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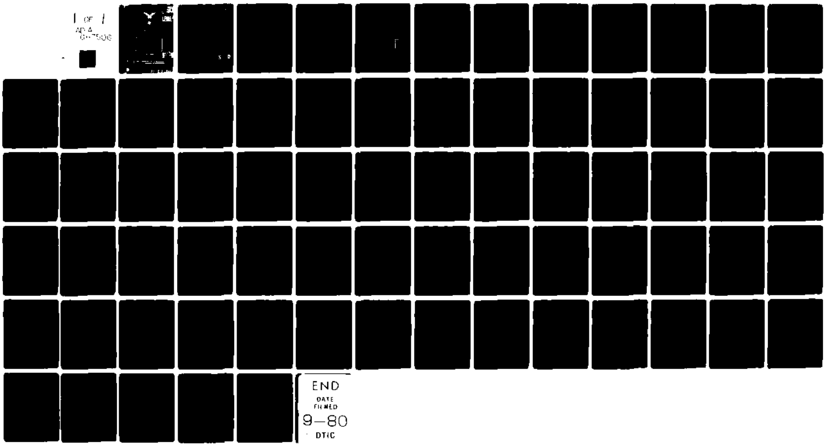

DEPARTMENT OF THE AIR FORCE
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AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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A CONTROLLED EVALUATION OF THE DIFFERENCES BETWEEN TWO APPROACHES TO RELIABILITY INVESTMENT SCREENING

Russell M. Genet, GS-13
John M. Wallace, Captain, USAF

LSSR 36-80

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There is a continuing concern about the high aircraft support cost and poor availabilities caused by some aeronautical equipments. It is generally accepted that basic research, engineering development, and improvements in fielded equipments should concentrate on "high burner" types of equipment. This has been countered by the suggestion that the emphasis would be better placed on those equipment types with the highest return-on-investment. An experiment was conducted, using data from over 20,000 aeronautical equipments, to determine if the high burner and return-on-investment approaches really emphasize different equipment types. It was found that, in fact, different equipment types were emphasized. The high burner approach emphasized jet engines, radar sets, etc., while the return-on-investment approach emphasized valves and actuators, fuel gauges, and other mundane but troublesome equipments. These research findings suggest that a change in policy might be appropriate.

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A CONTROLLED EVALUATION OF THE DIFFERENCES BETWEEN TWO APPROACHES TO RELIABILITY INVESTMENT SCREENING

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

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and

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Joel B. Knowles
COMMITTEE CHAIRMAN

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CHAPTER 1

INTRODUCTION

This research explored two methods for identifying aircraft equipment types where applied research might best be concentrated to improve equipment reliability on future aircraft. The research determined if different identification algorithms emphasized different types of equipments. Chapter I provides background to the problem, summarizes the two approaches, compares the results obtained from each, identifies explanations other than the differences in algorithms which could account for the observed difference between the two sets of results, and states the research questions.

BACKGROUND

In 1973, Johnson and Reel, in their study of the impact of maintainability and reliability on support cost, pointed out that more than two thirds of the national defense budget for the past six years has been required to support the existing military inventory of equipment (10:1). They went on to point out, "if this trend is allowed to continue, support costs could equal, or exceed the amount of dollars presently allocated for national defense (10:1)."

The National Academy of Sciences found in 1975 ". . . that a very important factor in the force of military aircraft is the low reliability . . . (12:1)." The Academy went on to suggest that poor reliability contributed to the cost of ownership in three ways: (1) the direct cost of maintaining the unreliable equipment; (2) the indirect cost of downtime; and (3) the indirect cost of equipment failure during a mission (12:1).

In a 1977 study by the Air Force Aeronautical Systems Division, the total cost penalty of support, nonavailability (downtime), and aborted missions was estimated to be $19 billion for the remaining lives of 18 style types and series of Air Force aircraft. Of this total: (1) $8.1 billion was for support cost; (2) $10.3 billion was for nonavailability; and (3) $0.5 billion was for aborted missions (7:6).

Johnson and Reel suggested that "data derived from specific equipment/ system programs showed that designed efforts to increase reliability . . . can significantly reduce equipment/system life cycle costs (10.1)." They went on to point out that

> Emphasis in this area [reliability] may result in higher costs during RDT&E [Research, Development, Test, and Evaluation] but any increased front end costs are offset many times by long-term savings in man-hours and material when properly applied [10:23].

They suggested, however, that ". . . it is not appropriate or economical to apply the same level of effort on all equipment (10:23)."

In a similar vein, a 1977 Productivity, Reliability, Availability, and Maintainability (PRAM) Program Office study suggested that ". . . it is not entirely obvious, with our essentially fixed Research and Development budget, what types of equipment should research be concentrated on (13:1)." The study also stated,

> It is, we believe, the responsibility of the logistic support community to identify the areas where the potential exists for a high return on investment for basic research to improve reliability [13:1].

The overall problem then, was to identify those types of equipment where it would be best for the Air Force to invest its limited reliability improvement funds in during RDT&E.

APPROACHES TO THE PROBLEM

A 1975 Rand Report by Dr. Fiorello and Mrs. Dey pointed out that an "important step in determining how to improve the management of costs of ownership is to analyze historical data on operational weapon systems (6:iii)." The 1977 Aeronautical Systems Division study mentioned above, also suggested that "this [sic] data [on operational aircraft by equipment type] in much greater detail could indicate areas where research . . . might best be concentrated (7:7.)" Increased Reliability of Operational Systems (IROS) and Logistics Investment Screening Techniques (LIST), are two current approaches to identifying reliability improvement candidates based on data obtained from current aircraft.

Highlights of these approaches are discussed below. A more detailed discussion of IROS and LIST are contained in appendices A and B respectively.

Increased Reliability of Operational Systems (IROS-LSC)

An early attempt to use detailed data from operational aircraft to objectively guide the reliability investments was initiated in 1970, and was called IROS (Increased Reliability of Operational Systems). While IROS has several different data outputs, the most widely used product was the Logistics Support Cost[1] (LSC) Ranking described in AFLCM 66-18, Programming and Technical Processes (16:17-1 to 17-17). The IROS-LSC ranking was generated by listing equipment by the estimated, annual logistics support cost of every work unit coded equipment on operational Air Force aircraft (over 120,000 coded equipments). Routinely available data were used to estimate the annual logistics support cost. These data consisted of field reports on the maintenance manhours expended on each equipment that was repaired or replaced, and the number of equipments sent to central depots for repair. These data were combined with standard field labor rates, standard shipping costs per pound, and standard depot repair costs for each of the equipments repaired at the central depots (16:17-1 to 17-17). Lists of top 100 and top 500 ranked equipments were generated by IROS-LSC.

In his 1978 masters thesis at Ohio State University, Spray concisely stated,

> Very simply, the idea of a high burner list (such as the IROS-LSC ranking) is that with so many equipment items and so few engineers and investment dollars, why not concentrate our efforts on those items creating the most havoc . . .? Why waste time or money on items that are causing little or no difficulties [15:10]?

He went on to say that "the primary advantage of the high burner approach was that it was almost totally objective (15:10)."

The high burner approach, as exemplified by the IROS-LSC "top 500 equipments," was not without its critics.

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[1]The term Logistics Support Costs, as used in this paper, refers to the maintenance costs charged to or prorated to a specific equipment. It includes costs for field labor and materials, second destination transportation to and from central repair depots, and the cost of labor and materials for repair or replacement of items at the central depots.

Meitzler, in a 1976 study clearly identified a potential weakness.

> . . . [A] serious problem is that equipment performing some aircraft functions is inherently more expensive than that for other functions. Thus, we might not be surprised if, for example, the most reliable and lowest support cost inertial navigation system in the inventory costs more to support than the worst UHF radio. If this was actually the case, should we consider replacing or modifying the lowest cost, most reliable inertial navigation system in the inventory before we consider acting on the worst UHF radio? [11:1-2].

