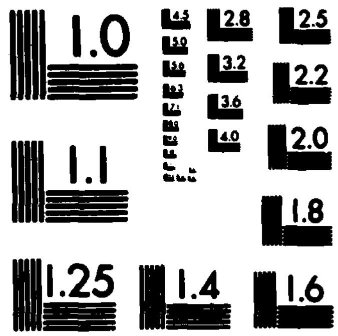
AD-A186 926 A MODEL TO DETERMINE THE ECONOMIC LIFE OF AIR FORCE 1/1
MOTOR VEHICLES(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF SYST P S ALBERT
UNCLASSIFIED SEP 87 AFIT/GTM/LSM/87S-2 F/G 13/6 NL

END



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

A MODEL TO DETERMINE THE ECONOMIC LIFE OF AIR FORCE MOTOR VEHICLES

THESIS

Paul S. Albert
Captain, USAF

AFIT/GTM/LSM/87S-2

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

(2)

AFIT/GLM/LSM/87S-2

A MODEL TO DETERMINE THE ECONOMIC LIFE OF AIR FORCE MOTOR VEHICLES

THESIS

Paul S. Albert
Captain, USAF

AFIT/GTM/LSM/87S-2

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information is contained therein. Furthermore, the views expressed in the document are those of the author and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

AFIT/GLM/LSM/87S-2

A MODEL TO DETERMINE THE ECONOMIC LIFE OF AIR FORCE MOTOR VEHICLES

THESIS

Presented to the Faculty of the School of Systems and
Logistics of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Logistics Management

Paul S. Albert, B.S.
Captain, USAF

September 1987

Acknowledgments

I am indebted to many people for their assistance in researching and writing this thesis, and for all that I've learned in the process. My thanks, first of all, to my thesis advisor, Lt Col Bruce Christensen, for his guidance, statistical expertise, and patience. Many thanks also to my faculty advisor, Maj Kent Gourdin, and Capt Carl Davis for their advice at critical steps along the way.

I am grateful also for the sponsorship of the Air Force Logistics Management Center, and especially Capt Jim VanScotter for his help in literature research, perspective, and enthusiasm.

None of this research would have been possible without the help of vehicle managers at Kelly, McClellan, Tinker, and Wright-Patterson Air Force Bases who provided the necessary VIMS data, and Maj Gladden and MSgt Cardy from Warner-Robins ALC for their knowledge and technical expertise.

Several representatives from private industry also provided valuable information and insight. I would like to especially thank Mr. Richard J. Falkner from Crown Credit Company; Mr. Robert C. Hill, Hyster Corporation; Mr. Thomas Nicely, Vice-President of National Services Incorporated; and Mr. Skip Strosser of Miami Industrial Trucks.

Table of Contents

	Page
Acknowledgments	ii
Abstract	v
I. Introduction	1
Overview	1
General Issue	1
Background	2
Problem Statement	4
Research Questions	5
Investigative Questions	5
Scope	6
Limitations	7
Definitions	10
Summary	12
II. Literature Review	14
Introduction	14
Life Cycle Cost and Vehicle Procurement	14
Life Cycle Costing for Procurement Source Selection	16
Replacement Decisions Using Life Cycle Costs	18
Economic Life Determination for Lift Trucks	25
Linear Regression to Predict Maintenance Cost	31
Summary	32
III. Methodology	33
Introduction	33
General Model Design	33
The Operations and Maintenance Data	34
SAS Regression	38
The Maintenance Cost Function	40
The Amortized Acquisition Cost Function	41
Model Construction	44
Summary	45

	Page
IV. Results and Analysis	46
Descriptive Statistics on VIMS Data	46
The Maintenance Cost Curve	47
The Amortized Acquisition Cost Curve	54
The Economic Life Model	58
Summary	60
V. Conclusions and Recommendations	61
Research Conclusions	61
Model Utility	62
Model Interpretation	66
Recommendations for Model Applications	67
Recommendations for Further Study	68
Conclusion	69
Appendix A: Data Set	71
Appendix B: Economic Life Model for Vehicles (Spreadsheet)	75
Appendix C: Economic Life Model for Vehicles (Spreadsheet Template)	77
Bibliography	79
Vita	82

<u>List of Tables</u>

Table		Page
I	4K Forklift Descriptive Statistics	46
II	Independent Variable Regression Results .	48
III	Forlifts in the Sample by Year-Group . . .	53

List of Figures

Figure		Page
1	Economic Life Model for 4K Electric Forklifts	59

Abstract

The purpose of this thesis was to develop a model to determine optimum service lives for Air Force motor vehicles. The scope was limited to testing the model's feasibility on one type of vehicle. The vehicle selected was the 4K electric forklift, National Stock Number 3930-00-053-9175.

The sample consisted of 158 vehicles out of a population of 742. Operations and maintenance data were extracted from VIMS reports from four Air Force Logistics Command installations. Age was not distributed normally; only 6 of the 158 vehicles were more than 12 years old.

Linear regression was used to develop a maintenance cost function with vehicle age as the independent variable. The function was not linear, and heteroscedasticity was present. A weighting technique was applied to correct for heteroscedasticity, and the model was transformed to account for the curvilinear relationship.

An "amortized acquisition cost" function was also obtained by linear regression. Depreciation was derived from the amount maintenance hours per operational hour increased as the vehicles aged.

The total cost curve was found by summing the amortized acquisition and the maintenance cost functions. The economic service life was found to be 14 years; however, given the distribution of the sample, the results were not

considered conclusive enough to dispute the current 15 year service life.

The overall utility of the model was demonstrated - with limitations. Data requirements would preclude its use for some types of vehicles, but it could prove useful for many others. The author recommended incorporating the model in a VIMS upgrade with the admonition that it be used only where appropriate, and in conjunction with other management indicators.

A MODEL TO DETERMINE THE ECONOMIC LIFE OF U.S. AIR FORCE MOTOR VEHICLES

I. Introduction

Overview

Motor vehicles are critical to the Air Force mission. An adequate, dependable vehicle fleet is essential to everyday effectiveness and efficiency. Insufficient numbers of operable buses, cargo vehicles, or material handling equipment can severely limit mobility capability. Lack of snow plows, sweepers, or crash trucks close flightlines. But in spite of their obvious operational importance, vehicles don't share the acquisition priorities of the weapon systems they support. The vehicle procurement program has been under funded since the late 1960s. Of the current 1987 $1.2 billion budget requirement for new vehicles, less than 26 percent ($309.4 million), has been allocated (20).

General Issue

If vehicle replacement criteria and one-time repair limits listed in TO 36A-1-1301 have any economic validity, the Air Force is spending a lot of money to maintain vehicles that should have been replaced (10). Even so, there is currently no way to determine how much total costs could be reduced if the funding situation were improved. In the early 1980s, vehicle funding doubled based on high level impact statements and justifications to substantiate the need for vehicle replacements. But with the current budget situation, it will be much harder to justify unquantified requirements in the future. HQ USAF vehicle managers anticipate no better than current, and possibly even lower levels of funding for the foreseeable future (20).

Assuming that the vehicle buy program will continue to be under funded, how can the Air Force maximize the return for its investments with the funds it does receive? And secondly, how can the need for vehicles be weighed against other under funded requirements?

Background

<u>Current Procurement Procedure</u>. The Vehicle Priority Buy Program is the Air Force's method for deciding what vehicles to purchase for any given level of funding. Specific procedures are explained in TO 00-25-249 (8). The process starts at base level two years prior to when the vehicles will be bought. For example, the 1987 priority buy program started in 1985. The local Vehicle Authorization and Utilization board (VAUB) considers all of its unfilled authorizations, and current assets which are or will be eligible for replacement, and places them into five priorities. Priority one is limited to no more than 20 percent of the total replacement cost of all eligible vehicles; the other four priorities receive approximately 20 percent each. Base level submissions are sent to the respective MAJCOMs where consolidated priority buy packages are prepared and

sent to Warner-Robins Air Logistics Center (WR-ALC/MMV). Warner-Robins prepares the Air Force priority buy package in coordination with HQ AFLC and HQ USAF vehicle managers. A review panel composed of representatives from HQ USAF, HQ AFLC, and WR-ALC uses the finalized priority buy package to decide how many and what kinds of vehicles to buy based on the money allowed by the budget estimate submission (BES). The item managers for each type of vehicle contact the MAJCOMs and tell them what vehicles they will be receiving. The commands generally use their base level submissions to decide how to distribute new vehicles, but they have the flexibility to have them shipped wherever they are needed most (16).

Problems with the Priority Buy Process. There are several weaknesses with the priority buy process. First, it's slow. It takes a minimum of two years from the time a base identifies a priority one need until a replacement vehicle is shipped. In the case of many special purpose vehicles, which are not included every year, the cycle can be much longer. It is particularly unresponsive in filling newly established mission requirements. Second, it leads to piecemeal replacement decisions which often fail to take advantage of larger volume discounts. Further, buying limited numbers of vehicles from a variety of manufacturers every year increases spare parts inventory holding costs and/or vehicle downtime. Finally, the priority buy system does not provide any way to monitarily quantify the need for vehicles.

Attempts to Improve the Priority Buy Process. There have been several attempts to improve the way the Air Force selects the types and number of vehicles to buy, and the method for justifying them in the budget process. Multiyear buying is an initiative whereby the Air Force contracts with a manufacturer to buy a type of vehicle for a number of years. The larger volume of vehicles tends to lower the procurement price and base level inventory costs for parts. Another similar concept that has been used in recent years is the family group buy. But instead of extending the contract over several years, it is extended across a range of similar vehicle types (20).

Problem Statement

Even though funding is insufficient to replace vehicles when they are eligible for salvage, it is still important that replacement criteria reflect the optimum strategy. The policy for deciding when to replace rather than repair motor vehicles directly affects how much transportation the Air Force gets for its money. It also forms the framework for many other fleet management and maintenance decisions. The vehicle life expectancies listed in TO 36A-1-1301 are used to develop replacement codes upon which the priority buy program and repair criteria are based.

