new B-1 bomber may cause dramatic increases in titanium large forging lead times once again. This problem is especially significant in view of the currently improving U.S. economy which would tend to encourage other commercial and military orders which would then affect lead times as well. Industry leaders, particularly Rockwell--the prime contractor for the B-1--are monitoring lead times for future industry planning purposes.

Summary

An important issue in the DOD weapon system acquisition process is the need to control weapon system costs as a part of overall Federal budget-cutting attempt. The production phase of the acquisition is an important area to examine in this regard; as a particular example, a possible relationship exists between large titanium forging lead times and F100-PW-100 engine production unit costs. Articles reviewed indicated also that the high lead times of the 1979-1980 time frame, currently somewhat lower because of economic and market factors, could result once more depending on economic recovery and future military and commercial trends in new orders for titanium forgings or parts. Therefore, if there is a relationship between the large titanium forging lead times fluctuations and engine production unit cost fluctuations, methods are needed to control the lead time fluctuations in order to control engine unit costs.

CHAPTER 3

METHODOLOGY

Introduction

Problem Restated

This research analyzed the relationship between large titanium forging lead time fluctuations and F100-PW-100 production unit cost fluctuations to determine if there is an independent/dependent variable relationship between the respective variables.

Research Questions

The following research questions served as primary focus:

1. Do fluctuations of large titanium forging lead times relate to F100-PW-100 engine prices in the years evaluated?

2. Have years of greatest increase for lead times been followed by similar engine price changes?

3. Is there any statistical correlation between the lead times and engine prices given that lead times are independent and engine prices dependent?

Data Collection

The research questions required the following data types:

- Large titanium forging lead times
- F100-PW-100 engine prices

The data comes from the most authoritative sources, the offices responsible for the original data. More specifically, the lead time data from the Joint Aeronautical Materials Activity (JAMAC) was from contractor surveys JAMAC performed. The Propulsion System Program Office of the Aeronautical Systems Division (ASD/YZ) has contract files containing actual engine prices from prior year negotiations. Therefore, both data types come from fundamental sources because the data was, in essence, contractor-originated.

Lead Time Data

For the large titanium forgings, lead times consisted of the delay in weeks between placing and receiving an order for raw titanium by forging manufacturers. As explained in more detail earlier in this report, the production part of the forging lead time was considered a constant; the variable part of the lead time--weeks between placement of the order and receipt of raw titanium--represented the entire forging lead time.

The source of the titanium lead time data was JAMAC. Throughout each calendar year, JAMAC surveys approximately 20 aerospace contractors to receive lead time data; JAMAC then averages the raw data to give the figures used in this research (Data from JAMAC is in the Appendix--Raw Lead Time Data). For titanium, the JAMAC lead time data was available only for the years 1977-1983. Titanium is a material whose lead time only recently has been tracked by JAMAC because of its scarcity in the world market and its increasing heavy use in high technology engines.

One limitation in this data is the obvious data scarcity. This scarcity stems from the following two basic causes:

1. Records on large titanium forging lead times do not exist prior to 1977;

2. Voluntary nature of JAMAC's contractor surveys: contractors are not required to participate and divulge lead time data.

Furthermore, averaging the data elements may be too general to reflect the true relationship because high and low fluctuations in a given year disappear. On the other hand, JAMAC does keep the results of contractor surveys on file; the actual lead time values of specific forgings (before any averaging) can be seen by government personnel if desired, subject to proprietary limitations (one contractor would not be allowed to see a competitor's data; government personnel could view and analyze data but could not release original data outside government organizations).

Table 1 lists the data received from JAMAC which was used in this research. Note that some years had more than one average titanium lead time value. In these years, the multiple values were simply averaged to calculate a yearly average value.