As pointed out by Dr. Womer, now at Clemson University,

> . . . high burner lists assume, by default, equal investment for all items. This wouldn't be so bad except all the high cost, high complexity devices are concentrated at the top of the list, thus blatently violating this assumption, since with other things being equal, one would expect the investment to be greatest for the most complex, expensive items [15:11].

Logistics Inventory Screening Technique (LIST-TD)

Recognizing these potential difficulties with the IROS-LSC high burner list, the PRAM Program Office in 1976, with the assistance of the Air Force Institute of Technology, initiated the development of the Logistics Investment Screening Technique-Total Degradation (LIST-TD).

LIST-TD was very similar to IROS-LSC, except for:

1. Quantification of the value of aircraft downtime and aircraft missions aborted (both measured in dollars), and

2. Calculation of the estimated investment required to improve the reliability of specific equipment.

Since its inception, LIST-TD has been used by about two dozen organizations (8:3). These have included the Avionics and Materials Laboratories, industries such as General Dynamics, Lockheed, Parker-Hannafin (valves and actuators), Grimes (aircraft lights), the A-10 System Program Office, etc. (8:3). Systems based on LIST-TD have been implemented at General Dynamics and Fairchild.

A COMPARISON OF THE RESULTS FROM CURRENT APPROACHES

IROS-LSC AND LIST-TD were two major competing approaches to screening equipment areas for improved reliability. The laboratories and others responsible for allocating research funds should be concerned about the difference between the types of equipments that were high on the IROS-LSC and LIST-TD rankings. If the top IROS-LSC and LIST-TD rankings both suggested the same types of equipment for investment, then no problem existed from the viewpoint of reliability investment in RDT&E. On the other hand, if differences in top IROS and LIST rankings of equipments were not the result of incidental differences such as different data bases, time period, etc., then questions need to be raised about the direction and thrust of the Air Force's program to improve the reliability of future aircraft.

Typical of the results obtained from the IROS/LSC approach was a 1975 McDonnell-Douglas Aircraft Corp. study. This study was based on an IROS-LSC ranking of all aircraft equipment types except engines. McDonnell-Douglas found an ". . . almost total absence of components [equipments] in the other nonavionics subsystems (4:56)." This study suggested that reliability improvement emphasis should be placed on avionics.

Several studies indicated that there were considerable differences between the IROS-LSC and LIST-TD top ranked equipments. The Aeronautical Systems Division (ASD) study, previously cited, found that with the LIST-TD top ranked items (i.e. high benefit-to-cost ratio) were low to medium value ($100 - $2000) items which caused unusually high degradations. (7:21).

To gain a different perspective on the ASD findings, in 1977 Houston analyzed the top ranked LIST-TD equipments by stock class[2]. Her findings are summarized in Table 1 (9:2-5).

Except for Bombing/Fire Control, her results, in sharp contrast to the McDonnell-Douglas findings, were noticably devoid of avionics.

In another study by the Air Force Institute of Technology, Baker and Hollingsworth re-examined the top ranked LIST equipments and confirmed Houston's finding that the stock class of valves and actuators contained the greatest number of equipments (1:15).

RANK	STOCK CLASS	NAME	NO. OF EQUIPMENTS
1	1650	Hydraulic Valves ...	41
2	1280	Bombing/Fire Control	22
3	6680	Flow Instruments	19
4	1660	Air Conditioning ...	17
5	6610	Flight Instruments	16

TABLE 1: TOP FIVE LIST STOCK CLASSES

ALTERNATIVE EXPLANATION FOR THE OBSERVED DIFFERENCES

Differences in top ranked equipment types between IROS-LSC and LIST-TD have been observed in the studies referenced in the preceding section.

[2]Federal Stock Class (FSC) is defined to be the first four digits of the stock number used in the supply system to identify a specific equipment. The FSC is a grouping of equipment with similar characteristics or functions (e.g., FSC 1280, Bombing and Fire Control Items).

However, it would have been risky to conclude that these differences were due to the different algorithms used in IROS-LSC and LIST-TD. Table 2 summarizes incidental (i.e., unintended) differences between the LIST-TD and IROS-LSC study methodologies. These could have produced effects which were confounded with the intended effects of the different algorithms. Five of the more obvious incidental differences are discussed below.

One obvious, but essentially incidental difference was that IROS-LSC results have always been of equipments classified by work unit code (usually the two digit code) while the LIST-TD results most studied have been of equipments classified by federal stock class. There was no general correspondence between these two equipment classification schemes.

	IROS-LSC	LIST-TD
1 Data	1974	1976
2 Aircraft Types	41 aircraft and helicopters	31 fixed wing aircraft
3 Equipment Classification	Work Unit Code	Federal Stock Class
4 Equipment Types	All Work Unit Coded Equipment	20% of the Work Unit Coded Equipment
5 Benefit Weights	Annual	Remaining Life of Aircraft
6 LSC Data	Quarterly	Annual
7 Number of Top Ranked Equipments	500	200

TABLE 2:
SEVEN DIFFERENCES WITH
POSSIBLE CONFOUNDING EFFECTS

Another obvious but incidental difference was that the IROS-LSC results were based on all the work unit coded equipments on Air Force aircraft, while LIST-TD was based on about 20% of the work unit coded items due to the necessity of using an incomplete work unit code to national stock number cross-reference (8:1). The method by which the cross-reference was formed guarantees that this 20% was not a random sample, but was in fact biased. In fact, Spray found that the equipments cross-referenced (20% of the total) accounted for almost 50% of the support, availability, and abort costs (13:120). If there were no bias 20% of the equipments should, of course, capture 20% of the cost.

Another incidental difference was that IROS-LSC drew on data from 41 different aircraft types, while LIST-TD drew on only 31 types (7:5).

Not only was the sample of aircraft different, but in each case, the time period covered by the data was different.

Finally, IROS-LSC used annual weights for its logistics support cost estimates, while LIST-TD estimates of total degradation were weighted based on the estimated remaining lives of each aircraft type (11:2). This difference would not affect the relative ranking of equipment if only a single type of aircraft were considered. However, when multiple types of aircraft were analyzed IROS-LSC implicitly weighted all aircraft types equally, while LIST-TD weighted them by the expected remaining life. In the LIST studies, the equipment on F-106, for instance, received only a small fraction of the weight of the equipment on an F-15 or even a B-52, because the projected remaining life of the F-106 is much less than that of either the F-15 or the B-52. The use of different weights constituted an incidental and even an erroneous difference when comparing the results of the two ranking methods. In this case either the expected life, a standard life (e.g., 10 year life), or annual values should be used in both methodologies (i.e., equal weights).

There were a number of alternative explanations that could have accounted for the observed differences. It should not have been concluded that a true or intended (i.e., nonincidental) difference existed between the IROS-LSC and LIST-TD algorithms until an unbiased comparison under properly controlled conditions was made.

The objective of this thesis was to perform a controlled comparison test between IROS-LSC and LIST-TD in order to determine if the different ranking algorithms caused the observed differences in the top ranked equipments.

RESEARCH QUESTIONS

Previous studies showed that the types of top ranked IROS-LSC and LIST-TD equipments were different. It was not known, however, whether these differences were due to incidental differences between the studies listed in Table 2, or to the fundamental differences between the IROS-LSC and LIST-TD algorithms. If all such incidental differences were eliminated would there have been a significant and practical difference between top ranked IROS-LSC and LIST-TD equipment types? If so, this difference could only have been attributed to the fundamental differences in the ranking algorithms.

Primary Research Question

The primary research question was:

> Do differences in the IROS-LSC and LIST-TD ranking algorithms cause significant differences in the resulting top ranked IROS-LSC and LIST-TD equipments?

Secondary Research Questions

There are other questions of interest if the differences in top ranked equipments were not explained by incidental causes.

> 1. Given an overall, nonincidental difference between the top ranked IROS-LSC and LIST-TD equipments, which specific equipment types are significantly different?