Therefore, the first objective of this thesis was to develop a method for calculating replacement criteria that would minimize total costs.

But knowing when to replace vehicles to minimize total life cycle costs does not mean the money will be available to do so. Therefore, the second objective was to find a way to estimate the opportunity cost of alternatives. This information would make it possible to compare the returns on investment for different strategies, and it would also allow the benefits of vehicle procurement programs to be quantified.

Research Questions

The first question this thesis attempted to answer was if it is possible to develop a model for Air Force vehicles given the operations and maintenance data currently available. Second, if it is possible to determine optimum economic life, could the model also be used to estimate the opportunity cost of replacing vehicles sooner or later than the optimum point? Finally the most challenging question was whether the management benefits of such a model would outweigh the cost and effort of using it.

Investigative Questions

The following specific questions had to be addressed in order to answer the above research questions:

1. What is the life cycle cost approach, and could it be used to calculate optimum economical service lives?

2. What data is needed to calculate the optimum economical service life for a vehicle, and is it available?

3. Would knowing the economical service life for a vehicle be of any use in vehicle procurement decisions?

4. How can the opportunity cost of keeping vehicles more or less than their optimum service lives be quantified?

5. Would knowing the opportunity cost of alternatives be useful?

6. Could a model be built that could use currently available data to estimate the optimum economic life, and analyze the impact of different procurement costs and replacement options?

Scope

Cost patterns can vary significantly between individual vehicles; variations between different types of vehicles can be even more substantial. Ideally, a different cost model should be developed for each type. However, the focus of this thesis was the process, not the product. Therefore, only one type of vehicle was studied to determine the feasibility of the model itself before spending the time and effort to apply it to others. Another reason for limiting the experiment to one kind of vehicle was the availability of data. Data had to be collected from several bases in order to obtain an adequate sample since the information was not readily available at a central location (see data limitations below). It was determined that field support would be better if the amount of data requested was kept to a minimum. The type of vehicle selected was the 4,000 pound capacity (4K) electric forklift (Air Force vehicle management code E842). The 4K electric forklift was considered a good candidate for this research because it was believed to be less affected by limitations described below than many other vehicles.

The 4K electric forklift is represented in the VIMS system by management code E842. The prime (I/S) stock number, 3930-00-053-9175, includes 14 different "in-use" stock numbers. There are a total of 833 authorizations and 742 assets Air Force-wide. The largest user is Air Force Logistics Command. The current procurement price for these vehicles, as of April 1986, was $23,335 (10; 15).

Limitations

Data Limitations. CAFVIMS, the Consolidated Air Force Vehicle Integrated Management System, provides Warner-Robins (WR-ALC) O&M cost data, but direct maintenance, operations and overhead costs are not specified for individual vehicles - only as management code totals. The VIMS system, which provides the data to CAFVIMS, contains detailed cost data on individual vehicles, but the information was only available at base-level. WR-ALC would have had to write a special application program to retrieve the necessary information (4).

Maintenance standards need not be consistent throughout the life of a vehicle. The older a vehicle gets, the more maintenance tends to be deferred. This was expected for three reasons. First, as a vehicle gets older and accumulates mileage, its one time repair limit decreases; spending in excess of this amount requires a waiver (8). Second, as a vehicle gets close to the salvage point, quick fix repairs are substituted for more complete repairs the vehicle would need if it had to remain in service longer. For example, an automobile that needed a rebuilt engine might be able to get by with a tune up. Third, managers tend to care less about how older vehicles look, and maintenance tends to be limited to "safe and serviceable" conditions specified by the vehicle maintenance manual, AFM 77-310, Vol II (9). A two year old vehicle would receive extensive body work if it was involved in an accident; an eight year old would normally receive only the repairs necessary to get it back on the road. These limitations were considered to be less limiting for 4K forklifts because there is a shortage of assets with respect to authorizations (15), and material handling equipment was thought to be less subject to cosmetic repairs than vehicles like sedans or pickup trucks.

The use of inappropriate maintenance costs was another potential source of error. Modification work, such as spark arrestors, pintle hooks, and light bars are dubious maintenance costs since they add to the current value of the vehicle. Accidents incur additional expenses which should also not be attributed to normal life-cycle maintenance.

Model Limitations. The model was based on the regression line function of operations and maintenance data from a large sample of vehicles in various stages in their service lives. It was hoped that the regression function would be able to accurately predict the maintenance cost of the fleet given the average cumulative hours of use for the management code, but it was not expected to be able to predict maintenance costs for any individual vehicle with much reliability.

Vehicles vary considerably within each management code. Costs can sometimes differ significantly depending on design and manufacturer (5). It may not be accurate to compare older vehicles produced by one manufacturer against newer vehicles by another; i.e., there could be some degree of error in concluding newer brand X vehicles will cost the same as brand Y vehicles when they reach the same age. In fact, variation can be expected even in vehicles made by the same manufacturer if there are substantial design changes over time. The predictive power of the model would depend upon the degree these variations were present within the management code.

The accuracy of the model would also depend on a current operations and maintenance cost data base. If updating the data base is complicated or time consuming, the model would have little practical value. Ultimately, any similar model would have to be programmed to update itself automatically from base level VIMS inputs. Vehicles are procured according to their I/S (prime) stock numbers, while cost data is tracked in VIMS by management code. I/S stock numbers often include two or more management codes. Determining the optimum service life for a management code would have limited procurement value if it can't be related to a corresponding I/S stock number (6:3).

Definitions

The following definitions are provided to assist the reader:

Amortized Acquisition Cost: Represents the remaining value of a vehicle at any point in its service life (21). It was also called "replacement" or "ownership" cost by some authors. In this thesis, the amortized acquisition cost was added to the maintenance cost to obtain total cost.

CAFVIMS: "Consolidated Air Force Vehicle Integrated Management System." This is a summarization of selected VIMS data by management code. It was not used in this research because it does not routinely provide information on individual vehicles, only the aggregate operations and maintenance cost for each management code (4).

I/S Stock Number: "Interchangeable and Substitutable Master Stock Number." This is the "vehicle type" for procurement purposes. It is also known as the "prime" stock number. For the vehicle used in this thesis, the 4K electric forklift, the I/S stock number is 3930-00-053-9175. There are 13 other "in-use" stock numbers in the inventory which are considered identical to the I/S for procurement purposes.

<u>Life Cycle Cost</u>: Is the total cost of capital, operations, and maintenance for the life of an asset. The life cycle cost approach is generally used as an alternative to procurement by lowest bid (19:399).

<u>Maintenance Cost</u>: For the purposes of this thesis, maintenance cost means the direct cost of parts and labor to repair vehicles. It does not include overhead.

<u>Management Code</u>: A vehicle type code used in VIMS and CAFVIMS. Codes for all vehicles in the Air Force inventory are listed in TO 36A-1-1301.

<u>PCN 32</u>: A monthly VIMS report provided to base level transportation managers.

<u>PCN 56</u>: A quarterly VIMS report which is required only if there were errors in the quarter's PCN 32 reports. All vehicles, not just those requiring corrections, appear on the report. Some corrections are almost always necessary on all but the smallest bases because of the volume of data involved. Therefore, the report, known as the "Quarterly Correction Listing," effectively serves as a summary of the preceding three month period.

Registration Number: An identification number for a vehicle asset. The first two numbers tell the year of manufacture. The letter indicates the general type of vehicle. For example, "B" means general purpose; administrative use vehicles like sedans, pickup trucks, and buses. Forklifts all have the letter "E" in their registration number which identifies them as material handling equipment.

REMS: The "Registered Equipment Management System" is the part of the Air Force supply computer system that keeps track of motor vehicle authorizations and assets.

SAS: Stands for "Statistical Analysis System" (22). It was the computer software package used to analyze the operational and maintenance data.

VIMS: the "Vehicle Integrated Management System" is a computerized information system for Air Force motor vehicles that tracks operational and maintenance data. Information is provided for each vehicle assigned on an installation, with totals for each management code and the overall fleet. Air Force bases send VIMS magnetic tapes to Warner-Robins ALC monthly to update the CAFVIMS system.

Summary

The first chapter began with an overview of the funding problems facing vehicle managers. Then, the general issue of maximizing procurement funds, and the inability to adequately justify the budget were explained. A background of the Air Force Vehicle Priority Buy program was provided next, followed by the problem statement - to develop a method to calculate optimum economical service life, and to find a way to quantify replacement alternatives. The research questions and their corresponding investigative questions were then presented, followed by the scope and limitations for this study. Chapter one concluded by defining some of the terms used in this thesis.

II. Literature Review

Introduction

The following Literature Review attempted to answer some of the investigative questions presented in the first chapter, and indicated areas where additional research would be required. It begins by discussing the life cycle, or "total" cost approach for motor vehicle procurement. The use of the life cycle cost approach to evaluate different sources of procurement is covered first (5; 17; 18), followed by its application in this thesis - to determine optimum economic life (Armour; Parsons; Streilein). Several specific examples are then provided where private industry has used the total cost approach to determine economic life for forklifts. The chapter concludes with writings which provided insight on how to derive the amortized acquisition cost and the maintenance cost curves which are the essential components of the total cost curve used in this thesis.

Life Cycle Cost and Vehicle Procurement

Dr. Leroy Gill, Professor of Economics at the Air Force Institute of Technology, defined life cycle cost as "the total cost of a system (or item) over its full life which includes a research and development phase, an investment phase, an operating phase, and final disposal" (14:1).

His class handout "Life Cycle Cost" provided information on cost analysis and life cycle cost models, with an emphasis on the problems of weapon system procurement. The handout mentioned models for replacement decisions as a valid application of life cycle costing principles (14:87).