Table 1

Lead Time Data

Year	Month	Actual Delay (weeks)	Yearly Average (weeks)
1977	Dec	38	38
1978	Dec	74	74
1979	Mar	105	106
	Aug	105	
	Nov	108	
1980	Feb	118	112
	May	113	
	Aug	121	
	Oct	95	
1981	Mar	88	81
	Jul	84	
	Oct	70	
1982	Jan	73	60
	Apr	65	
	Jul	52	
	Oct	48	
1983	Jan	44	44

Source: JAMAC

Engine Price Data

The Propulsion System Program Office (ASD/YZK) supplied the engine unit cost data reflecting actual historical costs accumulated from government contracts with Pratt and Whitney Aircraft. The data was available for fiscal years 1972-1982. Table 2 portrays the yearly breakout starting with actual dollar amounts in column 2. For comparability, column 3 lists the inflation adjustment factors given by ASD/YZPR. Column 4 lists the engine prices after adjustment to the 1982 base year. The following formula was used to adjust the original data, where X is original data, F is factor for adjustment, and A is adjusted data:

$$A = \frac{X}{F}$$

Similar to lead time data, the data scarcity is the noticeable limitation for price data. For price data the scarcity results from having only a yearly price quote for engine data (discrete points only) and from having no data before 1972--the first full production year for this engine.

Joint Limitations

For purposes of data analysis, there were at least the two following limitations:

Table 2

Engine Price Data

Fiscal Year	Unit Price[a]	Weighted Index[b] (March 83)	Adjusted Price
1972	$2,020,853	0.3569	$5,662,239
1973	1,613,322	0.4063	3,970,765
1974	1,619,353	0.4734	3,420,686
1975	1,619,353	0.5225	3,099,240
1976	1,619,353	0.5637	2,872,721
1976T	1,619,353	0.6064	2,670,437
1977	1,629,344	0.6098	2,671,932
1978	1,666,772	0.6945	2,399,960
1979	1,675,108	0.8247	2,031,172
1980	1,921,859	0.9326	2,060,754
1981	2,282,619	0.9993	2,284,218
1982	1,568,015	1.0647	2,411,961

[a]Source: ASD/YZK

[b]Source: ASD/YZPR

- Mismatch of data years for independent versus dependent variables

- Fewer data points for independent variable than dependent variable

The mismatch of data years for independent versus dependent variables reflects the inherent nature of the lead times for large titanium forgings. In other words, lead times experienced for forging this year must correctly match the engine price for a future year--the year in which those forgings appear in the finished F100 engine. To compensate for data mismatch, Table 3, Timing Decision Rules, was developed and applied to the data sets analyzed.

Table 3

Timing Decision Rules

Range of Weeks	Rule
0 - 26	Match given fiscal year of lead times with corresponding fiscal year of engine prices.
27 - 78	Add one year to given fiscal year of lead times. Match this new fiscal year with corresponding fiscal year of engine prices.
79 - 130	Add two years to given fiscal year of lead times. Match this new fiscal year with corresponding fiscal year of engine prices.

The second limitation--that of fewer independent data points than dependent--restricted the years available to compare data for independent with dependent variables.

The Model Explained

The effects of titanium lead time fluctuations enter the model in at least the following two ways:

- Titanium price fluctuations
- Production schedule changes

Titanium lead time fluctuations are caused in part by market forces. For example, because the supply of titanium is initially limited, it will take a specified number of weeks to receive a titanium metal shipment. Should commercial and military demands on the raw material market for titanium increase, the lead time to obtain the metal would increase; at the same time prices for titanium would increase. Forgings and other products would then increase in price. These changes, in turn, would cause engine cost increase. A decrease in forging price and engine cost would be expected, using the same reasoning, should military or commercial demands for raw titanium decrease.

In a different way, titanium lead time fluctuations enter the model through production schedule changes. For example, whenever the engine manufacturer--in this case, Pratt and Whitney Aircraft--must change its engine production schedules in response to changes in material availability, it incurs additional costs. The costs will be passed, at least in part, to the DOD as an engine cost increase.

Apart from the cost-driving relationship which may exist between titanium forging lead times and engine production unit costs, other factors exist which affect engine cost rises. Chief among these are the effects of inflation which drives up engine prices artificially. To compensate for inflation, the engine prices which were part of later data analysis were adjusted using 1982 as the base year for all engine prices. For purposes of this study, any other factors will be considered constant to enable focus on the model of interest.

Variable Comparison Methods

The independent and dependent variables were analyzed with regard to the research questions presented earlier using primarily graphical descriptive statistics. In addition, limited correlation analysis was performed in analyzing the data; however, no advanced linear regression techniques were employed. Specifically, the first research question was evaluated using two line graphs having large titanium forging lead times against years on one graph, and engine prices against years on the other. The second research question was probed during the years of greatest lead time increases--the years 1977-1980; the engine price increases were then shown on a bar graph for each year using 1977 as the beginning year. Percentage engine price increases were calculated comparing data for the years 1978 to 1979, 1979 to 1981, and 1981 to 1982. In this set of calculations, Table 3 determined what engine price data corresponded to the respective lead time data. For the third research question, a simple correlation for the years 1977-1982 was conducted using a TI-58 hand calculator. Results of analysis and related graphical figures for the research questions will be given in Chapter 4, Findings and Conclusions.