The thrust of this question was to identify which equipment types were emphasized by IROS-LSC, and which types were emphasized by LIST-TD. While it might be informative to know that the types of top ranked IROS-LSC and LIST-TD equipments are truly different, it was of practical importance to know which types of equipment were significantly emphasized by IROS-LSC as compared to LIST-TD, and vice versa.

> 2. Given an overall, nonincidental difference, was this due, at least in part, to the estimated investment feature of LIST-TD?

If the types of equipments emphasized were significantly different when the return on investment alogrithm was used, this might suggest that more consideration should be given to the question of estimated investments in reliability improvement.

> 3. Given an overall significant difference and a significant estimated investment effect, does the inclusion by LIST-TD of benefits due to reduced downtime and aborted missions, make a significant difference?

Specifically, this question pertained to whether or not there was a significant difference between top ranked LIST-TD equipments where only support cost benefits were considered, as opposed to the case where only downtime and abort benefits were considered. If a significant difference existed, this would be of interest because it could imply that the types of equipments one would invest in to reduce support cost are different from those that one would invest in to reduce downtime and aborts.

CHAPTER SUMMARY

There was considerable concern about the high equipment support costs, the excessive downtime, and the high mission abort rates of modern weapon systems, such as Air Force aircraft.

It has been suggested that poor equipment reliability was an important root cause of this situation. Research to improve equipment reliability would have high payoff on future aircraft if the research were concentrated on the appropriate types of equipment. Central to the use of research to improved equipment reliability, was a method of identifying types of equipment with the highest potential payoff.

Data on fielded aircraft were used to identify equipment types for reliability investment. One approach to doing this was the IROS-LSC (Increased Reliability of Operational Systems - Logistic Support Cost) which simply ranks equipments by their quarterly logistics support costs. Another somewhat similar approach, LIST-TD (Logistics Investment Screening Technique -Total Degradation), also ranks equipments, but in so doing LIST-TD considers the investment required to make equipments more reliable and also combines the benefits of reduced support cost with those of decreased maintenance and supply downtimes and reduced preflight and inflight aborts.

The quarterly lists of top 500 equipments generated by the IROS-

LSC approach emphasized expensive equipment types such as jet engines and radar sets while the LIST-TD approach, as analyzed by Houston (9:2-5), emphasized more "mundane" equipment types such as valves and actuators. The conditions under which these results were obtained were not entirely comparable. The IROS-LSC results were reported by work unit code while LIST-TD results were reported by federal stock class. The specific aircraft and equipments in the data bases were different as were the time periods of the data. Finally, logistic support costs were calculated in IROS-LSC using annual cost values, while LIST-TD's calculations were based on the remaining aircraft life.

Previous studies showed that the types of top ranked IROS-LSC and LIST-TD equipments were different. It was not known, however, whether these differences were due to incidental differences among the studies, or to the fundamental differences between the IROS-LSC and LIST-TD algorithms. If all such incidental differences were eliminated, would there still be a significant and practical difference between top ranked IROS-LSC and LIST-TD equipment types? This difference could only be attributed to the fundamental differences in the ranking algorithms.

The primary research question was "can the observed differences in top ranked IROS-LSC and LIST-TD equipment types be explained by the incidental differences in data samples, use of different remaining lives, etc., or was there an intended, significant difference due to the inclusion in LIST-TD of estimated investments and/or the additional benefits of reduced downtime and aborts?"

Given the background leading to the problem and the establishment of the research questions, the next task was to develop a research approach to answering the research questions. This is accomplished in Chapter 2. The results of the research are presented in Chapter 3, while conclusions and recommendations are stated in Chapter 4, the final chapter.

CHAPTER 2

RESEARCH METHODOLOGY

In Chapter 1 the following primary research question was developed:

> Do differences in the IROS-LSC and LIST-TD ranking algorithms cause significant differences in the top ranked IROS-LSC and LIST-TD equipments?

Depending on the answer to this question, secondary research questions are of interest. In this chapter, the experimental design used to answer the primary question is developed. Next the experimental controls used to control the confounding factors noted in the first chapter are discussed. After a description of the sample used in the research, the critical research question is stated as a statistically testable hypothesis. In the next section the methodology used to answer the supplemental research questions is presented.

The final section of this chapter explains the exact computational procedures used in testing this hyopthesis.

EXPERIMENTAL DESIGN

A valid comparison between IROS-LSC and LIST-TD must eliminate, as much as possible, all incidental influences while preserving the nonincidental, intended differences in the ranking algorithms. If the incidental influences were not controlled in the experimental design, they might produce effects confounded with the effects of the intended experimental treatment (14:5). In the classical experiment, assessment of the effect of a treatment would be made by running the controlled experiment with and without the treatment. The outcomes would be observed and recorded. The two groups of outcomes then would be compared. If a statistically significant difference existed, it would be presumed due to the treatment.

While the analogy of the classical experiment to this research situation was not exact, it was of explanatory value. The incidental effects were considered extraneous variables requiring control. The "no treatment" case considered the logistics support cost (IROS-LSC) ranking algorithm. The "treatment" case was the list ranking algorithm which had an Return On Investment feature and included, in addition to LSC, downtime and abort costs. The distributions by stock class of the top 500 ranked equipments in each case were analogous to "outcomes." A statistical comparison between the two distributions of top 500 ranked equipments by stock class was employed to discern significant effects in the different algorithms. This methodology was schematically depicted in Figure 1.

This experiment was capable of replication by using data from other time periods. Also, this experiment could be repeated under widely differing circumstances to check for wider generalizations. For example, while this "experiment" used only Air Force aircraft, there was no reason why it could not be repeated on Navy, RCAF aircraft, etc.

While the design of the critical experiment was straight forward, its success was entirely dependent on identifying the major incidental influences and controlling them, so that any observed differences could only be due to the nonincidental, intended differences between the IRO-LSC and LIST-TD algorithms.

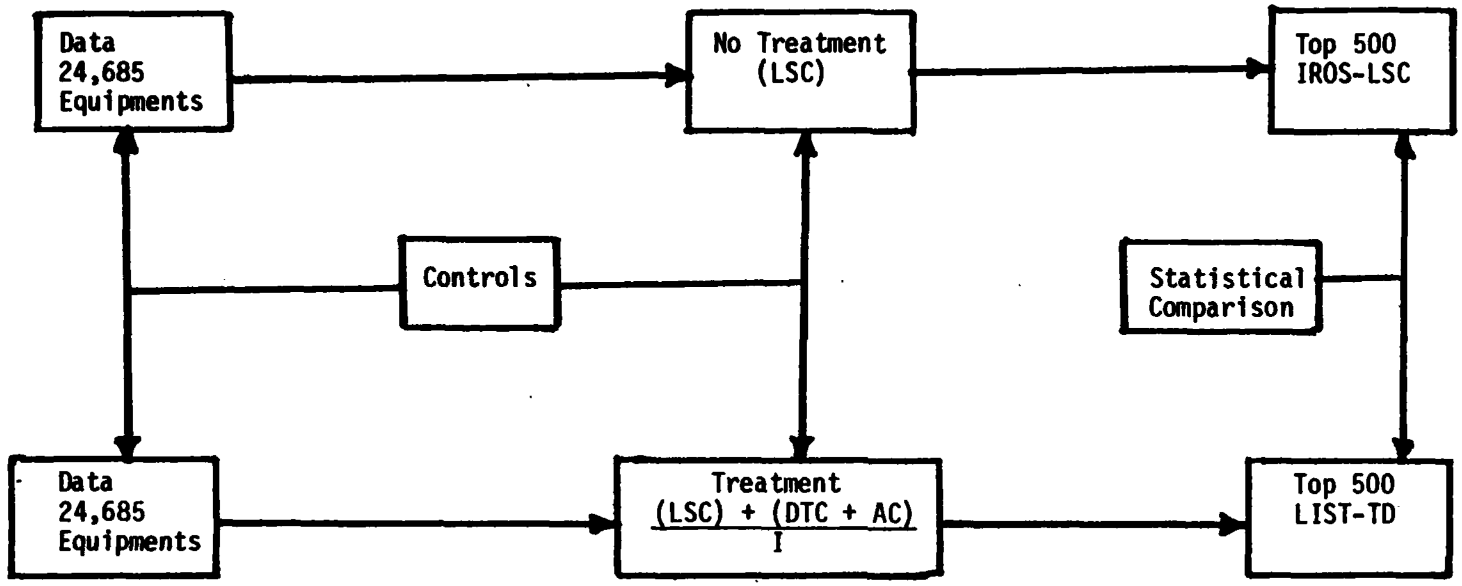


FIGURE 1: EXPERIMENTAL DESIGN

EXPERIMENTAL CONTROLS

Seven incidental influences were identified in the first chapter that could have caused the previously observed differences between IROS-LSC and LIST-TD. These incidental differences are discussed below, together with the approach taken to control each.