A July 1986 article in the Transportation Quarterly by T. H. Maze and Allen R. Cook discussed the use of life cycle costing in the transit industry. It provided some interesting insight to some of the practical problems encountered when using the life cycle cost approach for procuring vehicles. The article described how the Urban Mass Transportation Administration's (UMTA) push to consider other costs besides the initial purchase price "turned sour." In 1982, the UMTA required that all vehicle procurement be based on life cycle costs. By 1983, consideration of life cycle costs was made optional. The authors cited several reasons why the total cost approach failed. First, the UMTA did not provide adequate guidance to the local transit industries. Second, there were no standards to tell manufacturers how to submit their estimates for the various cost elements; they were left to devise their own, which prevented any meaningful comparison between them. Another problem was the lack of operations and maintenance data which made it difficult for transit agencies to establish standards or track the results (19:397-404).

Life Cycle Costing for Procurement Source Selection

One of the principle purposes of the life cycle cost approach is procurement source selection. The idea is to look beyond the initial purchase price and consider all relevant costs which are likely to differ between two competing products. Though deciding between the manufacturers of similar products is not the objective of this thesis, the following studies were included because they identified relevant costs and potential sources of error.

Capt Scott K. Claypool and Capt Jeffery B. Webb used life cycle costing in their 1982 AFIT thesis to demonstrate that significant differences could exist between manufacturers. In 1979, the Air Force bought both Chevrolet and Dodge pickup trucks for approximately the same price. The Dodge trucks were found to cost an average of $1,218 per year more to operate and maintain. Claypool and Webb's study made a strong argument for considering all costs when buying vehicles. Their finding that vehicles could vary significantly between manufacturers suggested reasons for some of the regression error observed later in this thesis (5).

In 1984, Capt Michael Harris used life cycle cost analysis to evaluate the European Vehicle Buy program. He compared the costs for U.S. and European models of 18 different types of vehicles and concluded that, with a few exceptions, it was less costly to buy European vehicles for intratheater use than to ship U.S. manufactured assets overseas. Transportation, as well as maintenance costs, proved to be as relevant as the initial procurement price (17).

In 1974, Capt Ernst Karsten and Capt Larry T. McDaniel also questioned whether the Air Force was getting the most for its money. Their AFIT masters thesis entitled "Suggested Methods for Implementation of Life Cycle Costing Techniques in the Procurement of Air Force General Purpose Commercial Vehicles," recommended procurement be based on total life cycle costs, not just the initial purchase price. They discussed two methods for using life cylce costs: the "total life cost method," and "guaranteed maintenance" (18). Under the total life cost method, the historical costs of different models of a product were to be balanced against the initial purchase price. In other words, if a vehicle of brand X's purchase price is $1,000 less than brand Y's, but brand X will cost $1,500 more for maintenance during its service life, brand Y would have the lower life cycle cost (18:22-29). The guaranteed maintenance method required the bidder to bid not only on purchase price, but on the total maintenance cost for the vehicle as well. The contract could then be enforced by requiring the manufacturer to reimburse the government for all costs above the amount included in the bid. Appendix C of their thesis contained a sample request for quotation using the guaranteed maintenance concept (18:45-46).

Replacement Decisions Using Life Cycle Costs

The use of the total cost approach to determine optimum economic service lives for vehicles and other capital assets was also well documented. W. J. Fabrycky and G. J. Thuesen devoted an entire chapter of their book, Economic Decision Analysis to minimum cost decision models (12: 329-347), and another chapter to the evaluation of replacement alternatives (12:140-171). The authors cite physical impairment and obsolescence as the two basic reasons why an asset might be considered for replacement. "Physical impairment" meant changes in the asset itself that result in declining service, higher maintenance costs, higher operations costs, or any combination thereof. "Obsolescence" was considered to be the result of changes in the environment that reduce the value of the asset over time (12:141). The "economic life" of an asset was defined as "the time interval that minimizes the asset's total equivalent annual costs or maximizes its equivalent annual net income" (12:152).

An optimum economic life was presumed to exist as long as the total cost function was made up of both increasing and decreasing cost components. Fabrycky and Thuesen presented two special cases where these conditions do not hold and the economic life was indeterminant. The first case was when neither the annual operating costs nor the future salvage value change as the asset ages. If the future salvage value approaches zero at some point in the future, and the costs to operate and maintain the asset do not increase, the economic solution would be to keep the asset as long as possible (allowing for obsolescence). The second special case was if the present and future are constant, and the operating and maintenance costs continuously increase. In this case the optimum economic age would be as short as feasibly possible (12:154). Aside from these two special cases, a minimum cost point exists mathematically. The problem is to find it.

Fabrycky and Thuesen presented a general model for finding the minimum cost life of an asset with zero salvage value and linear, increasing maintenance costs. The model for the total cost curve was given as follows:

$$TC = P/n + (n + 1)*M/2$$

where:

TC = total cost
P = the first cost in dollars
n = the age in years of the asset
M = the maintenance cost the first year and the amount maintenance increases each subsequent year

(12:344-345).

The minimum point was then described as the first derivative of the above equation:

$$n = (2P/M)^{1/2}$$

The book didn't explain how the depreciation schedule of P/n was derived. The purchase price at the end of year one would be 100% of the purchase price, and 50% of the purchase price at the end of the second year. Fabrycky and Thuesen went on to say that the computation of economic life was "primarily an end to which to strive;" it hasn't been used very often to determine when to replace individual assets. They gave three reasons for this.

First, the economic life is valid as a replacement interval only under the restrictive assumptions that all future replacements are the same as the replacement under consideration with regard to first cost, salvage value, operating expenses, and net income produced. Second, reasonably good data describing the costs of an asset are rarely available for an asset at the time of its purchase. A third reason is that the decison to retire an asset almost always results from considerations of factors in existence shortly before the time of retirement (12:345).

In the early 1970s, the Air Force contracted with the Federal Simulation Center to develop a vehicle replacement model. The model was to provide a priority listing of vehicles to replace in order to minimize overall fleet cost. In 1978, the Air Force Logistics Management Center (AFLMC) was tasked to evaluate the model prior to its implementation. The AFLMC report concluded that the model did not offer any advantages over the current priority buy process, and that there were several additional deficiencies. Implementation was not recommended (6:ii).

The model's weaknesses and incompatibilities were of particular interest since they *indicated limitations* for this thesis. The following specific problems were noted:

1. The model was incompatible with the priority buy program. As previously mentioned in chapter one, vehicles are bought not by management code, but by I/S stock number. The model made replacement decisions based on management codes, which often included several I/S stock numbers. In addition, the model considered only assigned assets. Shortages (open authorizations) were not identified for initial fill, and unsuitable substitutes (vehicles temporarily filling an open authorization for another type of vehicle) were not accounted for. Finally, the model did not allow for changes in the fleet such as depot maintenance plans to rebuild current assets, redistribution of authorizations due to mission changes, or the inventory replacement of one type of vehicle by another (6:3-4).

2. In addition to the above conceptual limitations, the model had several practical weaknesses:

a. The model did not consider the condition of individual vehicles; it recommended replacement by replacement codes within each management code (6:4). Replacement codes are primarily based on the age and mileage of a vehicle. Therefore, within each management code there is a distribution ranging from "A" (most serious need for replacement) to "U" (for new or remanufactured vehicles (16:26-27). However, replacement codes do not consider every aspect of a vehicle's condition; therefore, there can be considerable variation within a management code. Since the model did not account for the unrealiability of the replacement code system, it couldn't accurately predict the right number of vehicles to replace (6:4).

b. The report also mentioned the danger in using historic costs to decide whether or not to replace a vehicle. Costs for older vehicles can be particularly misleading. Costs may vary from base to base because of local management policies. One vehicle maintenance shop may spend a lot of money keeping even their oldest vehicles in top condition, while another may reduce the level of maintenance on older vehicles in anticipation of replacing them. If the level of maintenance is reduced as vehicles get older the model would underestimate the need for replacement. On the other hand, unnecessarily high repair costs would overestimate the need for replacement (6:5).

Dr. James Streilein did a study in 1979 for the U.S. Army's Materiel Systems Analysis Activity entitled "Economic Lives of Administrative Use Vehicles" (24). The purpose of the study was to update 1963 based vehicle maintenance manpower standards, and replacement criteria. Dr. Streilein used linear regression to develop models to predict maintenance cost based on both age and mileage.

Calculus was used to integrate the instantaneous maintenance cost function into a cumulative maintenance cost function. The average system cost function was then calculated by adding the acquisition cost to the cumulative maintenance cost function. The minimum point on the average system cost curve was concluded to be the optimum economic age, and it could be determined by solving the derivative of the average system cost equation for where the zero points occur (24:23-32).

A 1980 transit journal article by Rodney Armour discussed the use of life cycle costs to calculate the most economical time to replace transit buses (3). At the time the article was written, Mr. Armour was a transit planner for the Municipality of Metropolitan Seattle. The article was inspired by his work with Seattle's public transit system.

Mr. Armour began with the following assumptions:

1. Depreciation is a function of age, not mileage (as long as maintenance standards are reasonably high).

2. Operating costs are a function of age and are directly proportional to miles driven.

3. The discount rate is equal to the inflation rate.

He estimated depreciation by contacting a used bus brokerage firm to get resale value quotes for buses of various ages. The data was used to construct a depreciation curve. Maintenance and repair costs were related to vehicle age using linear regression. The costs of trouble calls and maintenance downtime were also determined to differ with age and were included as costs. The maintenance and repair costs, trouble calls, and downtime costs were summed to get "operating costs." Neither indirect maintenance nor fuel costs were considered as part of "operating costs." Mr. Armour explained that overhead was not included because it could be applied proportionately over all the vehicles. The article did not say why fuel costs were not included; it did say that only costs which vary with coach age were considered, so it may be that any difference in fuel economy was considered negiligible (3:43-45).