CHAPTER 4

FINDINGS AND CONCLUSIONS

Introduction

This chapter presents findings derived from data analysis, and discusses conclusions derived from those findings. The findings will be presented in connection with each respective research question; the conclusions will appear as summary statements following each set of findings and related discussion. In short, the presentation format for each set of findings will be the following:

- Research question restatement
- Related findings
- Discussion
- Conclusions

Research Analysis

Research Question 1

Do fluctuations of large titanium forging lead times relate to F100-PW-100 engine prices in the years evaluated?

Findings: Research Question 1. The related findings are graphically displayed in Figures 2, 3, and 4. These graphs were derived by placing large titanium forging lead times against years on one graph, by showing engine

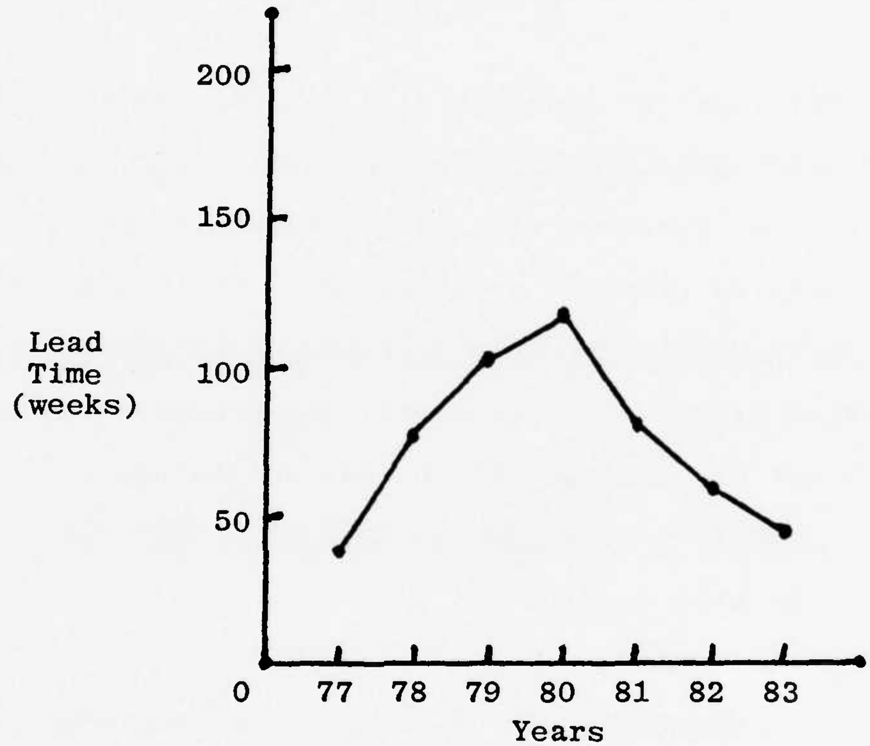

Figure 2. Large Titanium Forging Lead Times

(Source: JAMAC)