1. Different Time Periods - The data used in previous comparisons came from different time periods. For example the data used by Houston in her LIST-TD study (9:1-5) were compiled using data available two years older than the McDonnell aircraft IROS-LSC data. Specific changes such as missions, major modifications, or aircraft maturation might produce effects confounded with the intended effects of the different algorithms. To control for this, data from the same time period were used, eliminating this as a potential cause of any observed difference between the IROS-LSC and LIST-TD algorithms.

2. Different Aircraft - In previous comparisons, the data utilized were drawn from different types of aircraft. The McDonnell aircraft study, for instance, considered fighter type aircraft, while the Houston study contained a mix of fighter, bomber, and cargo aircraft. If particular type of equipment and/or the failure rates were significantly different among aircraft types, these could produce effects confounded with the intended effects of the different algorithms. The control used in the present research was to draw IROS-LSC and LIST-TD data from an identical set of aircraft.

3. Time Duration - IROS-LSC results have always been based on a single quarter (three months) of data. LIST-TD, on the other hand, has always employed four quarters of data. The difference could have

had an unintended, incidental effect on previous comparisons between IROS-LSC and LIST-TD. This was controlled by using four quarters of data for both IROS-LSC and LIST-TD.

4. Equipment Classification - IROS-LSC results have always been expressed by work unit code (one or two digit). LIST-TD results have usually been expressed by stock class, as in the Houston and Baker and Hollingsworth studies. As there was not a direct correspondence between the work unit code and stock class, the previously observed differences could have been due to the use of different schemes for classifying the results. By using either the work unit code or the stock class classification scheme, but not both, control can be achieved. The exclusive use of stock classes was arbitrarily chosen for control in this study.

5. Different Equipments - Even for the same time period, the same aircraft, and the same time duration, the actual equipments in the data base for IROS-LSC and LIST-TD would be considerably different. The equipments in the LIST-TD data base are actually a subset of the equipments in the IROS-LSC data base. LIST-TD contains about 20% of the equipments in the IROS-LSC data base. LIST-TD must use a cross reference between work unit codes and master stock numbers in order to obtain a unit price for the equipment. The cross reference used by LIST-TD was developed by the Logistics Management Institute, and it does not contain equipments that fail infrequently. This was controlled for by using only equipments with a valid cross reference between work unit code and master stock number.

6. Assumed Lives - IROS-LSC ranking algorithms did not consider the aircraft lives over which the benefits were amortized. LIST-

TD, on the other hand, explicitly made an assumption about remaining aircraft lives. In the Houston and Aeronautical System Division studies cited earlier, the official, planned remaining lives were used. Other things being equal, equipment on aircraft with long remaining lives will be ranked higher than equipment on aircraft with short remaining lives. This difference in weighting could have accounted for the observed difference between IROS-LSC and LIST-TD top ranked equipment types. It was controlled for by assuming a ten year life for all aircraft in both IROS-LSC and LIST-TD.

7. Number of Top Ranked Equipments - In previous studies, the number of equipments defined as "top ranked" varied from one study to the next. A larger number would, of course, allow more lower ranked equipments to be included, possibly of different types. This could have accounted for the observed difference between IROS-LSC and LIST-TD. This was controlled for by ranking exactly 500 equipments.

With the experimental design and controls specified, the actual sample used in the experiment is defined in the next section.

SAMPLE

The universe of the critical experiment was all equipment on all currently fielded US Air Force aircraft. The population was all work unit coded equipments on the 31 fielded aircraft contained in the LIST-TD data base, a subset of those contained in the IROS-LSC data base.

The sample was all equipments on the 31 fielded US Air Force aircraft with a valid cross reference reported on during the period, 1 October 1976 to 31 September 1977. There were exactly 24,685 valid cross referenced equipments. Each one represented a specific work unit coded equipment type on a specific aircraft type.

The primary research question developed in Chapter 1 lacks the operational definitions required to be statistically tested. In the next section the primary research question is restated as a precise, statistically testable hypothesis.

PRIMARY HYPOTHESIS

Having described the experimental design, experimental controls, and sample the primary research question can now be stated as a precise and statistically testable hypothesis:

> H_0: The difference in the federal stock class distribution of the 500 top ranked IROS-LSC equipments as compared to the 500 top ranked LIST-TD equipments was not significantly different.
>
> H_1: The difference was significantly different.

Significance was determined by the application of the Chi-Square statistic to a contingency table formed by the stock class frequencies of top ranked IROS-LSC and LIST-TD equipments. The significance level was .01(2:139).

If the null hypothesis was not rejected, then the other research questions are moot. The research conclusion would have been that no significant difference existed between the top ranked IROS-LSC and LIST-TD equipment types. From this, it would follow that the previously observed differences were entirely incidental.

Rejection of the null hypothesis would infer that a true significant difference existed between top ranked IROS-LSC and LIST-TD equipment types for the sample examined. From this, it would follow that at least some of the previously observed differences between IROS-LSC and LIST-TD results were not incidental. If the null hypothesis was rejected, the secondary research questions would have to be addressed to determine more specifically, the source of the difference.

SECONDARY RESEARCH QUESTIONS

Having defined the experimental design and the primary hypothesis, the methodology used in answering the secondary research questions follows directly. Discussion is limited to those key features differing from the primary research question. In all cases it is assumed that the null hypothesis in the primary hypothesis was rejected.

Significantly Different Equipment Types

The first secondary question was, "Which particular federal stock classes, taken one at a time, show a significant difference between top ranked IROS-LSC and LIST-TD equipment types?"

This question was answered by assuming for each stock class that no difference exists (H_0), and then examining the observed difference. If the difference between the assumed and observed frequencies was significant then reject the null hypothesis. The Chi-Square test was used to compare frequencies. On these individual tests the level of significance was set at .01 (2:139).

Return-On-Investment

The next secondary question was, "Does the return-on-investment feature (i.e., the estimated investment feature) of LIST-TD cause a significance between top ranked IROS-LSC and LIST-TD equipment types?"

This question was answered by performing an experiment exactly like the critical experiment in every way except one. The single difference was to leave out the added benefits of reduced downtime and aborts in LIST-TD (i.e. the only benefit used was the logistics support cost). Significance was determined by application of the Chi-Square Test to the Contingency Table. The significance level was .01 (12:139).

Failure to reject the null hypothesis would have led to the conclusion that the difference in the critical hypothesis (e.g., between IROS-LSC and LIST-TD) was not due to the return-on-investment feature of LIST. To reject the null hypothesis would imply that the difference in the critical hypothesis was due at least in part to the return-on-investment feature.

Added LIST Benefits

Did the LIST-TD feature of including downtime and abort costs make a significant difference? If equipments that have high support costs always had high downtime and abort costs, then there would not have been a significant difference between equipment types ranked by support cost and those ranked by downtime plus abort costs.