As a result of considering all life cycle costs, Mr. Armour concluded that the optimum economic age for Seattle's transit buses was 26 years. But he also noted that transit managers should include other considerations in formulating a replacement policy. Earlier replacement might be in order if operating costs were held to be more important than procurement costs, or to the degree that the quality of service was a consideration. In spite of the uncertainties involved, the average replacement could be increased or decreased to a considerable degree with minimal consequences since the average cost curve was relatively flat near the point of minimum cost (3:53-54).

Major Parsons, of the Directorate of Support Vehicle Engineering and Maintenance (Canadian Forces) did a study to determine the optimum economic life for their 1-1/4 ton, 4 x 4 trucks. Unlike Armour's study, Parsons estimated optimum economic life based on cumulative use rather than age. In order to do this, depreciation had to be expressed as a function of kilometers. Unfortunately, the method was not described in the study - only that the "amortized aquisition" cost function was calculated based on data extracted from the Department of National Defence Financial Information System" (21:1). The "instantaneous maintenance cost" function came from the Canadian Forces field maintenance management system known as LOMMIS (Land Ordinance Maintenance Management Information System). The raw data extracted from LOMMIS were the cost of parts and labor hours. Labor hours were multiplied by a 1982/83 labor rate of $31.10 (Canadian) to compute the labor cost. Though not specifically stated, the amount of the labor rate suggested that the cost of indirect labor was included (Parson: 4-5). The average total cost function was calculated by summing the instantaneous maintenance and the amortized acquisition cost functions (21:1-5).

Economic Life Determination for Lift Trucks

Trade journals like _Material Handling Engineering_ and _Plant Engineering_ provided valuable information even though they typically lacked the rigorous methodology, analysis and references common to studies in more research oriented publications. The following literature was, however, extremely valuable in that it provided a view of what the experts in private industry recommended as prudent economic replacement policies for lift trucks. ("Lift truck" appeared to be the preferred term for forklifts in private industry.)

Arthur A. Andrew has had two articles published in the current decade in Material Handling Engineering regarding the economic replacement of lift trucks. As of March 1987, Mr. Andrew was the president of National Services, Inc., a management consulting company specializing in economic motor vehicle fleet design and maintenance (1:92). In July 1980, his article entitled "When to Replace Your Lift Trucks - and How to Make the Program Pay Off!" claimed that over half of the approximately 1 million lift trucks operating in the United States were past their economic lives, and that this was resulting in a loss of about $500,000 in profits per year. He claimed that the average economic life for an internal combustion lift truck was 11,000 engine hours, or about five years. The article went on to explain how this 11,000 hour figure was determined by summing the maintenance cost curve and the ownership cost curve to obtain a total cost curve. The ownership cost curve was defined as the "difference between the delivered cost of the truck and its residual value when traded in," but the article didn't say how trade-in values were determined. The maintenance cost curve appeared more or less linear to approximately 12,000 hours, but the slope increased after this point. The minimum point on the total cost curve was visually estimated from the graph to be 11,000 hours (1:46-47). Mr. Andrew recommended a four step process to minimize lift truck costs. The first objective was to replace the trucks at their lowest total cost. This did not mean replacing all trucks at the average economic age; it meant tracking each individual vehicle's maintenance costs and trade-in value. The second step was to reduce the overall cost of inventory and maintenance by gradually standardizing the fleet. And the final objective was to convert the fleet to the most economical fuel system for the job at hand. Propane, gasoline, diesel, and electric power all have their economic and practical advantages and disadvantages. Which was best depended on the operating environment (1:49-50).

A more recent article by Arthur Andrew appeared in the March 1987 issue of Material Handling Engineering under the title "The Proactive Approach to Reducing Lift Truck Maintenance Costs" (2). The author used essentially the same approach for determining economic life as he did seven years earlier, but he also provided additional information and recommendations. He said that a truck has three life cycles: an accounting life cycle, a useful life cycle, and an economic life cycle. The accounting life cycle was defined as "an arbitrary value set by financial people" which plays no part in vehicle economics. The useful life cycle represented the length of time a vehicle is kept in service, upon which over 50% of American corporations base their decisons and procedures. The economic life cycle, on the other hand, ends at the point that the truck attains its lowest total cost; beyond this point, total costs continue to increase (2:89). The article also described some factors which can cause economic life cycles to vary. The author said that the projected maintenance cost of new trucks varies 38% due to make (including qualitative differences in manufacturers), model, and the operating environment. Another important difference was the fuel system (gas, diesel, propane, or electric). The economic hour life was said to vary between 6,500 and 19,000 hours depending on the fuel system (2:90). In addition to replacing lift trucks at the end of their economic lives, another part of the "proactive approach" involved using the available cost information to reduce operating costs directly. To do this Mr. Andrew suggested keeping track of cost per hour rates for individual trucks, and using the low cost trucks in high utilization areas (2:91).

EBS Incorporated, a battery manufacturer which makes lift truck batteries under the trade name "Exide," published a brochure in 1977 entitled "Economic Analysis of Industrial Lift Trucks" (11). The brochure was the result of a survey of both internal combustion and electric powered lift truck users. The survey involved five of the nations largest corporations, five medium-sized companies, and five small companies. The pamphlet was designed to help customers decide what kind of power source woud be most economical for any particular application by estimating the total cost of the alternatives. It also gave guidelines for estimating life expectancy. Life expectancies were divided into three categories based on use. Long life trucks were characterized by having less than 1,500 hours of operation per year, lighter than average loads and runs less than 100 feet, good floors, no extreme environmental conditions, an active preventative maintenance program, and trained drivers. Medium life expectancy applied to lift trucks which averaged 1,500 to 2,500 engine hours per year and similar operating conditions. Short life vehicles were described as having more than 2,500 operating hours per year, poor operating conditions, bad maintenance, and untrained drivers. Life expectancies between the extremes for short life and long life cycle vehicles ranged from 5 to 15 years. Each category also allowed for internal variations based on the characteristics mentioned above. For example, the life expectancies for the long life category could be as short as 10 years or as long as 15 depending on how well an operation fit the description for the caegory (11).

An August 1984 Plant Engineering article by W. H. Weiss also recommended using the total cost approach to determine the economic life of lift trucks. Weiss claimed that approximately 53% of America's lift trucks were "obsolete," and that nearly a billion dollars was being wasted annually to operate and maintain worn-out vehicles. Based on a standard of 2,000 engine hours per year, the economic life was said to be 5 years for an internal combustion truck, and 6 years for battery powered forklifts. Cumulative maintenance costs were estimated to be almost 90% of the purchase price by the time a forklift attained its economic age, and they generally increased more rapidly after that point. Like Andrews (2), Weiss recommended using the difference between the trade-in, or residual value, and the cost of a new vehicle to determine the ownership cost curve. The author concluded the article by citing some of the indirect cost savings that could result from adopting an economic life replacement policy. Weiss stated that labor savings should be realized since fewer mechanics would be required because the severity and frequency of breakdowns would be reduced by having newer equipment. Lower maintenance requirements would result in higher in-commission rates for assigned vehicles which would allow management to reduce the size of the fleet. Finally, inventory costs would decrease because fewer spare parts are required to maintain a fleet that is less prone to maintenance problems (25).

Paul C. Whyte, a representative of Clark Rental System, Inc., provided an analysis of industrial forklift use which was very similar to those of Andrew and Weiss. An industrial survey was performed for Clark Rental System in 1978 which found that 51% of the lift trucks were being used beyond five years. The mean age for internal combustion trucks was 9.05 years. On the average, they were operated 22,760 hours before they were retired. Electric powered lift trucks were kept in service 26,260 hours before they were replaced. Like both Andrew and Weiss, Whyte determined that the economic service life of an internal combustion truck was 5 years (10,000-12,000 hours), and 6 years (12,000-15,000 hours) for an electric truck. The age estimates were again based on a standard of 2,000 hours per year (26).

Linear Regression to Predict Maintenance Cost

Capt John Golden used linear regression in his AFIT masters thesis to predict maintenance costs for general purpose vehicles with age and cumulative mileage as the independent variables. He obtained data from monthly PCN 32 VIMS reports from two Air Force bases. The intent was to develop a model for allocating general purpose vehicles to bases in a way that would minimize overall fleet costs. The results were not conclusive, but the regression model itself did prove effective for predicting maintenance costs. Capt Golden's study also provided a good summary and references for the Air Force priority buy program, and the vehicle procurement process (16). His use of linear regression to predict maintenance cost can be added to the work of other authors already cited who also used this technique (3; 5; 17; 18; 21; 24).

Summary

Several studies relevant to using the total cost approach to estimate the economic life of motor vehicles have been reviewed in this chapter. The chapter began with articles that dealt with the use of the "life cycle" or "total" cost approach in general. Next, research using the total cost approach to evaluate sources of procurement were discussed, followed by several papers advocating its use to determine optimum economic life, and to establish minimum cost replacement policies. Then, several trade journal articles were presented which recommended the total cost approach specifically for minimizing lift truck fleet costs. Many of these articles discussed how to determine one of the total cost curve's component functions, the amortized acquisition cost curve. Several authors argued against using accounting methods of depreciation to estimate the value of vehicles as they aged and accumlated engine hours; the determination of current market value was the preferred method. The use of linear regression to determine the maintenance cost function was also well documented in the literature.

III. Methodology

Introduction

The following is an overview of the methodology used to answer the research questions presented in chapter one. The general model design is described first, followed by the procedures used to determine the maintenance and amortized acquisition cost functions which comprise the total cost function. The chapter concludes by describing how the total cost function was used to find the optimum economic life for 4K electric forklifts.

