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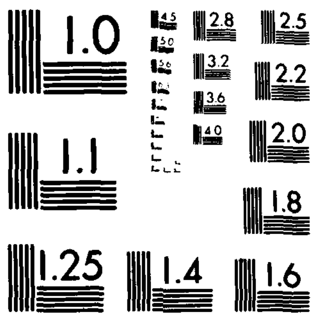

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This staff study report is an analysis and evaluation of the applicability of economic theory to aircraft engine and accessories repair-discard decisions. The study is based upon an extensive review of the ERRC (expendability, recoverability, and repairability category) coding system and CIP (component improvement program) system at the Oklahoma City Air Logistics Center. The basic implication is that present repair-discard decisions do not account for higher costs and production delays in the future because of shortages of

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) critical materials. Accounting for this factor could change a discard decision to repair resulting in dollar savings and better field support for engines and accessories.

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STAFF STUDY REPORT

Final rept.

AN ANALYSIS AND EVALUATION OF USE OF ECONOMIC THEORY IN AIRCRAFT ENGINE REPAIR-DISCARD DECISIONS

Prepared for

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Shortages of materials which are processed from strategic natural resources have resulted in significant price increases for many processed products. Documented evidence shows that these shortage related price increases have created a high cost situation for the Air Force and DOD in terms of new acquisitions and maintainability of current assets which contain significant amounts of shortage type materials.[1,2,3] However, various actions should have been undertaken by the Air Force and DOD which would significantly reduce the impact of these cost increases. Those actions include programs designed to anticipate cost increases and to prolong use of current assets which are processed from strategic natural resources.

Economic resource allocation theory is useful in analysis of the utilization of materials which are processed from strategic natural resources. In analyzing the efficient and equitable utilization of natural resource related products, four factors must be considered: durability of materials, material embodiment in items, waste generation in production and recycling. Prices of materials and reliability requirements generally dictate control of the first three factors during the production process. However, the often neglected but extremely important aspect of resource management is that of recycling.

Economic theory tells us that significant price increases for durable materials should result in significantly more recycling of current asset material. This action would significantly reduce the impact of the cost increases.[4] Under such conditions the recycling (repair-discard) process becomes one of the most important aspects of total resource management because it is the one area in which the immediate manager can have a significant impact on the resource utilization process. A review of natural resource related economic theory leads to a conclusion that material shortage costs must be included in the immediate management level repair-discard decision process in order to assure an efficient and equitable use of resources.*

For an economic, efficient utilization of shortage materials and as part of the Air Force and DOD's responsibility to society[5] in terms of the use of natural resource processed products**, the long-term costs associated with shortage materials which come from these critical natural resources must be reflected in repair-discard type, short-run material use decisions.

*Comprehensive review contained in Appendix B.

**Current market forces do not sufficiently take care of our obligations to future generations with respect to present consumption and destruction of natural resources. In making choices among alternative allocation of resources, many relevant costs lie in the future and many of those have not been included in market price. For an efficient and equitable allocation of resources, these costs must be included in all resource use decisions.

In making choices among alternative allocations, some tools are available to attach relevant costs to future uses of those resources. The use of a discount rate with an allowance for risk lets the decision maker take some relevant future costs into consideration. However, the choice of a discount rate depends upon the alternative possibilities available for exchanging today's dollars for future dollars. The Government's average long-term borrowing rate has been used as a minimum rate on Government investments, but that rate by no means reflects the real cost of Government investment decisions, much less the real cost of resources consumed.

Theoretically, as resources become scarce, their relative prices rise, thereby discouraging their use and providing strong incentives to find and use substitutes. Even though technological progress between the present and the time of increasing scarcity may serve to mitigate the effects of higher prices for materials, economizing considerations may require the gradual alteration of consumption patterns in response to pressures on natural systems. Economists are beginning to take a closer look at factor substitution which could prove to be an important input into the repair-discard decision framework. Cost of products would be expected to increase as lower grades of resources are used and environmental and safety requirements become more stringent. For this reason, if none other, repair of existing assets which were manufactured from scarce natural deposits should be encouraged as those product prices increase.