The significance of adding the downtime and abort costs was determined by repeating the return on investment experiment with one difference. In this experiment the comparison was between LIST-LSC (i.e., the only benefit used was LSC) and LIST-AB, where AB stands for "added benefits." LIST-AB was defined as the sum of downtime cost and abort cost divided by the estimated investment for each equipment.

Since on any specific given equipment, the estimated investment, I, was the same regardless of whether one considers the support cost of the added benefits (e.g. downtime and abort costs), differences resulting from the above experiment were attributed to the inclusion of the different benefits. Significance was determined by application of the Chi-Square Test to the Contingency Table. The significane level was .01 (12:139).

A failure to reject H_0 would have implied that there was no significant difference among top ranked equipment types if one considered logistics support costs vis-a-vis downtime and abort costs. Rejection would have implied that the difference between IROS-LSC and LIST-TD was due at least in part to the different types of costs, namely logistics support costs versus downtime and abort costs. Considerable emphasis has been placed by top Air Force managers on improving aircraft availability. If the equipment types emphasized to reduce support costs were considerably different than the equipment types emphasized to reduce downtime and aborts, then working on the former might not do much for the latter.

COMPUTATIONAL PROCEDURES

For the critical experiment, the data tape containing the 24,685 equipments in the sample was processed on a CDC 6600 computer to obtain the 500 top ranked IROS-LSC and LIST-TD equipments as specified previously. These two groups of 500 equipments were each sorted by stock class and the two groups were printed. The number of equipments in each Federal Stock Class were then counted and the frequencies in each stock class recorded.

STOCK CLASS	IROS	LIST
1650	A	E
1280	B	F
6680	C	G
1660	D	H

TABLE 3:

SAMPLE CONTINGENCY TABLE

The results were formed into a contingency table similar to the one shown in Table 3. In Table 3 the upper case letters in each cell represent the observed cell frequencies.

Siegel gave some special considerations in applying the Chi-Square (X^2) test to contingency tables with more than one degree of freedom.

> The X^2 test may be used if fewer than 20 percent of the cells have an expected frequency of less than 5 and if no cell has an expected frequency of less than 1. If these requirements are not met by the data in the form in which they were originally collected, the researcher must combine adjacent categories in order to increase the expected frequencies in the various cells. Only after he has combined categories to meet the above requirements may he meaningfully apply the X^2 test.[1] [14:110]

To insure the Chi-Square test was meaningfully applied, all cells with an expected frequency of less than two were combined into a single miscellaneous class (stock class 0000). Additionally when the number of cells with expected frequencies less than five and greater than one, exceeded 20% of the total cells, stock classes with the fewest observations where combined with stock class 0000 until these conditions were met.

---

[1] Underlining added by the authors.

The Chi-Square value for each stock class was then calculated as

$$X_i^2 = \frac{(f_1 - f_{ei})^2}{f_{ei}} + \frac{(f_2 - f_{eL})^2}{f_{eL}}$$

where

X_i^2 was the Chi-Square value for stock class i

f_1 was the IROS-LSC observed frequency for stock class i

f_2 was the LIST-TD observed frequency for stock class i.

f_{ei} was the expected frequency for the IROS-LSC for stock class i.

f_{eL} was the expected frequency for the LIST-TD for stock class i.

F_{ei} was calculated by multiplying the IROS/LSC marginal probability by the total observed frequency for stock class i. Because the same number of observations was used in both the IROS-LSC and LIST-TD, the marginal probability for both was equal to .5. F_{eL} was calculated by multiplying the LIST-TD marginal probability by the total observed frequency for stock class i.

The total X^2 value was simply the sum of the individual values across all stock classes (treating the combined "000" stock class as a single class).

$$X^2 = \sum_{i=1}^{n} X_i^2$$

where

X^2 was the total Chi-Square value

n was the number of unique stock classes (treating the combined miscellaneous as a single class)

The total X^2 value was then compared with the critical value from the statistical tables (Fisher and Yates) for .01 significance and [(2-1) x (n-1)] degrees of freedom. The null hypothesis was not rejected if the total Chi-Square value was less than the table critical value. The null hypothesis was rejected if the total value was greater than the critical value (14:106).

In the event the null hypothesis was rejected, each stock class can then be tested individually for a significant difference by noting whether its Chi-Square value exceeds that of the critical value from the table for .01 level of significance and 1 degree of freedom. This value was 6.64.

If the null hypothesis was rejected on the primary experiment, then this entire process would be repeated for the secondary experiments with the treatments being changed as previously described.

CHAPTER SUMMARY

As an aid to understanding the research approach, the IROS-LSC and LIST-TD processes were summarized. In an uncontrolled comparison between IROS-LSC and LIST-TD, there were seven major incidental differences that could affect the results.

A design for an "experiment," similar in many respects to the classical controlled experiment, was developed. It was shown how this design controlled for the major incidental effects.

The universe, population, sample, and other terms were then given operational definitions. With these in hand, the primary and secondary questions were restated as mathematical hypotheses. Finally, the exact mathematical procedures used in testing the hypothesis were given.

CHAPTER 3

RESULTS AND CONCLUSIONS

PRIMARY HYPOTHESIS

It will be recalled, from Chapter 2, that the primary hypothesis was:

> H_0: The difference in the federal stock class distribution of the 500 top tanked IROS-LSC equipments as compared to the 500 top ranked LIST-TD equipments was not significantly different.
>
> H_1: The difference was significantly different.

This hypothesis was tested with the Chi-Square statistic at the .01 significance level as defined in Chapter 2. The details of the Chi-Square calculations are given in Appendix C.

The calculated Chi-Square value was 342.3. For a .01% level of significance and 39 degrees of freedom, the critical Chi-Square value was 62.4. As 342.3 was greater than 62.4, the null hypothesis, H_0, was rejected, and the alternative hypothesis, H_1, accepted.

The consequence of such an outcome was given in Chapter 2 as:

> Rejection of the null hypothesis would infer that a true significant difference exists between top ranked IROS-LSC and LIST-TD equipment types for the sample examined.
>
> From this, it would follow that at least some of the previously observed differences between IROS-LSC and LIST-TD results were not incidental. If the null hypothesis was rejected, the secondary research questions would have to be addressed to determine more specifically, the source of the difference.

The conclusion was limited, in that it only applied to the experimental sample. More generalized conclusions, and the risks inherent in such generalizations are considered in the next chapter.

SECONDARY RESEARCH QUESTIONS

As the null hypothesis in the primary hypothesis was rejected, the secondary research questions were addressed.

Significantly Different Equipment Types

As stated in Chapter 2, the first secondary question was:

> Which particular stock classes, taken one at a time, show a significant difference between top ranked IROS-LSC and LIST-TD equipment types?

The stock classes that were significantly different are shown in Table 4 below. Those stock classes emphasized by IROS-LSC (i.e. those stock classes with the greatest frequency of occurence) were shown in the left column, while those emphasized by LIST-TD were shown in the right column. It can readily be seen that IROS-LSC emphasized jet engines and avionics while LIST-TD emphasized valves, actuators, fuel gauges, air conditioning and other miscellaneous or "mundane" items.

IROS-LSC EMPHASIS (.01%)

STOCK CLASS	EQUIPMENT TYPE
1270	Fire Control
1430	Missile Remote Control
1610	Props
2840	Jet Engines
5821	Radios
5841	Radar
5865	Electronic Counter Measures
6605	Navigation
6615	Autopilot

LIST-TD EMPHASIS (.01%)

STOCK CLASS	EQUIPMENT TYPE
1620	Landing Gear
1650	Hydraulic Valves and Actuators
1660	Air Conditioning
1680	Misc. Accessories
2620	Tires
6340	Alarms
6620	Engine Instrm.
6680	Fuel Gauges

TABLE 4: SIGNIFICANTLY DIFFERENT EQUIPMENT TYPES

Return-On-Investment

The second supplemental question was:

> Does the return-on-investment feature (i.e., the estimated investment feature) of LIST-TD cause a difference between top ranked IROS-LSC and LIST-TD equipment classes?