General Model Design

The model development and procedures described below were inspired by previous research in estimating optimum vehicle age. A study by Armour used to develop a replacement policy for Seattle's transit buses, and Parsons' research on 1-1/4 ton trucks for Canadian forces were discussed in more detail in the previous chapter (3; 21). The same approach was advocated in trade journal articles by Arthur A. Andrew and W. H. Weiss, who represent management consultants that specialize in economic motor vehicle and equipment fleet design and maintenance (1; 2; 25). The basic problem was to find the minimum point on a total cost curve, which represented the optimum economic life for the vehicle. The total curve was derived by summing a maintenance cost function and an amortized acquisition cost function. Since maintenance costs increased and the amortized acquisition costs decreased as the vehicles aged, a minimum point on the typically U-shaped total cost curve had to exist mathematically. The authors differed on the more subjective problem of determining the component costs (3:42; 21:20; 24:28-30).

The Operations and Maintenance Data

The source of the operations and maintenance data for the 4K electric forklifts was the Air Force's Vehicle Integrated Management System (VIMS). As previously explained in the first chapter, there is a centralized component of the system located at Warner-Robins ALC known as CAFVIMS, but it could not readily provide data on individual vehicles this study required. The most detailed report base-level VIMS produces is a standard monthly printout known as the PCN 32. A quarterly report, the PCN 56, is required only if there are corrections to data in the monthly reports. But since some corrections are almost always required, the PCN 56 is essentially a standard periodic report for all but the smallest Air Force bases. The quarterly PCN 56 is not as detailed as the PCN 32 report, but it was determined to be sufficient for the purposes of this research. Another reason the PCN 56 was chosen over the PCN 32 was that it was less troublesome for base personnel to provide since at least six months of data on each vehicle was considered necessary to obtain a reasonable estimate of its use and maintenance. Two PCN 56s could provide the same range of information as six PCN 36 reports. Using a single three month report would have disqualified vehicles that did not have any maintenance costs charged for the period. In addition, shorter periods risked showing a disproportionate share of maintenance costs since charges are made to VIMS after maintenance is completed. It is always possible for work performed in one period to be charged to the next. This possibility, and the impact of the error, is reduced by looking at maintenance over a longer period of time.

The following data elements from the PCN 56 report were used in this study:

1. vehicle registration number
2. cumulative hours of use for each vehicle
3. hours of use during the quarter
4. direct maintenance labor hours
5. direct maintenance labor and maintenance costs
6. contract and other government agency repair costs

Kelly AFB, McClellan AFB, Tinker AFB, and Wright-Patterson AFB provided copies of pages from their quarterly VIMS reports for 4K electric forklifts covering the six month period from October 1986 through March 1987. Kelly AFB had 52, McClellan 35, Tinker 87, and Wright-Patterson 27 assets, for a total of 201 vehicles; but many were eliminated from the sample according to the criteria described below. Vehicles were deleted from the sample if:

1. More than 960 hours were recorded for the six month period. To accumulate more hours than this would mean constant operation for eight hours a day, five days a week. Exceeding this number of hours would not be unusual for a manufacturing firm operating two or three shifts per day, but it is highly unlikely for a peacetime air logistics center operation. Therefore, utilization above 960 hours was considered sufficient indication of a reporting error to eliminate the vehicle from consideration.

2. The cumulative hour total for the Oct-Dec 86 report was larger than the total for the Jan-Mar 87 report. This would obviously indicate a reporting error.

3. No maintenance was charged for the entire six month period. This would mean either that not even scheduled maintenance was performed, or that the report was in error. Either way, the data would be useless since the maintenance cost per hour would not exist.

4. The Jan-Mar 87 report recorded neither use nor maintenance. If accurate, this would mean that the vehicle was not used, or maintained for three months, which is possible but unlikely. However, it is also possible that the vehicle was still in maintenance at the end of the reporting period; therefore, the maintenance cost for the current period would be charged against the next period. This would grossly underestimate the cost of maintenance for the period in question.

5. The cost of maintenance labor was zero. Since the installation of parts requires labor, this would indicate an error in the report.

6. There were less than 60 hours of use during the six month period covered by the two PCN 56 reports. Lower utilization than this was considered insufficient to obtain an adequate estimation of the hourly maintenance cost for these vehicles. Scheduled maintenance alone would be enough to raise costs to unwarranted proportions compared to vehicles with normal utilization.

Of the original sample of 201 forklifts, 43 were eliminated for one or more of the above reasons leaving a sample size of 158 for further analysis.

Compiling the Data. After screening, the VIMS data was compiled in order to derive the data elements required to determine the maintenance cost function. The following procedures applied:

1. Vehicle Age: determined by subtracting the year of the vehicle indicated in the registration number from 87 (the current year).

2. Cumulative Hours: calculated by averaging the cumulative hours from the two PCN 56 reports.

3. Current Hours: found by summing the current hours for each quarter.

4. Maintenance Cost per Hour: obtained by summing the cost of parts, direct maintenance hours, and contract maintenance costs (if any); and dividing the result by current hours.

5. Reliability Index: the maintenance labor hours divided by the hours of operational use, multiplied by 100. The result provided the number of maintenance hours required per 100 hours of use.

SAS Regression

A SAS data file was then created using data for the 158 vehicles which passed the screening process. Each was listed by registration number followed by entries for each of the four numerical variables described above. A copy of the data was included in Appendix A.

SAS regression programs were prepared to use the data to develop the two component cost functions which were used to derive the total cost curve. The same general procedures were used for both the amortized acquisition, and the maintenance cost functions. Only the dependent variables were different. For the amortized acquisition cost function, the dependent variable was the number of maintenance hours per 100 hours of use. The dependent variable for the maintenance cost function was the cost of maintenance per hour of operation.

The first step was to determine whether the independent variable(s) should be age, cumulative engine hours, or both. SAS programs were run on all three, and the best one was selected for further analysis. Plots of the data were examined to check for linearity and heteroscedasticity (nonconstant variance). Parsons found both to be a problem in his cargo truck study for Canadian Forces (21).

Heteroscedasticity was tested by dividing the data in half, performing a regression on each half, and calculating an F-value by dividing the largest mean squared error (MSE) by the smallest MSE. The results were evaluated with the aid of an F-probability distribution table. If heteroscedasticity was determined to be present, the model was revised by weighting the independent variable. The weighting procedure was accomplished by writing a weight statement to the SAS regression program. The weight statement minimizes the residual sum of squares according to the formula:

$$\sum w(y-\hat{y})^2 \text{ (22:456).}$$

Linearity was tested through the use of stepwise regression. New independent variables were created by raising years to the second and third powers. If maintenance costs and/or the reliability index increased at an increasing rate, years-cubed and/or years-squared would provide a significant contribution to the model. Three SAS stepwise procedures were used: stepwise-stepwise, stepwise-backward, and stepwise-maxr. The stepwise-stepwise procedure starts with the most statistically significant independent variable, and then adds others until no other variables can be added which meet the specified significance level. (The default setting for a significance level of .15 was used.) With this method, variables may also be deleted from the model at subsequent steps if the addition of new variables decreases the utility of existing variables (22:764-765).

The stepwise-backward procedure starts with all the variables in the equation and deletes the most insignificant variables one by one until all variables in the equation meet the specified significance level. The SAS significance level default value of .10 was used (22:764).

The stepwise-maxr option does not select a single "best" model. Instead of employing a specified significance level, it identifies the models with the highest coefficients of determination (r-squared) for the number of variables in the equation. This is because r-squared values alone can not be used to compare models with different numbers of variables in them. Adding more variables typically increases the r-squared of a model, but much of the improvement might be the result of redundant information (22:765).

The Maintenance Cost Function

The maintenance cost curve was determined using the SAS procedures described above. The y-intercept of the regression line provided an estimate of the initial cost per hour for a new machine. The other parameter(s) provided the rate that maintenance costs increase as the forklifts deteriorate. The maintenance cost curve estimated the cost per hour of a forklift at any stage in its life. Average annual maintenance costs were found by multiplying the regression function by the average annual use. Annual use for the forklifts was calculated by finding the mean hours of use for the six month period for the vehicles in the sample, and multiplying the result by 2. Since vehicles with less than 60 hours of cumulative use during the six month period were deleted for maintenance cost purposes, they were added back for this calculation to prevent overestimating the mean utilization.

The Amortized Acquisition Cost Function

Amortized Acquisition Cost Function Defined. The amortized acquisition cost function is a term Parsons used to describe the concave curve that resulted by depreciating the initial purchase price of a vehicle over time (21). It has also been described by other authors as the "replacement cost curve" (3), or the "ownership cost curve" (1; 25). Whatever it's called, the purpose of this function is to represent the current value of the average vehicle based on either age or engine hours. The concept of "current value" is essentially subjective; therefore, methods for quantifying it differ. Some of the methods found in the literature are described below.

Depreciation. One common method used by private industry to determine the current value of an asset is to reduce its value according to some depreciation schedule. The various methods of depreciation were described in the previous chapter; none of them were considered appropriate for this thesis since all of them require "life expectancy" to be known beforehand. Since the purpose of the proposed model is to determine what life expectancies should be, another method to determine current value was necessary.

Current Market Value. The current market value is the resale value of an asset. This method was used by Armour to determine the value of Seattle's metrobuses of any given age. He obtained it by contacting a used bus brokerage firm (3:43). Aside from the initial purchase price, the "value" of an asset is considered to be what a buyer would pay for it, which may be considerably less than what it is worth to its owner. For example, the resale value of a brand new automobile is immediately much less than its initial purchase price the same day it's purchased. The decline in resale value is due mostly to the fact that the car can never be "brand new" to anyone else again. Yet the car's value to the owner is, at least theoretically, what he paid for it. The Air Force does not generally buy used vehicles, nor does it sell them before they are sent to the salvage yard. It is, therefore, questionable whether the "value" of an asset to the Air Force can be equated to the value for which it could be sold.