The optimum extent of recycling (repair or discard) depends on the circumstances of the product but does require a calculation of all relevant costs. The overall objective of this study was to examine and evaluate selected aspects of aircraft engine and component parts repair-discard decisions to determine whether recycling is at the optimum level. We formulated the study in terms of the question of whether the recycling is below optimum because of deficiencies in cost calculations; that is, are long-term resource costs (material shortages and social costs) properly reflected in the decision framework?

Specific objectives of the study were:

1. A review of natural resource economic theory,

2. Evaluation of DOD and Air Force directions and regulations on economic aspects of engine repair or discard decisions,

3. Review of maintainability and reliability analysis in engine maintenance and repair decisions,

4. Evaluation of the current repair-discard decision framework for engine and component parts with respect to the first three objectives.

The first three objectives were completed and results provided in Appendices A-C of the overall report. This specific report is designed to present results of objective four.

The first step is to evaluate the current systems in terms of existing directives, regulations, and the current repair-discard decision framework.

Current Air Force and DOD Policy*: DOD directives contain policies which in theory are designed to enhance the quality of recoverable resources and to approach the maximum attainable recycling of depletable resources.[6,7] For instance, DOD Directive 6050.1 requires, along with economic and technical factors, concurrent consideration of environmental amenities and values in decision making. In practice, costs associated with the use of shortage resources and future option alternatives are reflected to some degree by cost escalating factors and the use of discount factors during analysis for the initial provisioning process or in adjustments to major programs. Although limited to major modification or large investment proposals, AFLC policies and procedures do exist for developing, reviewing, and evaluating cost factors and cost estimates to support program recommendations.[8] Regulations require preparation and evaluation of an economic analysis not only

*Comprehensive review contained in Appendix A.

when a program or project is initiated but again when a program evaluation of an on-going program reveals that a significant adjustment is necessary.[9]

Although criteria and principles have been established for use by all Air Force activities in estimating the cost of repair to determine eligibility for economic repair, it appears that decisions on repair-discard subsequent to the initial provisioning process usually do not reflect these economic factors.[10]

AFLCR 65-2 provides economic repair criteria for use by Directorates of Materiel Management personnel in establishing initial maintenance codes or for changing these codes as supply and maintenance experiences dictate.[11] Economic analysis techniques are provided as a supplement to the technical and operational considerations which can and do affect maintenance decisions. If non-economic considerations do not dictate the decision, or only dictate a partial decision, economic analysis techniques can be applied.

Procedures in AFLCR 65-2 were developed under the premise that support costs which most influenced an economic repair decision are the support equipment, spare/repair parts costs, and maintenance costs. AFR 67-93 requires current purchase price for material purchased with appropriated funds to be restricted to manufacturing costs, manufacturer's overhead not included in manufacturing costs, packaging and preservation costs, and profits. Standard prices for items currently being purchased are reviewed once a year and revised when significant changes occur. However, long-run costs associated with use of critical natural resource materials are not included as part of the decision process.

The expendability, recoverability, and repairability category (ERRC) coding for aircraft engine components and accessories designates the methodology to be employed in computing material requirements, designates disposition when the item is no longer economically repairable, and are used in reporting of asset and supply usage data.[12] As a corollary program to the ERRC system, the component improvement program (CIP) is designed to maintain specifications of the engine, but not improve specifications.

A review of ERRC codes and the CIP program for aircraft engines at the Oklahoma City Air Logistics Center indicates that non-economic factors always receive first consideration in both programs. Economic factors receive only secondary consideration, if any, in both the ERRC and CIP processes.[13] Documentation is almost non-existent for ERRC code changes. However, item managers and equipment specialists for the TF-30 and J-57 engines indicated that very few ERRC code changes had been made in response to economic factors and material shortages, nor do long-term resource use and social costs receive any consideration in the ERRC process. CIP decisions on the other hand are well documented. A small number of CIP decisions are based on economic cost factors, but few, if any, decisions are based on material shortage or social cost factors. Apparently, contractors do take into consideration some long-term resource use costs as an indirect cost. These economic factors are considered in the CIP process only to the extent that they impact on short-term material cost in the contractor's calculation of his immediate rebuilding or new product cost. As equipment technicians recommend code changes, they are passed on to requirement-buy personnel who generate requirements based on specifications, assets on-hand and on-order, and forward purchase requests to procurement. Procurement simply carries out purchase requests. According to those interviewed, neither the requirements-buy nor procurement process consider economics of shortage materials in their decisions.