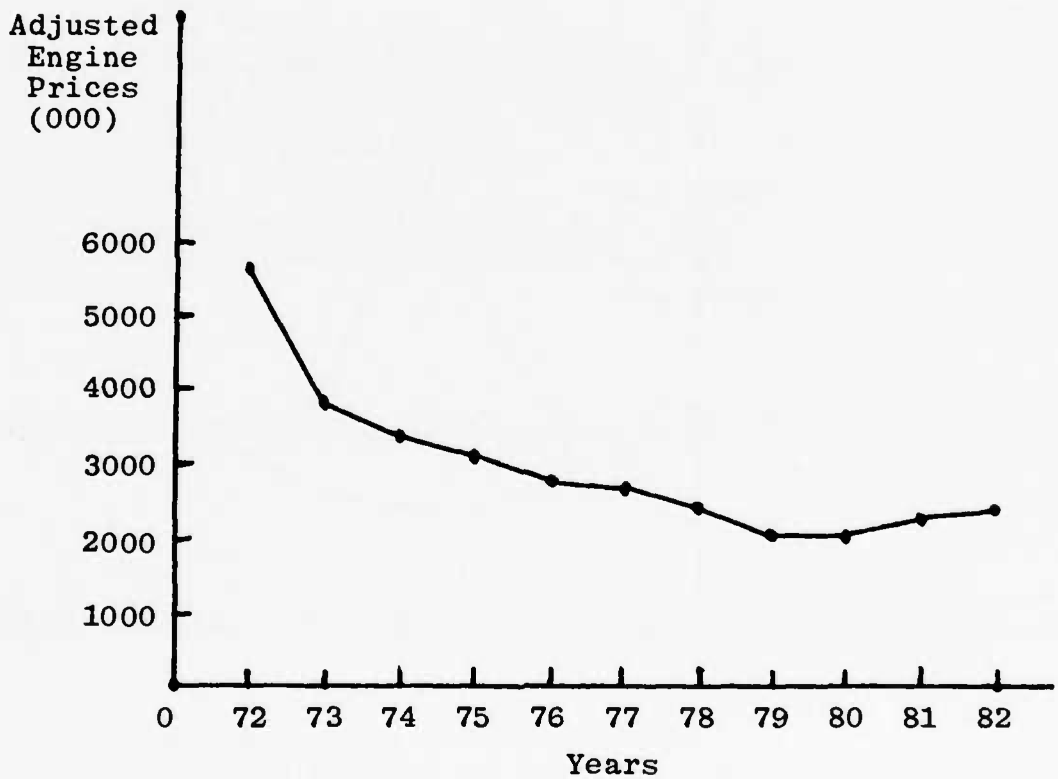

Figure 3. Engine Prices

(Source: ASD/YZ)

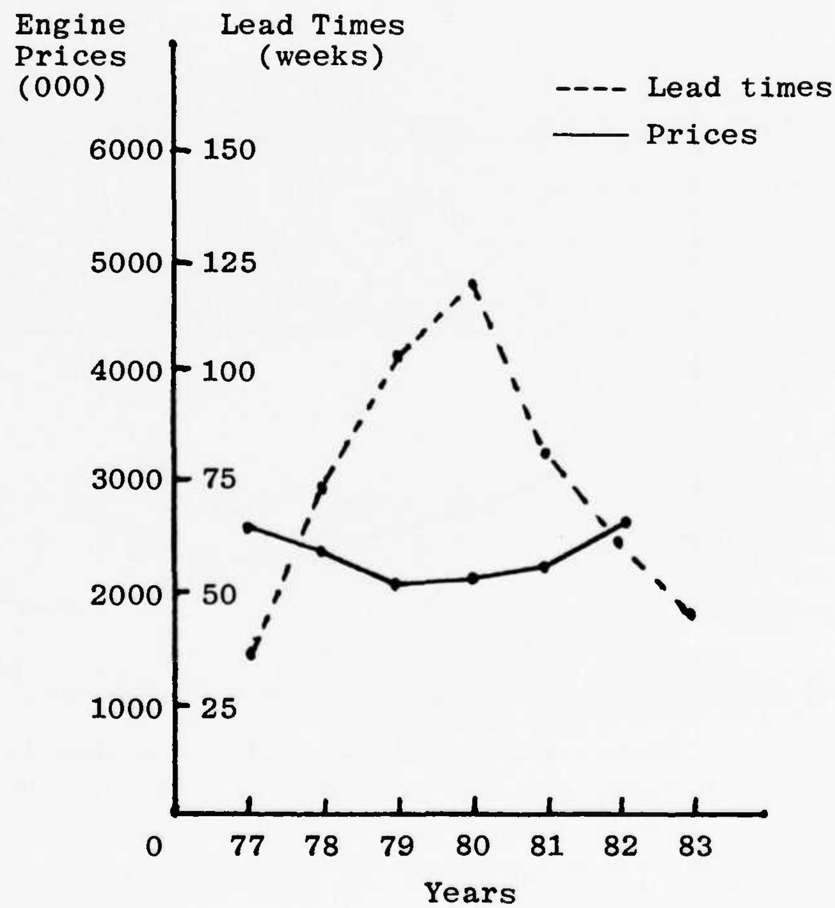

Figure 4. Prices and Lead Times

prices compared to years on another, and by giving lead times and prices over time on the final graph (the sources of the data for graphing purposes were Tables 1 and 2, respectively).