This was tested by comparing IROS-LSC with LIST-LSC, where the later was identical to IROS-LSC except the logistic support costs for each equipment were divided by the estimated investment, i.e., LSC/I.

The resulting Chi-Square value (see Appendix C for details) was 297.7. As 297.7 was greater than the critical Chi-Square value of 62.4 (for a .01% level of significance), the null hypothesis that there was no significant difference was rejected. This led to the conclusion, as stated in Chapter 2, that

> The difference in the critical hypothesis was due at least in part to the return-on-investment feature [of LIST-TD].

Having rejected the null hypothesis, the individual stock classes were examined for a significant difference. Those stock classes with a significant difference (.01% level of significance) were shown in Table 5. As before, when IROS-LSC had the greatest frequency, the stock class was listed in the left column, while LIST-LSC results were shown in the right column. For the sample examined, IROS-LSC again primarily emphasized jet engines and avionics, although pumps and engine assessories were now included. LIST-LSC emphasized an assortment of "mundane" items.

IROS-LSC EMPHASIS (.01%)		LIST-TD EMPHASIS (.01%)	
STOCK CLASS	EQUIPMENT TYPE	STOCK CLASS	EQUIPMENT TYPE
1270	Fire Control	1620	Landing Gear
1430	Missile Remote Control	1630	Wheels and Brakes
2840	Jet Engines	1650	Hydraulic Valves and Actuators
2995	Engine Assessories	1680	Misc. Assessories
4320	Pumps	2620	Tires
5821	Radios	6220	Lights
5841	Radar		
5885	Electronic Counter Measures		
6605	Navigation		
6615	Autopilot		

TABLE 5: RETURN-ON-INVESTMENT RESULTS

Added LIST Benefits

The last supplemental research question given in Capter 2 was:

> Did the LIST-TD feature of adding in downtime and abort costs make a significant difference?

The calculated Chi-Square value (see Appendix C for details) was 149.7. As this was greater than the critical Chi-Square value of 64.2 (for a .01% level of significance), the null hypothesis that there was no difference was rejected.

As was stated in Chapter 2:

> Rejection of the null hypothesis would have implied that the difference between IROS-LSC and LIST-TD [at least for this sample] was due at least in part to the different types of costs, namely logistics support costs versus downtime and abort costs.

Because the null hypothesis was rejected, the individual stock classes were examined for significant differences. The results are shown in Table 6.

LIST-LSC EMPHASIS (99%)		LIST-AB EMPHASIS (99%)	
SC	EQUIPMENT TYPE	SC	EQUIPMENT TYPE
1640	Batteries	6610	Flight Instruments
2620	Tires	4920	Maint Special Equipment
1630	Wheels and Brakes	4810	Valves
		2915	Engine Fuel System
		1660	Air Conditioning

TABLE 6: ADDED BENEFITS RESULTS

CHAPTER SUMMARY

For the sample examined it was found that:

1. There was a significant difference between top ranked IROS-LSC and LIST-TD equipment types.

2. That this difference was due to both the inclusion in the LIST-TD algorithm of an estimated investment and the added benefits (reduced cost) of downtime and aborts.

3. That the types of equipments emphasized by IROS-LSC were jet engines and avionics, while those emphasized by LIST-TD were mundane items such as hydraulic valves and actuators, fuel gauges, etc.

The final chapter considers the generalizations of these findings beyond the sample examined.

CHAPTER 4

RISKS, CONCLUSIONS, AND RECOMMENDATIONS

In Chapter 2, specific experiments were devised to address the research questions. Chapter 3 presented results for a particular sample of 24,685 equipments. While these specific results may be generally valid when applied to other periods, other aircraft, etc., there were a number of risks inherent in such generalizations. The acceptability of these risks depends, in the end, on the judgment of each user of the results of this research.

The risks to generalization are given below, followed by some conclusions (keeping the risks in mind), and, finally, some recommendations.

RISKS TO EXTERNAL VALIDITY

Four potential sources of risk in generalizing the experimental results will be discussed.

(1) If instead of comparing the stock class frequencies of the top 500 in each case, the top 100, top 1000, etc., had been compared, the result might have been different.

(2) The use of only WUC/MSN cross referenced equipments means that the "IROS-LSC" results of the "experiment" will be different, to some extent, from the true IROS-LSC results based on all equipments. There were grounds for believing that this could introduce a considerable bias favoring equipments with frequent failures and maintenance

actions. While such a bias would certainly seriously affect the outcome of an experiment intended to gauge the precise change in an interval or ratio level parameter, it was difficult to conceive of any systematic bias in this case that could mask a difference in the ordinal level results or falsely create a difference where one did not truly exist.

(3) The one year of data used might not be representative, and the use of data from some other year could change the conclusions.

(4) The input data gathered and consolidated by various automated systems contained errors. It was possible that some systematic error could have interacted with the treatment in such a way as to falsely create an apparent difference when in fact there was none, and vice versa. For example, errors in the stock list prices (e.g. such that they were extremely low) would cause the estimated investment to be understated. Since investment was a divisor in the treatment case, the rank would be falsely high. As there would not be a similar effect in the untreated case, this would be an interaction effect with the treatment and a source of invalid difference.

CONCLUSIONS

As discussed above, there were a number of risks to making any generalizations. The large sample of over 24,000 equipments, the use of controls in the quasi-experimental design, and the use of the .01 level of significance should, however, have reduced such risks. Until the experiment is independently replicated and rerun under other conditions using other aircraft from other time periods, no generalization will be completely without risk.

With full knowledge of these risks, the authors concluded that it was highly probable that top ranked IROS-LSC and LIST-TD equipment types would be found to be significantly different for all reasonably sized samples of Air Force aircraft equipments. This significant difference would be due to both the investment and the added benefit features of LIST-TD. These were the principle conclusions of this research. It was the authors' intent to show that for at least one high burner algorithm (IROS-LSC) and one estimated return-on-investment algorithm (LIST-TD), that the results obtained were significantly different and that this difference was of sufficient magnitude to be of concern to Air Force decision makers.

RECOMMENDATIONS FOR FURTHER RESEARCH

As with most research, one possibility for further research is replication using data from different time periods, different aircraft, etc. Such replications would either strengthen or weaken the conclusions reached in this research. While not discouraging such research, it may be more fruitful to consider some of the larger questions that remain.

It would be most useful to know whether the significant differences established by this research were due to peculiarities in the algorithms used by LIST-TD to: (1) estimate the added benefits of downtime and aborts; and (2) estimate the investment required to improve equipment reliability. A number of alternatives to the highly simplified LIST-TD algorithms have been suggested, and it would be most instructive to determine whether or not the types of equipments emphasized were sensitive to the forms of the algorithms involved. The present researchers offer two postulates: (1) "high-burner" lists, such as IROS-LSC, will mostly emphasize jet engines and avionics, while return-on-investment lists, such as LIST-TD, will usually emphasize such mundane equipments as hydraulic valves and actuators, fuel gauges, etc.; (2) the types of equipments emphasized for support cost reduction will usually be significantly different that those emphasized for decreasing downtime and aborts.

If further research should confirm these postulates, then the case that there was a fundamental and significant difference in the logic behind the single benefit high-burner and the combined benefits return-on-investment approaches would be strengthened. In this event the objections of Meitzler (11:1-2) and Woomer (15:1) to the logic of the high burner approach should be given serious consideration. Ideally, the issue would best be resolved by the consideration of the actual investments and benefits made in past reliability improvements, but as Coleman and Edison have established (5:17), this is at best a difficult and uncertain undertaking.