ERRC System: ERRC coding is established during the initial provisioning conference between technicians and the contractor. Records of these transactions are not maintained. The applicable Technical Services Branch of the system manager/item manager for material assigned by TO 00-25-115 is responsible for establishing the repairability or nonrepairability status of an item. The technician bases his decision mostly on experience and the information provided by the contractor.[13] Recommendation of the vendor generally is accepted at the provisioning conference. After design consideration, established maintenance policy is the most important consideration as criteria for establishing codes. In maintenance coding only those costs provided by contractors are considered. Therefore only current cost of the item is used in establishing the level of repair. The SM/IM has responsibility to maintain cognizance of the repairable or nonrepairable status of assigned items and take necessary action for changing the status when dictated by AFM 66-1 maintenance data, improved repair techniques, costs, design changes, or changes in operational requirements dictate. In general, ERRC codes are changed only: in response to significant change in lead time for specific components (but only after the increased lead time creates a problem); when the contractor is unable to provide components due to non-availability of resources; or when the contractor develops a new product. Otherwise equipment specialists generally stay with the initially established ERRC code. Usually changes are made only when a problem arises. In any review of codes for possible changes, economics is not a first consideration although current costs are used as a guide. A general rule is to repair if repair cost is less than 75 percent of new costs. Input of unit prices are developed using standard pricing methods prescribed in AFM 67-1 and AFR 67-93.

Although documentation does not exist on ERRC code changes, several examples were provided in which a repair decision may have been based partly on costs factors, that is, cost of repair is more or less expensive than cost of new item or old procedure. Examples include code changes for manifold spray rings for the TF-30 engine, the TF-30 main bearing, the J-57 and J-59 engine ignition harness, turbine disc for the J-79 engine, coating change on J-79 engine fan blades, compressor air seal for the TF-30 engine, and replacement of plasma spray on TF-30 engine.

One reason long-term material shortage and social cost factors are not included in the ERRC coding system is because inclusion of those factors is not required. Also, the information has not been provided to equipment specialists or the item managers. The specialists and managers seem willing to incorporate any information that will eliminate future critical situations.

CIP System: Because the CIP program is designed to maintain specifications of assets, those personnel generally react to performance problem situations or to availability of a new product. The engineering section of the system manager/item manager has decision responsibility for the CIP program of an item. As problems arise, they request an engineering program notice from the appropriate contractor or vendor. The engineers then react to his proposal and decide to accept or reject the contractor's proposal for a solution to the performance problem. The solution may be a modification of the asset or the adoption of a new product.

A review of all CIP changes for the TF-30 aircraft engine during 1975 and 1976 revealed that all changes were in response to a performance problem situation or a new product was developed or adopted for use on existing equipment. A good example of this situation exists with the J-57 engine. Original metal used for blades, vanes, and discs was not available; and, therefore, new materials were utilized. In similar cases where the vendor makes the decision, some relevant material shortage costs may be factored into these decisions just as costs are factored into new acquisition decisions. Long-term material shortage factors are considered only when the vendor provides a different product or the CIP program responds to a performance problem situation.

Maintainability/Reliability Analysis*: The basic foundation for aircraft engine component repair-discard decision framework has been maintainability and reliability analysis. Level of repair-discard is dependent on many factors and even though the Air Force has made progress in the inclusion of costs into the maintainability decision, long-term cost of natural resource critical material has not been included in these factors. Optimum level of discard has depended on the cost of initial hardware procurement as weighted only by current availability requirements and the user's support cost.

Several maintainability/reliability models have been developed to provide a decision framework for repair-discard analysis. Jardine developed a model to determine an optimal replacement policy which maximizes total discounted net benefits (present value) derived from operating the equipment over a long-time period.[14] Trend in cost is taken to be discrete. Smith and Babb developed a throw-away level analysis as a function of cost and failure rate.[15] Their value of availability (price and cost of failure and maintenance) corresponds

*Comprehensive review contained in Appendix C.

to a minimum owner's cost. Inclusion of long-term material shortage costs most likely would shift the minimum cost points.