Discussion: Research Question 1. It was apparent from Figures 2 through 4 that both lead times and engine prices have broad fluctuations in their values for the years considered. As a general rule, however, it appeared that engine prices are decreasing (recall again that these prices are adjusted for inflation's effect so that factor is not relevant). For this analysis it seemed that the years of interest for lead time increases would be 1977-1980 because these years showed the lead time increases. This is, in fact, consistent with the literature discussed in Chapter 2, Literature Review, under the heading Lead Time Trends. To get a better view for comparing changes of the variables of interest, Table 3 was again applied. In short, the correspondence determined after applying the rules is the following:

Table 4

Variable Correspondence

Lead time year	Engine price year
1977	1978
1978	1979
1979	1981
1980	1982

Using this adjustment, the engine prices associated with the respective lead times decreased for the period 1978 to 1979. On the other hand, the prices for 1979 to 1981 and 1981 to 1982 increased. These mixed results allow no clear evaluation of the results; more detailed data is required to permit further analysis.

Conclusions: Research Question 1. More data is needed to enable better development of graphical trends for the two variables. This, of course, must be weighed against the cost and time required to develop and maintain the data base.

Research Question 2

Have years of greatest increases for lead times been followed by similar engine price increases?

Findings: Research Question 2. Figure 5 displays the related findings by graphing percent engine price increases. In addition, the lead time percent increases for the years 1977-1980 were also placed on a bar graph for analysis (Figure 6). As discussed in Chapter 3, the years for which engine price increases were evaluated were selected by applying Table 3 to the lead time and engine price data sets.

Discussion: Research Question 2. Figures 5 and 6 clearly show that the increasing lead times for large titanium forgings were followed by F100-PW-100 engine