Reduced Reliability Depreciation. The method used to determine current value in this study was based on the theory that the value of a mechanical asset declines with age and/or use due to such factors as technological obsolescence, reduced reliability or performance, and subjective factors like physical appearance. In the case of the 4K electric forklift, the researcher decided to focus on reliability and to disregard technological obsolescence and physical appearance. The measure for reliability selected was the number of maintenance hours required per 100 hours of use. This "reliability index" was derived from data already available in the VIMS PCN 56 reports. The higher the reliability index, the more likely that a vehicle would be either unavailable for use, or that it will fail during use. Depreciation in the original purchase price could then be estimated by determining the amount the maintenance hour ratio increased beyond what it was when the vehicles were new. The resulting inverse function was defined as the "amortized acquisition" cost curve, a term borrowed from Armour (3).

The Amortized Acquisition Cost Function. As described above, the initial value of the asset, the initial maintenance hour ratio, and the rate the maintenance hours increase were needed to estimate the amortized acquisition cost function. The amount of money required to purchase a new forklift was provided by Warner-Robins Air Logistics Center (WR-ALC/MMVV). The current cost to the Air Force for a new 4K electric forklift was $23,335 as of September 1986 (15). The initial maintenance hour ratio and the rate of maintenance hour ratio increase were determined by linear regression using SAS. The general formula for the amortized acquisition cost function was:

Current Value = P * B/Rh

where: P = current purchase price
B = basic maintenance labor ratio (y-intercept)
Rh = the maintenance hour ratio regression line

Since "B" is the y-intercept of the regression line, the value of the vehicles at year 0 will always be the same as the purchase price since B/B = 1. The current value decreases from this point according to the rate the maintenance hours increase as indicated by the other components of the regression line function. The actual determination of the regression line is described in the next chapter.

Model Construction

The final model was constructed with the aid of a personal computer and a spreadsheet software program. The formulas for the amortized acquisition and the maintenance cost functions were entered into the spreadsheet. The spreadsheet was then used to sum the two functions to illustrate the total cost curve represented by the following equation:

$$\text{Total Cost} = P * B/Rh + H * Rc$$

where: P = the current purchase price
B = the initial maintenance hour ratio
Rh = maintenance hour ratio regression line
H = average annual hours of operation
Rc = the maintenance cost regression line

The minimum point on the total cost curve represented the optimum economic age. It was estimated graphically by inspection from the spreadsheet, and could also be determined directly by taking the first derivative of the above equation:

$$\text{Optimum economic life} = \frac{Pb\ (Rh)dx}{(Rh)^2} + (H * Rc)dx$$

Summary

This chapter described the methodology for answering the research questions not covered by the Literature Review. First, the overall model design was explained. Then the methodology was described for obtaining, screening, and using VIMS data to develop the maintenance cost function and the amortized acquisition cost function. The chapter concluded with the procedures for determining the total cost curve and the optimum economic life for the 4K electric forklift. The next chapter presents and discusses the results of the data analysis using this economic life model.

IV. Results and Analysis

Descriptive Statistics on VIMS Data

The sample consisted of 158 forklift trucks from four different Air Force Logistics Command (AFLC) bases: Kelly AFB, McClellan AFB, Tinker AFB, and Wright-Patterson AFB. The sample size was initially 201, but 43 observations were deleted according to the data screening procedures described in the previous chapter. This left a sample size of 158 vehicles (except for the data for current hours to which 6 low utilization vehicles were replaced for a total of 164 observations). Table I statistics were provided by SAS:

TABLE I

4K Forklift Descriptive Statistics

Description	Mean	Std. Deviation	Low	High
Age (years)	8.3	3.0	3	17
Cumulative Engine Hours	4,287	2,310	399	11,873
Current Use (for 6 months)	328.512	187.6	30	773
Maint. Cost per Hour of Use ($)	1.926	3.233	0.07	25.89
Dir. Maint. Hrs per 100 hrs use	5.26	5.24	0.5	37.8

The Air Force "Vehicle Management Index File" listed the life expectancy for 4K electric forklifts as 15 years or 18,000 engine hours (10). The newest vehicles were 1984 models, but only two 17 year-old forklifts in the sample exceeded the 15 year life expectancy; one was 15 years old, another was 14 years old, and there were two 13 year old 1974 model machines. In sum, only 7 vehicles in the sample were more than 12 years old.

None of the forklifts were beyond their 18,000 engine-hour life expectancy. The most heavily used vehicle, a 1975 model, had accumulated 11,873 hours, only 66% of its expected engine-hour life. Only three other vehicles had logged more than 9,000 hours (half the expected life). At the present mean annual utilization of 657 hours a year, the average 15 year old forklift would be expected to accumulate 9,855 hours, far short of the 18,000 hours listed in TO 36A-1-1301 (10).

The Maintenance Cost Curve

The first step in developing the economic life model was to determine the maintenance cost curve. As explained in the previous chapter, the methodology for estimating this function was linear regression. Three SAS programs were written using first cumulative hours, then age, and finally both age and hours as the independent variables; the maintenance cost per operating hour was the dependent variable. Each model was evaluated based on its F-value, the adjusted r-squared, and the alpha levels indicated by t-tests on the parameters for the independent variables. The results are summarized in Table II below.

TABLE II

Independent Variable Regression Results

Ind. Variables	F-Value	Adj r^2	t-Test	Alpha Level
Cum. Hours	2.0	.01	1.42	.158
Years	12.9	.07	3.60	.0004
Years/Hours	6.5	.06	3.30/-.34	.001/-.73

The results showed cumulative hours to be a weak indicator of hourly maintenance cost. Vehicle age in years appeared to be preferable as the single independent variable.

Model Assumptions. A plot of the data with years on the x-axis, and maintenance cost per hour on the y-axis suggested that some of the model assumptions for linear regression might have been violated. The variance in hourly maintenance cost appeared to be increasing, and the possibility of a curvilinear relationship was suggested by the high maintenance costs for some of the older vehicles. However, plots of the studentized residuals against both the predicted value for the cost per hour, and the actual age in years described a distinct megaphone shape. This suggested that the model assumption of constant variance had been violated.

In order to determine whether heteroscedasticity (nonconstant variance) was present, the data were sorted in order of increasing age and split into two data sets of 79 observations each. Regression was then performed on each data set and the mean squared errors (MSE) were noted. The MSE for the newest half of the data set was 13,953.97; the older half was 173,856.37. The larger MSE was divided by the smaller to obtain an F-value of 12.46. An F distribution table was used to obtain a critical value of 2.25 for a 99.9% confidence level with 60 upper and 60 lower degrees of freedom. Since the observed F-value was more than five times the critical level required to reject the null hypothesis that the variances were equal, heteroscedasticity was concluded.

As previously explained, hourly maintenance cost appeared to be increasing at an increasing rate, but it was difficult to determine from the SAS plot how much of the higher costs for some of the older vehicles could be explained by increasing variance alone. Parsons, in his study on cargo vehicles, determined that a curvilinear relationship existed between cumulative miles and maintenance cost (21). Two articles by Arthur Andrew discussed in the Literature Review also described the maintenance cost function for lift trucks as an increasing curve (1; 2). Therefore, it was decided to explore the possibility of a curvilinear model before attempting to correct for heteroscedasticity.

Another SAS procedure was written using years-cubed, years-squared, and years as independent variables. The adjusted r-squared improved from .07 to .16, but the F-value decreased from 12.9 to 10.6. The significance levels for the independent variable parameters were .06 for years-cubed, .18 for years-squared, and .28 for years.

Stepwise regression was then used to see what combination of the above variables would provide the best model. Three SAS stepwise options were used: stepwise-stepwise, stepwise-backward, and stepwise-maxr. The stepwise-stepwise procedure starts with the most statistically significant independent variable and then adds others until no other variables can be added which meet the specified significance level. (The default setting for a significance level of .15 was used.) With this method, variables may also be deleted from the model at subsequent steps if the addition of new variables decreases old variable utility. The stepwise option selected the years-cubed/squared model as the best, i.e., straight years failed to meet the .15 significance level.

The stepwise-backward procedure starts with all the variables in the equation and deletes the most insignificant variables one by one until all variables in the equation meet the specified significance level. The SAS significance level default value of .10 was used. The backward option also selected the years-cubed/squared model.

The stepwise-maxr selects the models with the highest coefficients of determination (r-squared) for the number of variables in the equation. Besides the original three dependent variable model, the procedure selected the years-cubed/squared model as the highest r-squared two-variable model, and years cubed as the best one variable model. Significance levels for the dependent variable parameters in the years-cubed/squared model were .002 for yeas-cubed, and .064 for years-squared. The years-cubed model had a dependent variable significance level of .0001.

F tests for determining the difference in variances (described above) were performed on both the years-cubed, and the years-cubed/squared models to see if the exponential modifications would reduce the heteroscedasticity. Only slight improvements were noted. The F-value was reduced from 12.46 to 12.10 by both the years-cubed/squared and the years-cubed models. Heteroscedasticity was still evident.

A SAS weight statement against years was used to correct for heteroscedasticity and the three stepwise options were rerun to ensure that corrections for non-constant variance would not change the optimum solution. The stepwise and backward options still selected the years-cubed/squared and years-cubed models as viable alternatives. The r-squared value for the years-cubed model increased from .14 to .18, the significance level for the slope parameter stayed at .0001, but the y-intercept parameter's significance level rose from .08 to .58. The r-squared value for the years-squared model increased from .17 to .20. The significance level for years-cubed stayed at .002, and years-squared improved from .06 to .05. The y-intercepts' significance level went from .01 to .03. The weighted years-cubed/squared model appeared to be statistically superior based on the weakness of the weighted years-cubed model's y-intercept, and the fact that a .05 alpha level for the two variable model would still allow for a 95% confidence level. The formula for the years-cubed/squared model is mathematically described as:

$$y = \$2.1674 + \$0.00508x^3 - \$0.05365x^2$$

The model was then compared to the actual data to verify its feasibility. The negative x-squared parameter (years-squared) would cause the maintenance cost to decrease from an initial $2.17 per operating hour all the way through the first seven years. A decrease in maintenance costs was not described by any of the studies covered in the Literature Review. However, the data did in fact indicate a slight negative trend in maintenance costs from the 3 year point through the 7 year point, and a significant increase thereafter as Table III below shows. The scarcity of data for 13, 14, 15, and 17 year old vehicles might account for the variances in the mean maintenance costs for these years. However, the increasing maintenance cost trend beyond the 7 year point is well established by the data for 9, 10, and 12 year old vehicles. The lower maintenance costs for years 5 and 7 might be explained by differences in the vehicles themselves. Each year group would have been purchased under a different contract, and are therefore likely to have been made according to different specifications, and most likely, by different manufacturers. As Claypool and Webb found in their study on pickup trucks, difference in manufacturers alone can account for substantial differences in operations and maintenance costs (5).