The Air Force uses an optimal repair level analysis (ORLA) only where major equipment-oriented decisions are made.[16] In this analysis basic trade-offs are reliability versus maintainability versus costs. Aircraft engines are, however, considered limited life items and not subject to this type analysis. ORLA analysis does consider future cost of repair decisions but only includes a current cost for replacement units. Factors in the equation are determined during maintenance analysis.

The discussed analysis and other similar techniques are applied only during the initial provisioning process. Most often, discard level has been stipulated by the designer based on current cost factors if costs are included at all. Level of discard as opposed to repair is dependent on many factors and may be established at any point between entire systems and parts of a subsystem. Although some progress has been made in the inclusion of costs in maintainability decisions, long-term cost of shortage raw materials has not been included in those cost decisions.

Several procedures exist to provide an estimate of the magnitude and significance of long-run natural resource material shortage and social costs in repair-discard decisions. Where these costs form a significant part of the cost, several analysis techniques could be modified to provide for inclusion of these factors in the decision framework. In any such analysis, however, one must maintain a balance between input data requirements and output result accuracy.

One possibility for determining magnitude and significance of material shortage and social costs is to develop a scoreboard account for strengths and relative weaknesses of long-run cost components as a part of total component costs. In other instances an indication of ranking of these with other critical parameters may be sufficient. Sensitivity analysis could be used to discriminate between critical cost components or factors and those of lesser importance. A key factor is a parameter which strongly influences the total costs. For instance, sensitivity analysis could be used to analyze criticality of long-run costs as it relates to maintenance costs, consumable costs, spare costs (initial and receiving), facilities costs, and other support costs. Through this parametric analysis one can analyze possible outcomes under different assumptions to determine which variables or parts are crucial to the analysis. As an example, the analysis has been used effectively to evaluate changes in future benefit streams as a result of varying discount rates.

Where material shortage and social costs are significant, current techniques should be modified or new ones developed to incorporate these factors into the decision process. Accounting models generally only provide a mechanism to simply add up cost components. However, two such models, the AFLC logistics support cost model and the AFLC operations and support cost model, do contain separate costing elements which possibly could be modified to account for repair or discard of shortage materials components. Cost estimating relationship models exist which contain equations which make possible the incorporation of repairs, replacement, and condemnation policies.

Life cycle costing procedures are currently used as the mechanism to incorporate research and development and operation and maintenance costs into the decision framework.[17] During the past decade much emphasis has focused on life cycle costing as a tool to consider various components of ownership cost and to bring them into line with real needs. Therefore, any methodology to consider long-run material shortage and social costs must also consider its applicability to life cycle costing models.

Simulation models appear to be too costly and time-consuming to be of much value in decision making on repair-discard of individual or minor component parts after the initial provisioning conference.

SUMMARY

Shortages of certain critical materials which are used in the production and maintenance of aircraft and component parts are creating an extremely high cost situation for some Air Force and Department of Defense (DOD) operations. In view of recent budget constraints and an increased social responsibility awareness in Congress and the country in general, mitigation of the situation requires appropriate action by all levels of management. Inefficient management of selected items and components which depend on utilization of specific natural resources in their production is a critical factor to this shortage situation.

Efficient and equitable utilization of those products whose production is based on supply of natural resources must form the cornerstone of the resource management program. For durable materials, significant price increases should require more and more recycling of current asset materials. Thus, the repair-discard decision process is the one area in which the user can have a significant impact on the resource utilization process.

Repair-discard decisions for aircraft engines and accessory parts provide a good example of the recycling factor. A comprehensive review of the ERRC (expendability, recoverability, and repairability category) coding system and the CIP (component improvement program) system at the Oklahoma City Air Logistics Center provided a basis for

an analysis and evaluation of the applicability of economic theory (both efficiency and equitable allocation) to aircraft engine and accessories repair-discard decisions.