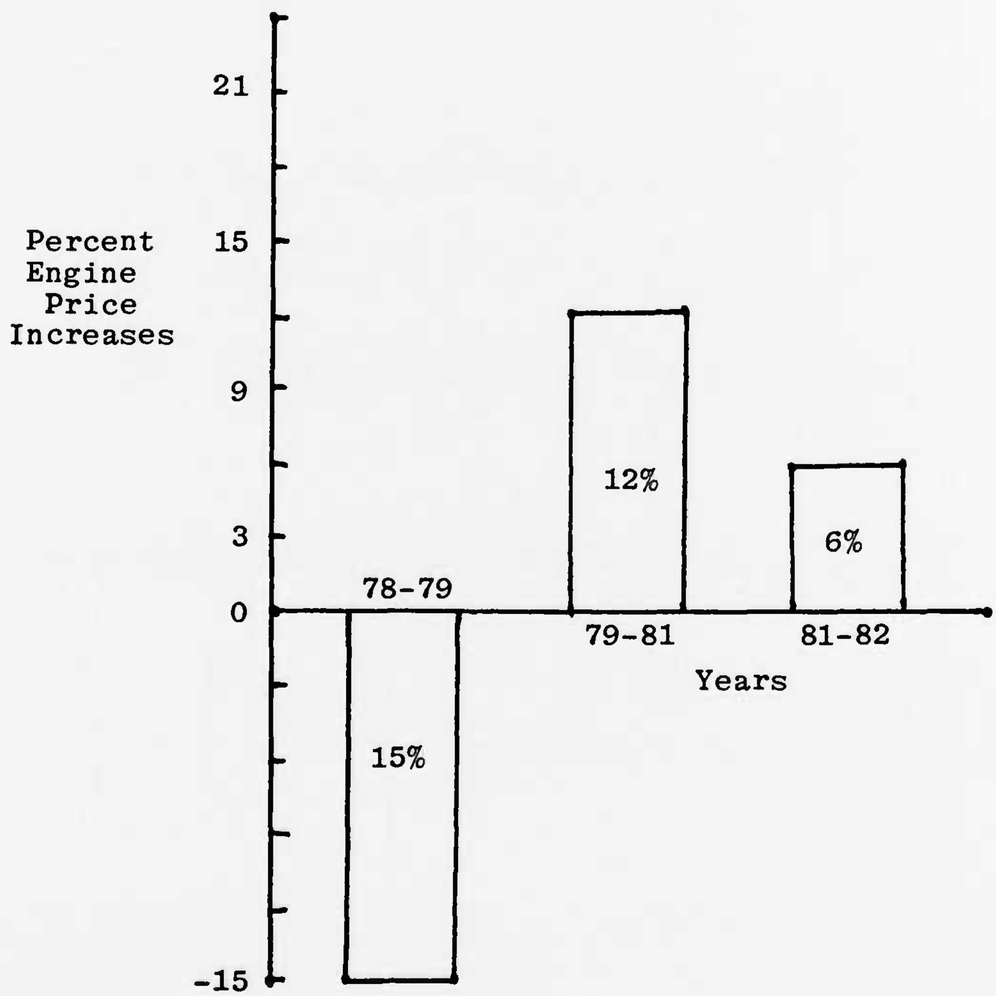

Figure 5. Engine Price Increases

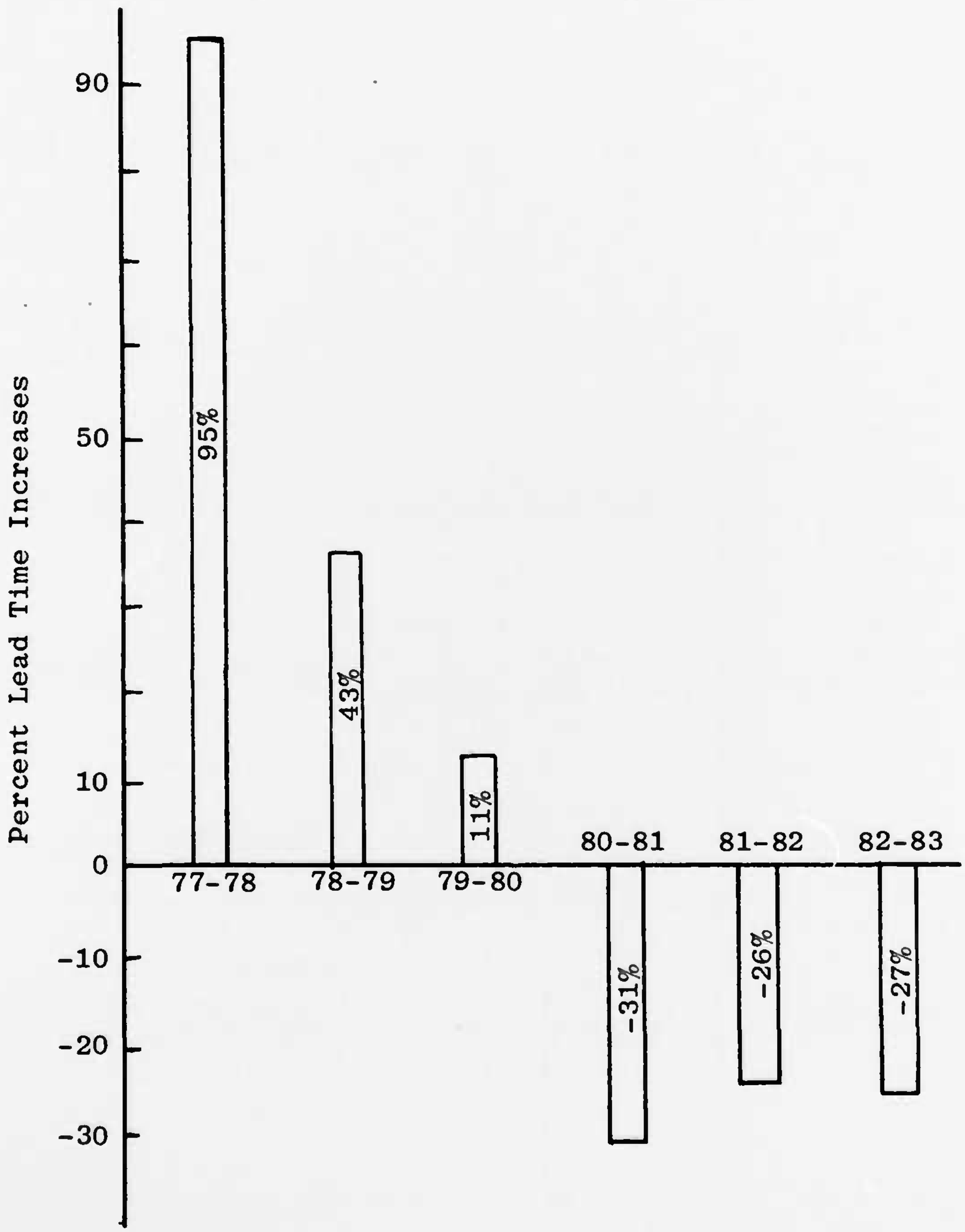

Figure 6. Lead Time Increases

price increases in two of three cases considered. These particular increases occurred during the period for which lead times of large titanium forgings had nearly doubled.