RECOMMENDATIONS FOR MANAGEMENT

It was the authors' understanding that a high priority Air Force goal was to make sizable reductions in the support costs and downtimes of future aircraft. As pointed out in Chapter 1, a number of researchers suggested that concentrated basic research to improve reliabilities of carefully selected types of equipment could contribute significantly towards this goal. Several of the researchers felt that the rational, systematic use of data on currently fielded aircraft was a sound approach to selecting the types of equipments for research concentration.

As was shown by this research, however, two different, systematic approaches gave significantly different results.

Managers, particularily those concerned with the allocation of resources for basic research, should be aware that for at least one case, the types of equipment one would emphasize for reliability improvement are significantly different when one uses a single-benefit, high-burner algorithm (IROS-LSD) as opposed to a combined-benefit, return-on-investment algorithm (LIST-TD). Managers might be prudent if they considered the possibility that these significant differences might not be unique to the specific algorithms in IROS-LSC and LIST-TD, but were the result of fundamental differences in thinking and approach.

APPENDICES

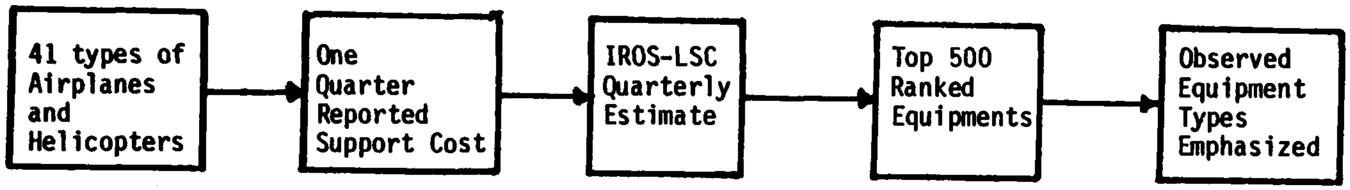
APPENDIX A:

IROS-LSC

The automated IROS system, known as K051, was based on reported data from 41 different types of aircraft. The input to K051 was extracted from a number of automated data systems that covered not only maintenance activities at individual air bases, but repair work at the central depots, etc. K051 extracted data from these data systems quarterly, and used it to estimate the annual logistics support costs of some 150,000 authorized work unit coded equipments. The K051 process was depicted in Figure 2.

The Logistic Support Cost (LSC) estimate, while primarily based on the reported data, also utilized a number of allocation factors and standards. The labor cost, for instance, was the product of the reported man-hours and a standard labor rate ($/hour). Transportation costs were based on reported weight and a standard cost per pound. Depot repair costs of each equipment type were based on the product of the number of units shipped to the repair depot and a standard cost per repair for that type equipment.

The accuracy of the IROS-LSC estimate and the data on which it was based were questioned by Fiorello (6:22). If one was interested in a fairly exact estimate of the annual logistics support cost of a specific work unit coded equipment, then qualms about the absolute accuracy of the data input to IROS and the roughness of the estimating procedures would be understandable. On the other hand, if one was only interested in what types of equipments (i.e. an ordinal scaled variable) freqquently occur in, say the top 500 ranked equipments, then the accuracy required for this objective was certainly met by IROS-LSC.



ALGORITHM: RANK BY LSC

FIGURE 2: IROS-LSC PROCESS

As shown in Figure 2, the top ranked IROS-LSC equipments can be grouped by their two digit work unit code (2 digit WUC). There were some 40 plus unique two digit WUCs on Air Force airplanes and helicopters. Finer classification, unfortunately, was not consistent from one aircraft to the next, and thus the two digit WUC was the most detailed classification available by work unit code. As mentioned in the introduction, the various two digit WUCs covering engines and avionics were the equipment types with the greatest frequency of occurrence in the IROS-LSC 500 top ranked equipments.

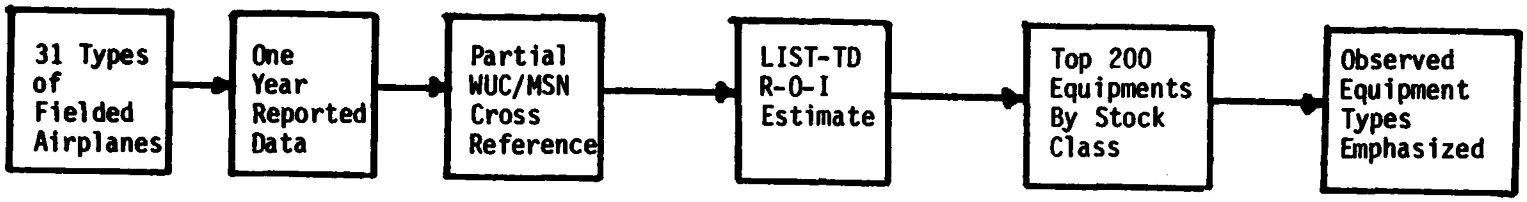
APPENDIX B:

LIST-TD

The LIST-TD estimates of return-on-investment were based on 31 types of fielded airplanes (helicopters were excluded). Data reported on the equipment on these aircraft were by both work unit code (WUC) and master stock number (MSN). An entire year of data was utilized in the LIST-TD estimates. Data by Master Stock Number (MSN), particularily stock-list prices, were required by LIST-TD to estimate the investment required to improve reliability. The logistic support cost (LSC) portion of the LIST-TD was exactly identical to the reported IROS-LSC, as the latter was utilized as the logistics support cost estimate in LIST-TD. The LIST-TD process was portrayed in Figure 3.

The fact that the logistic support cost (LSC) estimates were identical in both IROS-LSC and LIST-TD was a fortuitous coincidence (due to LIST-TD being a "decendent" of IROS-LSC), since this identity was exploited in the experimental design.

LIST-TD estimates of downtime and abort costs were based on reported downtimes, aborts, and the cost of the entire aircraft. There was no general agreement as to how downtimes and aborted missions should be converted into equivalent costs, or even whether this should be done at all. The originators of LIST-TD maintained that the inclusion of downtime and abort costs along with the support costs was essential as these costs represent, fully one half of the overall penalty of unreliable equipment (7:3). It was one of the objectives of this thesis to determine whether or not the inclusion of downtime and abort costs significantly influence the types of equipment suggested for reliability improvement research.



ALGORITHM: RANK BY: $LSC \cdot RL + \frac{DTC + AC}{I}$

where:
- LSC is the logistic support cost
- RL is the remaining life
- DTC is the downtime cost
- AC is the abort cost
- I is the investment

FIGURE 3: LIST-TD PROCESS

The investment in LIST-TD was estimated as being proportional to the cost of the installed equipment.

$$I \propto UP_E \times N_{AC} \times QPA$$

where

I was the estimated investment

UP_E was the unit price of the equipment in question (stock list price)

N_{AC} was the number of aircraft of the type in question

QPA was the quantity (of the equipment) per aircraft

The LIST-TD results were not portrayed as being absolute estimates of return-on-investment, but merely an approximate rank order list. It was for this reason that a proportionality rather than an equality was given. It was suggested that this proportionality should more properly vary from one technological area to the next, but this refinement was not pursed by the developers of LIST-TD.

The LIST-TD algorithm was

$$\text{Rank Order ROI by: } \frac{LSC \times RL + (DTC + AC)}{I}$$

where

ROI was the return-on-investment rank order

LSC was the IROS-LSC estimate

RL was the estimated aircraft remaining life

DTC was the downtime cost estimate

I was the reliability investment estimate

If RL was set to any nonzero constant value, if (DTC + AC) was set to zero, and if I was set to any nonzero constant value, then with identical data input, the top ranked IROS-LSC and LIST-TD equipment types will, of necessity, be identical. This was the fortuitous situation mentioned earlier.

APPENDIX C

DETAILED RESULTS

The results for the primary hypothesis were shown in Table 7. The first column was an identifying number. The second column was the stock class. The third and fourth columns were the observed frequencies, while the last column was the Chi-Square value for individual stock class. Stock Classes that were significantly different at the .01 level of significance (i.e. $X^2 > 6.64$) were annotated with an asterisk.