Although some actions to develop procedures which will identify existing and future material shortages in the DOD acquisition process have been taken, factors to account for material shortages are not used in the aircraft engine and component repair-discard decision process. Also, long-run costs imposed upon society for the utilization of natural resource related products have not been reflected in these type short-run costing decisions. In resource allocation many relevant costs lie in the future; most of these have not been included in market price, and, consequently in the repair-discard decision process.

Inclusion of these costs would aid management in identifying future cost problems to prevent disruption of operational and safety objectives and at the same time help satisfy Air Force and DOD's social responsibility in the use of these resources. One reason these costs are not implicitly included in repair-discard decisions is because they are not available to SM/IM personnel. Provision of this information possibly could save the Air Force millions of dollars by establishing repair instead of discard procedures now and aviod potentially higher cost due to material shortages at a future date. It would also help meet the Air Force's social responsibility in the use of natural resource-related materials.

FINDINGS

1. Although DOD and Air Force policies and regulations require enhancement of the quality of renewable resources and the attainment of maximum recycling of depletable resources, procedures often are not available in practice to carry out these policies and regulations.

2. Decisions by the item manager and equipment specialist are the heart of the ERRC coding process which establishes repair-discard procedures. Equipment specialists generally stick with ERRC codes as established during initial provisioning process and the contractors suggestions are usually accepted. In addition to information provided by the contractor, technicians rely mostly on their experience.

3. Documentation does not exist for ERRC code changes, but according to equipment specialists, most changes have been made in response to significant changes in procurement lead time which creates a problem or when a contractor is unable to provide a component due to non-availability of resources. Few, if any, ERRC code changes are based on economics. Maintenance policy is the major factor in ERRC code decisions with reference to repair-discard procedures.

4. A major reason long-term material shortage and social cost factors are not included in the ERRC coding system is because information is not available to equipment specialists or item managers.

5. As requirements are determined by the item manager and travel through channels, neither requirements-buy nor procurement for engine components consider economics of shortage materials in their decisions.

6. The CIP program changes are most always in response to a performance problem situation or a new product which is developed by contractor. Only those costs provided by the contractor are factored into the decision process. During the CIP program process, contractors do factor material shortage costs into the decision process only to the extent that they impact on short-term material cost in the contractor's calculation of his immediate rebuilding or new product cost. Social costs are not considered in the CIP decision process.

7. In maintenance decisions, economic analysis techniques are applied only if non-economic considerations do not dictate the decision. Only current prices of the item are included in the analysis.

8. Maintainability and reliability analysis has provided basic foundation for aircraft engine component repair-discard decisions. Although Air Force has made progress in inclusion of costs in the maintainability decision, long-term costs of natural resource critical materials have not been included.

9. Recycling of materials in engine maintenance is probably below optimum because of deficiencies in cost calculations. Several techniques could be used to incorporate these costs into the decision framework. Either simplistic or more sophisticated techniques may prove the most useful.

10. Inclusion of long-term resource costs would aid management in eliminating many future cost problems and prevent disruption of operational and safety objectives. At the same time, it would help satisfy Air Force and DOD's social responsibility in use of these resources.

11. In the aircraft engine repair-discard decision framework, the item managers and equipment specialists are the key chain in the process. A system does not exist to give them necessary information to incorporate these cost factors into the decision process.

<u>Recommendations:</u> While the staff study clearly establishes the fact that material shortage type resource costs are not included as a factor in the ERRC coding and CIP process, subsequent to the initial provisioning conference, the review of DOD and Air Force policies and procedures as well as that of economic theory clearly establishes the need for such action. One objective of the study was to determine the magnitude of the problem, that is, benefit to the Air Force of inclusion of long-term cost. However, because of a lack of documented information on ERRC code changes, that was not possible

during this study. Therefore, a comprehensive study should be undertaken to determine the magnitude of the problem situation.

Although the existence of the D041 System (recoverable consumption items requirements--mostly expensive and repairable items) and the D062 (economic order quantity expendable items requirements--items costing under $1,000) are designed to provide management data for item requirements, decisions by the item manager and equipment specialist are the important chain in the decision framework for repair-discard procedures on aircraft engines. Therefore, a procedure should be developed which will allow the item manager and equipment specialists to incorporate material shortage and social cost factors into the repair-discard decision process.

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