Conclusions: Research Question 2. Using the data bases considered, the years of greatest increases for large titanium forging lead times were indeed followed by similar F100-PW-100 engine price increases.

Research Question 3

Is there any statistical correlation between the lead times for large titanium forgings and F100-PW-100 engine price increases?

Findings: Research Question 3. Using Table 3, the following correspondence was established to determine the correlation between lead times and engine prices:

Table 5

Correlation Correspondence

Year	Lead time	Year	Price
1977	38	1978	$2,399,960
1978	74	1979	2,031,172
1979	106	1981	2,284,218
1980	118	1982	2,411,961
1981	81	1983	Not Available

Since no price was yet available for 1983, only the first four sets of data were correlated using the TI-58 calculator.

The correlation data points were taken from Tables 1 and 2, respectively. The value of the correlation constant was found to be 0.0815.

Discussion: Research Question 3. This correlation constant indicated a small correlation between the variables being studied; this indicated that the variables move relative to each other but there is virtually no statistical correlation between the variables. However, since titanium is only one of many components in the engine, it is possible that further research combining titanium and other lead time variables would yield a more significant correlation value.

Conclusion: Research Question 3. The results of the correlation analysis showed little, if any, relationship between the two variables studied. More data to allow more extended correlation and detailed regression analysis is required.

Summary

This chapter outlined the findings of research data analysis, discussed the findings, and presented related conclusions. To a great degree, the overall conclusion was mixed results for the study; more research into ways for more data availability is needed, especially for lead time data.

CHAPTER 5

RESEARCH SUMMARY

Conclusions

This study analyzed the relationship between large titanium forging lead times and F100 engine prices in attempting to discover another area for cost control within the DOD budget. The research yielded quite mixed results. In other words, the research questions had neither clearly all positive results nor clearly all negative. I believe such mixed results would be clarified if further data analysis had been possible; therefore, future research into the relationship between these two specific variables requires larger data bases allowing more advanced linear regression techniques to determine the relationship involved. Specifically, analysts should enlarge the data base for engines to include other high technology engines. In addition, analysts should survey defense contractors to increase the large forging lead time data base. However, the costs of such extended data bases could well be very high. In other words, unlimited contractor data for either lead times or engine prices would not be free; analysts must weigh development costs of these enlarged data bases against possible future benefits of further research in this area. Further research should be conducted only if benefits clearly outweigh costs.

Recommendations

1. Estimate costs of enlarging the data bases to more critically examine the relationship between engine prices and large titanium forging lead times. For example, the data bases could be expanded by doing the following:

a. Including other high technology engines to allow a larger sample of engine prices, and

b. Surveying defense contractors for additional large forging lead time data.

Only conduct further research if benefits to be derived from the research clearly exceed costs of enlarging the data bases.

2. Assuming research continues, use the enlarged data bases by applying advanced linear regression techniques in an attempt to more fully explain the relationship between the variables of interest.

3. To find other areas for cost control in the DOD budget, perform similar research on other USAF inventory engines and other critical materials to ascertain if the concept of a relationship between lead times and engine prices is generalizable to larger populations of either engines or critical materials.

4. Use any demonstrated relationships in DOD budget control efforts. For instance, the demonstrated relationships could signal the need to cut costs by doing any one (or both) of the following:

a. Building up stockpiles of the critical material to eliminate the effects of lead time increases. Stockpiles would greatly lessen contractor lead times by allowing quicker access to material. Costs of holding stockpiles must be balanced against savings from reduced lead times.

b. Using substitute goods having reduced lead times. This requires making full use of DOD research and development programs which discover substitute materials in high technology engines. Using materials with reduced lead times would lessen the effects of lead time increases on engine prices.