For (40-1) X (2-1) = 39 degrees of freedom and a .01 level of significance, the critical X^2 value was 62.4. As 342.3 > 62.4, the primary null hypothesis was rejected, and it was concluded that the difference between the distribution of top ranked IROS-LSC and LIST-TD equipment types was significant.

NO.	SC	IROS-LSC	LIST-RD	X^2	NO.	SC	IROS-LSC	LIST-TD	X^2
1	6680	4	29	18.9*	21	2995	18	10	2.3
2	6670	4	20	10.7*	22	2915	19	18	0.0
3	6615	27	4	17.1*	23	2840	43	10	20.5*
4	6610	14	18	0.5	24	2835	1	4	1.8
5	6605	55	21	15.2*	25	2620	9	27	9.0*
6	6340	0	9	9.0*	26	1730	1	3	1.0
7	6220	1	6	3.6	27	1680	10	61	36.6*
8	6210	0	4	4.0	28	1660	5	30	17.8*
9	6140	5	7	0.3	29	1650	20	52	14.2*
10	6115	9	1	6.4	30	1630	16	28	3.3
11	6110	0	6	6.0	31	1620	2	25	19.6*
12	3895	11	0	11.0*	32	1610	7	0	7.0*
13	5865	18	5	7.3*	33	1560	42	22	6.2
14	5841	25	1	22.1*	34	1440	4	0	4.0
15	5826	13	3	6.2	35	1430	17	1	14.2*
16	5821	14	2	9.0*	36	1280	18	15	0.3
17	4920	4	6	0.4	37	1270	31	6	16.9*
18	4820	2	2	0.0	38	1095	6	3	1.0
19	4810	1	7	4.5	39	1005	5	5	0.0
20	4320	12	4	4.0	40	0000	7	25	10.1*
					TOTALS		500	500	342.3

TABLE 7: PRIMARY HYPOTHESIS RESULTS

The "Miscellaneous" combined stock class (0000) was expanded in Table 8 for reference.

SC	IROS-LSC	LIST-TD	SC	IROS-LSC	LIST-TD
6685	0	2	4440	0	1
6645	0	1	4310	1	0
6250	0	1	4140	0	1
6105	1	1	4130	1	2
5995	1	0	3040	0	1
5990	0	1	2945	0	1
5960	1	0	2935	1	1
5850	0	2	2910	0	1
5831	1	1	1670	0	1
5340	0	2	1420	0	1
4730	0	1	1290	0	1
			TOTALS	7	25

TABLE 8: DETAILS OF MISC. CLASS

RETURN-ON-INVESTMENT

The analysis for the return-on-investment hypothesis was identical to that of the primary hypothesis, except that the comparison was between IROS-LSC and LIST-LSC/I.

The results were shown in Tables 9 and 10. The number of stock classes after consolidation was, coincidently, again 40, so that same critical table value applies for a .01 significant level. As the test statistics exceed the critical value (297.7 > 62.4), the null hypothesis was rejected. It was concluded that the significant difference between top ranked IROS-LSC and LIST-TD equipment types was due at least in part to the return-on-investment feature of LIST-TD.

NO.	SC	IROS-LSC	LIST-TD	X^2	NO.	SC	IROS-LSC	LIST-TD	X^2
1	6680	4	14	5.5	21	2915	19	10	2.8
2	6620	4	14	5.5	22	2840	43	19	9.3*
3	6615	27	8	10.3*	23	2835	1	4	1.8
4	6610	14	6	3.2	24	2620	9	38	17.9*
5	6605	55	18	18.7*	25	1730	1	3	1.0
6	6340	0	5	5.9	26	1680	10	50	26.7*
7	6220	1	17	14.2*	27	1670	0	5	5.0
8	6140	5	14	4.3	28	1660	5	8	0.7
9	6115	9	1	6.4	29	1650	20	41	7.2*
10	6110	0	4	4.0	30	1630	16	46	14.5*
11	5885	11	0	11.0*	31	1620	2	26	20.6*
12	5865	18	10	2.3	32	1610	7	3	1.6
13	5841	25	2	19.6*	33	1560	42	24	4.9
14	5826	13	11	0.2	34	1440	4	0	4.0
15	5821	14	3	7.1*	35	1430	17	0	17.0*
16	4920	4	2	0.7	36	1280	18	21	0.2
17	4820	2	3	0.2	37	1270	31	13	7.4*
18	4440	0	4	4.0	38	1095	6	5	0.1
19	4320	12	1	9.3*	39	1005	5	10	1.7
20	2995	18	5	7.3*	40	0000	8	32	14.4*
						TOTALS	500	500	297.7

TABLE 9: DETAILED RETURN-ON-INVESTMENT RESULTS

SC	IROS-LSC	LIST-TD	SC	IROS-LSC	LIST-TD
7310	0	2	5831	1	1
6685	0	1	5340	0	2
6645	0	1	4810	1	1
6250	0	1	4730	0	2
6210	0	2	4310	1	2
6125	0	1	4130	1	2
6105	1	1	3040	0	2
5995	1	1	2945	0	2
5990	0	1	2925	0	1
5915	0	1	2910	0	1
5850	0	3	1420	0	1
			TOTALS	8	32

TABLE 10: DETAILS OF MISCELLANEOUS CLASS

TYPES OF BENEFITS

The final hypothesis was analyzed exactly as the preceeding two except the comparison was between LIST-LSC and LIST-AB, the added benefit model (i.e., between LSC/I and (DTC+AC)/I).

The results were shown in Tables 11 and 12. The null hypothesis that the added benefits feature of LIST-TD was not a source of significant difference, was rejected as the total X^2 value of 149.7 was greater than 62.4. The alternative hypothesis that added benefits were a significant source of difference was accepted.

NO.	SC	IROS-LSC	LIST-TD	X^2	NO.	SC	IROS-LSC	LIST-TD	X^2
1	6685	1	7	4.5	21	4320	1	6	3.6
2	6680	14	30	5.8	22	4130	2	2	0.0
3	6620	14	17	0.3	23	2995	51	12	2.9
4	6615	8	6	0.3	24	2915	10	28	8.5*
5	6610	6	21	8.3*	25	2840	19	9	3.6
6	6605	18	21	0.2	26	2835	4	4	0.0
7	6340	5	10	1.7	27	2620	38	9	17.9*
8	6220	17	5	6.5	28	1730	3	4	0.1
9	6210	2	3	0.2	29	1680	50	58	0.6
10	6140	14	1	11.3*	30	1670	5	2	1.3
11	6110	4	1	1.8*	31	1660	8	32	14.4*
12	5865	10	8	0.2	32	1650	41	53	1.5
13	5850	3	0	3.0	33	1630	46	11	21.5*
14	5841	2	6	2.0	34	1620	26	20	0.8
15	5826	11	4	3.3	35	1560	24	27	0.2
16	5821	3	3	0.0	36	1280	21	18	0.2
17	4920	2	12	7.1*	37	1270	13	7	1.8
18	4820	3	6	1.0	38	1095	5	2	1.3
19	4810	1	10	7.4*	39	1005	10	4	2.6
20	4440	4	2	0.7	40	0000	27	19	1.4
						TOTALS	500	500	149.7

TABLE 11: DETAILED ADDED BENEFITS RESULTS

SC	IROS-LSC	LIST-TD	SC	IROS-LSC	LIST-TD
7310	2	0	4140	0	1
6645	1	1	3040	2	1
6250	1	0	2945	2	0
6125	1	1	2935	0	1
6115	1	2	2925	1	0
6105	1	1	2920	0	1
5995	1	0	2910	1	2
5990	1	1	1610	3	0
5915	1	0	1430	0	1
5831	1	1	1420	1	1
5340	2	0	1290	0	1
4330	2	1	1190	0	2
4310	2	0			
			TOTALS	27	18

TABLE 12: DETAILS OF MISCELLANEOUS CLASS

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