TABLE III

Forklifts in the Sample by Year-Group

Year	Mean Maintenance Cost	Number of Vehicles
3	\$1.27/hr	24
5	\$0.95/hr	10
7	\$0.92/hr	21
8	\$2.41/hr	2
9	\$1.86/hr	43
10	\$2.15/hr	38
12	\$2.92/hr	14
13	\$2.45/hr	2
14	\$1.68/hr	1
15	\$0.93/hr	1
17	\$14.33/hr	2

Based on the fit of the data to the hourly maintenance cost means for the year groups with more than 10 vehicles, the years-cubed/squared model was determined to be superior to the years-cubed model alone. The maintenance cost curve was therefore defined as:

$$Y = (S + R_1n^3 + R_2n^2) * H$$

where:

Y = the average maintenance cost per year
n = vehicle age in years
S = starting maintenance cost (y-intercept) = \$2.1674/hour
R_1 = the parameter for years-cubed = \$0.0051/hour
R_2 = the parameter for years-squared = \$-.0536/hour
H = average operating hours per year = 657.02/year

The Amortized Acquisition Cost Curve

As discussed at greater length in the previous chapter, none of the methods used by other authors to determine the current value of vehicles found in the literature were considered appropriate for this research. Depreciation schedules were not considered valid for determining real value by any of the studies described in the Literature Review, and one author specifically warned against the use of this financial information (2). The method of choice was to obtain estimates of current market value to determine how much an asset was worth at any point past the time when it was initially purchased. But the current value was not considered appropriate for Air Force use either. There are two basic reasons for this. First, the Air Force does not maintain data on the market value of vehicles since current policy is not to replace them until they are sent to salvage. Second, market value to the public is often much less than what an asset is worth to the Air Force. Military specifications for special operational and safety requirements, like nuclear surity, can result in significantly higher procurement costs which add nothing to the resale value of the vehicle; in fact, it can even reduce it if the modifications are seen as a hindrance to operational use (23). The same situation can exist in private industry if lift trucks are purchased as part of a specialized material handling system. Regardless, the rift between the concept of value to the owner and potential buyers can be substantial.

The Reliability Index. For the purposes of this research, the focus of the concept of value was on the user, the U.S. Air Force. Depreciation in value from the initial purchase price was related to the rate the level of service declines as the vehicles age. A new variable, the "reliability index," was defined as the number of maintenance hours required per 100 hours of operation. As summarized in Table I on the first page of this chapter, the reliability index ranged from 0.5 to 37.8 hours of maintenance per hundred hours of operation with a mean of 5.3, and a standard deviation of 5.2.

Selecting the Independent Variables. Three SAS runs were prepared to decide whether depreciation could best be represented by years, hours, or a combination of the two, and which had the most potential for a reliable model. Once again, years was determined to be the best choice. The r-squared value for the cumulative hour model was only .006, and the slope parameter had a significance level of .86.

The combination model had an r-squared of .06, but the significance level for the cumulative hour parameter was only .13.

Model Assumptions. A curvilinear relationship appeared likely for the maintenance hour ratio model since it was roughly similar to the maintenance cost model. Therefore, the same SAS stepwise procedure was used to select the best model. This time, both the stepwise, and backward options recommended the years-cubed model. The maxr procedure picked the years-cubed model as the best one variable model, and years-cubed/squared as the best two variable model. The years-cubed model had an r-squared value of .10, and a significance level of .0001 for the slope. Adding years-squared to the model raised r-squared to .11, but the significance level for years-squared was .23. The years-cubed model appeared to be far superior.

The years-cubed model was then tested for heteroscedasticity using the same F test for differences in variances used for the maintenance cost model. The mean squared error (MSE) for the first half of the data was 8.27, with a value of 40.81 for the second half. Dividing the second MSE by the first gave an F-value of 4.93 which was enough to conclude that heteroscedasticity was present with a confidence level of at least 99.9%.

In order to correct for the increasing variance, SAS was again used to weight the independent variable. The SAS stepwise regression was then reaccomplished with the data weighted. The years-cubed model was once again selected by the stepwise and backward options, as it had the highest r-squared value of any of the one variable models. The r-squared value was .14, and years-cubed had a significance level of .0001. The years-cubed/squared models r-squared improved to .15, but the years-squared parameter had a significance level of .22. Therefore, the years-cubed model was selected as the most accurate estimation of reliability index function. The reliability index function was defined as:

$$y = 3.1124 + .0025x^3$$

The reliability index function was then used to derive the amortized acquisition function. The purpose of the amortized acquisition cost function was to estimate the current value of the vehicles to the Air Force. It was derived by using the independent variable parameters and the y-intercept from the reliability index function, and the initial purchase price to be depreciated. The relationship was given by the following equation:

Amortized Acquisition Cost = P * [B/(B + An)]

where: P = the procurement price + $23,335
B = the y-intercept of the regression line = 3.1124
A = the slope of the regression line = 0.0025
n = the age in years

The Economic Life Model

The total cost (TC) function was found by summing the amortized acquisition function and the maintenance cost function:

$$TC = P * [B/(B + An^3)] + H * (R_1 n^3 + R_2 n^2 + S)$$

where:

P = the procurement price = $23,335
B = the Reliability Index (RI) y-intercept) = 3.1124/hr
A = the RI line parameter for years-cubed = 0.0025/hr
S = starting maintenance cost (y-intercept) = $2.1674/hr
R_1 = the parameter for years-cubed = $0.0051/hr
R_2 = the parameter for years-squared = $-.0536/hr
n^2 = the age in years = $ 657,02/yr

The amortized acquisition, maintenance, and total cost functions were put into a microcomputer spreadsheet program which facilitated the calculations required to display the cost curves and to analyze the results of manipulating the variables. The spreadsheet is included as Appendix B. Appendix C is a template for the spreadsheet which shows the underlying formulas. The software used was "VIP Professional," produced by VIP Technologies Corporation for use with the Amiga computer. A graph of the results are shown in Figure 1.

Using the above formula, the optimum economic age for the 4K electric forklift was determined to be 14 years. However, the accuracy of this estimate was considered questionable since only six of the vehicles in the sample were more than 12 years old. It would almost be extrapolation to conclude that any life expectancy beyond 12

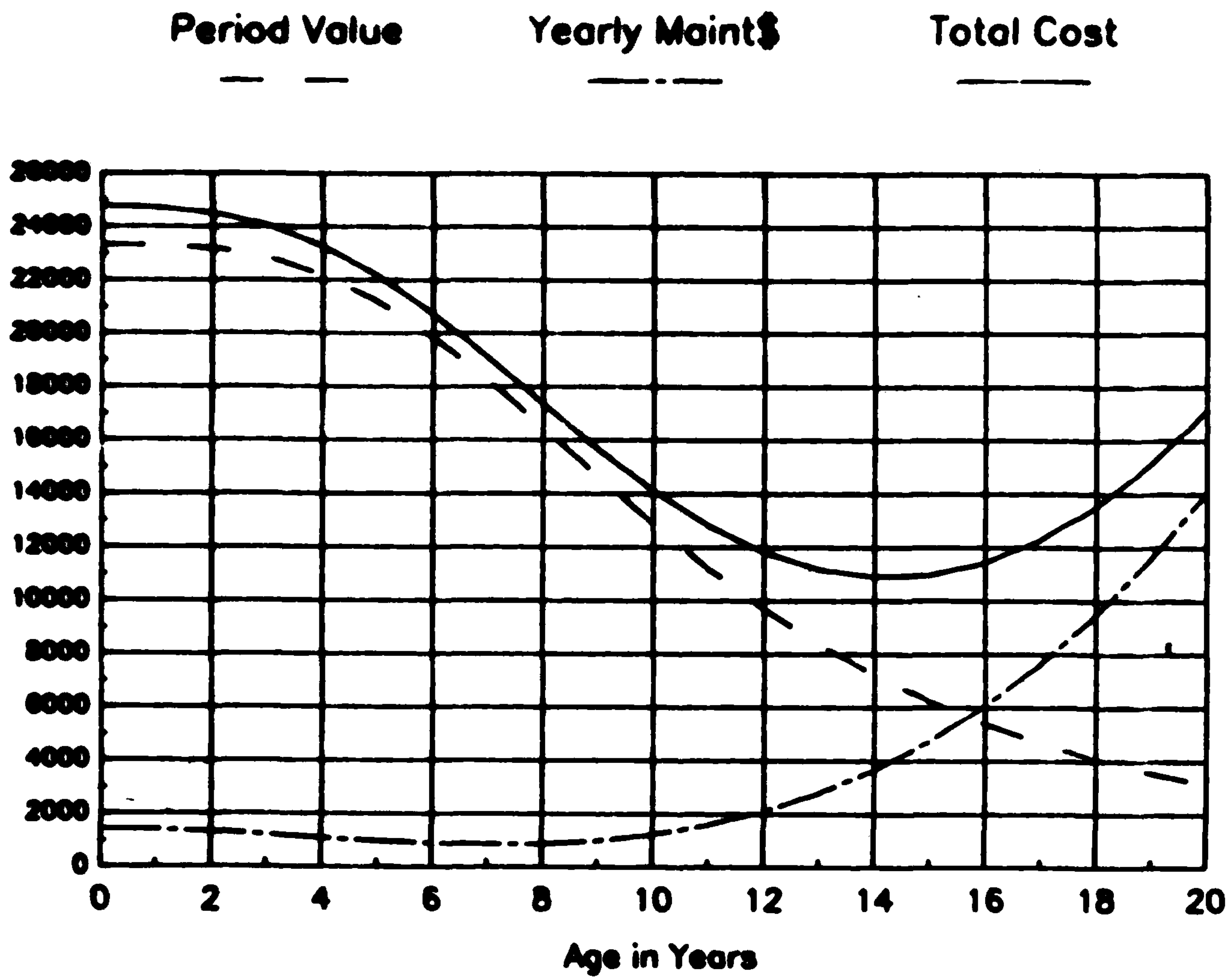


Figure 1: Economic Life Model of 4K Electic Forklift

years could be anything more than a prediction. In short, there was not significant evidence to conclude that the current 15 year life expectancy should be shortened.