APPENDIX

RAW LEAD TIME DATA

Table 6

Raw Lead Time Data*

Date	Average	Low	High
Dec 77	38		
Dec 78	74		
Mar 79	105		
Aug 79	105		
Nov 79	108		
Feb 80	118		
May 80	113		
Aug 80	121		
Oct 80	95		
Mar 81	88	20	156
Jul 81	84		
Oct 81	70	15	156
Jan 82	73	15	156
Apr 82	65	26	130
Jul 82	52	14	104
Oct 82	48	14	104
Jan 83	44	14	104

*Large titanium forging data only

(Source: JAMAC)

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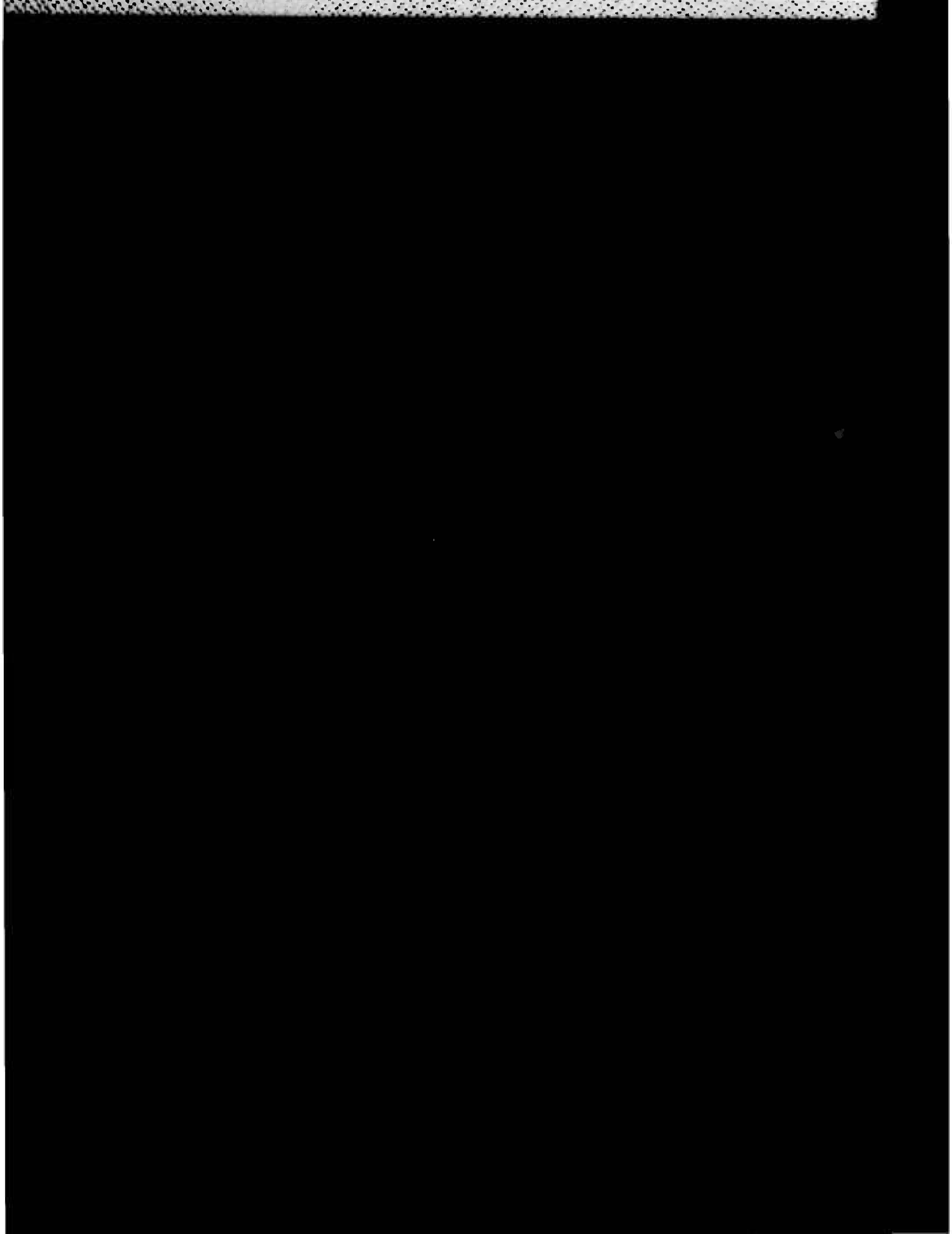
Figure 5. Engine Price Increases

Figure 6. Lead Time Increases

Since no price was yet available for 1983, only the first four sets of data were correlated using the TI-58 calculator.



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