Summary

This chapter presented and analyzed the VIMS data on the 4K electric forklifts. It then described how the VIMS data were used to obtain the maintenance cost function, and the amortized acquisition cost functions. A spreadsheet application was developed to perform the calculations and obtain the total cost curve. The total cost curve's minimum point was found to be 14 years, but due to insufficient data beyond the 12 years point, this was not considered to be sufficient evidence to conclude that the service life should be reduced. The next chapter provides the author's conclusions and recommendations.

V. Conclusions and Recommendations

Research Conclusions

The results of this study did not dispute or confirm the current 15 year life expectancy listed in TO 36A-1-1301 for 4K electric forklifts. Even though the model recommended a 14 year economic life, the results were not conclusive enough to dispute time frames as short as one year. Fortunately, the total cost curve is relatively flat within a year or two of the minimum point; therefore, there is a measure of relative safety before costs begin to rise geometrically on either side of the optimum.

The results were not more conclusive because there were not enough data in the model's prediction range. The sample provided data on 201 forklifts which represented 27% of the total population of 742 (15). From the original sample, 37 were eliminated because of errors or inconsistencies, and another 6 were deleted because their abnormally low utilization would have disproportionately magnified the amount of maintenance and labor required per hour of operation. Even with 43 observations deleted, the remaining sample of 158 still included more than 21% of the Air Force's 4K electric forklifts. The problem was not with the amount of data, but its distribution. In spite of a range from 3 to 17 years, only 6 of the 158 vehicles were more than 12 years old. None of the age groups from 13 to 17 had more than 2 observations. Because of this, any recommendation for an economic life beyond 12 years would be little more than extrapolation.

A larger sample, perhaps even the entire population of Air Force 4K electric forklifts, would have improved the probability of having enough data in the 12 to 17 year range to obtain conclusive results.

Model Utility

The key to the model's utility is how well it could be applied to other Air Force vehicles. Data requirements and other considerations pose limitations which may be difficult if not impossible to overcome. These limitations are different for each type of vehicle; therefore, the model's degree of confidence depends on the vehicle in question. It is important to understand the decision environment of each application to properly interpret the results. Factors which affect the decision environment are discussed below.

Data Requirements. Data is by far the most serious limitation for the economic life model. Both the range and distribution of maintenance data are critical. The economic life should ideally fall within the range of the vehicles currently in operation. Limited extrapolation outside the range might provide a good forecast, but caution is advised. The importance of the distribution of the data within the range was demonstrated by this study. Unlike the range limitations, the distribution problem may be reduced by using a larger sample, or even the whole population.

Even if the range and distribution of data are acceptable, a sufficient number of vehicles is required to accurately estimate the maintenance cost and amortized acquisition functions. In this thesis, the sample was large enough to obtain confidence levels of at least 95% for both models used to derive the total cost equation. However, approximately 80% of hourly maintenance costs, and 85% of the amount of maintenance labor required were not related to vehicle age in the case of 4K electric forklifts. It is likely that more data would have improved the coefficient of determination (r-squared), but the improvement would have probably been slight, and much would have remained unaccounted for in the final analysis. Other vehicles could show more or less correlation depending on a number of considerations. Some of the factors which might increase model error, and therefore, the amount of data required are described below:

1. Diversity of Design. This might be due to different manufacturers and/or changes in a single manufacturer's product from one year to the next. Both of these factors would be particularly prevalent in general purpose administrative vehicles like sedans and pickup trucks.

2. Complexity of Design. The more complex the vehicle is, the more difficult and costly it will be to maintain, and the greater the variance in its maintenance requirements.

3. Utilization Variance. The more utilization varies, the more cost can be expected to vary.

4. Operating Environment Variance. Maintenance requirements for vehicles performing specialized missions would be expected to vary less than for vehicles used for a wide variety of jobs.

5. Amount of Discretionary Maintenance. Maintenance beyond what is necessary for safe and serviceable operation may vary significantly depending on local policies. Some types of vehicles tend to be more subject to "cosmetic" maintenance than others depending on the degree appearance is considered important. In addition, higher levels of maintenance may be afforded individual vehicles if reducing the probability of unscheduled maintenance is considered more critical than for other vehicles of the same type.

Operations and Maintenance Costs. In this thesis, the operations part of the cost to keep a vehicle in service was not included because the amount of electricity the forklifts used per hour of operation was assumed constant. It was not possible to verify this since VIMS does not list energy costs for electric vehicles. But most vehicles in the Air Force inventory do burn gasoline, diesel fuel, or propane;

and fuel costs can vary considerably and should be included in the model along with the cost of maintenance.

The Reliability Index. The use of this factor to determine the depreciation schedule for the 4K forklifts was the most subjective part of the total cost model. Relating the concept of value to the amount of maintenance required per hour of operation ignored factors which the researcher decided were insignificant for the vehicles in question. These assumptions would probably hold less for many other types of vehicles.

Technological obsolescence, rather than reduced reliability or high operating costs could be the overriding reason to replace an asset. If a new machine becomes available that reduces cost or improves performance, the market value of machines based on the old technology usually drops significantly in value. The personal computer market is a good example of this. Vehicle technology does not evolve as quickly, but it can be important for long life expectancy vehicles. And even if the vehicle technology itself does not change dramatically from one decade to another, the Air Force's ever evolving mission will certainly mandate different types and mixes of commercially available, and militarily unique motor vehicles. Changing safety and environmental laws can also effectively createtechnological obsolescence where it might not otherwise exist. In summary, a vehicle should be evaluated in terms of the changing mission it supports in addition to manufacturing technology in order to determine the importance of technological obsolescence. Another variable could be added to the model, or it could be otherwise weighted to account for the relative affect of technological obsolescence on the depreciation schedule of the vehicle in question.

Physical appearance is an important determination of market value for privately-owned vehicles; it's much less of a consideration for the Government. Nevertheless, it is a concern to the degree necessary to maintain a positive public image short of what would be seen as wasting money. An aging vehicle fleet could also reduce the morale of the people who operate and maintain them, but this is much harder to measure. If physical appearance is considered a factor for the type of vehicle under consideration, it too could be accounted for by adding another variable to the basic model.

Model Interpretation

It is important that the total cost function not be misinterpreted. The minimum point on the total cost curve is only an estimate of the optimum economic service life. The accuracy of the estimate depends on the accuracy and amount of the data in the sample, and the degree to which the maintenance and amortized acquisition cost curves fit the data.

Because of the low coefficient of determination, the model and its component functions should not be used to predict the cost or maintenance reliability of individual vehicles. The curves are only useful in the aggregate; i.e., for estimating the behavior of the population at large.

Extrapolation should also be avoided. The inherent errors in the model could be magnified by the uncertainties of the future. The value of the economic life recommendation the model provides depends on the strength of the data in the vicinity of the recommendation. The model's recommendation is just that, a recommendation; it should not be used for decision making in isolation.

Recommendations for Model Applications

Some variation of these procedures could be incorporated in the VIMS system at the item manger level. A program could be designed which could use current VIMS data to produce the cost functions described in this study, and 100% of the available data could be automatically analyzed by computer for every vehicle management code. Such a program could be useful in several ways beyond estimating vehicle life expectancies. It might also be used to weigh the importance of replacing one type of vehicle against others, and to provide estimates of the financial opportunity costs of deferring replacement. This would allow the benefits as well as the cost of the vehicle buy submission to be expressed in monetary terms for budget justification.

Recommendations for Further Study

Several ideas for further study in the area of vehicle management developed in the course of this research. They are included here with the hope that they might be of use to managers, researchers, and future students in search of a thesis topic:

1. Develop a method to evaluate the current value for individual general purpose vehicles. A possible method for attacking this problem might be multiple linear regression using quantitative and qualitative variables to describe the condition of the vehicle. This could be of use to base level vehicle managers in deciding whether a vehicle should be sent to salvage or kept in service. One possible way to obtain data might be to use a delphi technique with several experienced maintenance experts responding to what items they consider important in determining the value of a vehicle.

2. Maintenance costs can vary significantly depending on how vehicles are manufactured. However, initial purchase price is usually the dominant, and often, the only consideration in procuring motor vehicles. In 1974, Karsten and McDaniel discussed the possibility of including maintenance "cost drivers" as part of the procurement bid for

contracts (Karsten). This might be a possible alternative to warranty work which can cost the Air Force considerable down time and lost productivity taking vehicles to dealers for service, especially in remote areas.

3. The advantages and disadvantages of diesel versus gasoline engines is often debated. Both diesel and gasoline versions of similar types of vehicles exist in the Air Force inventory. The cost characteristics of diesel and gasoline alternatives could be compared to determine what type of engine is more cost effective given the vehicle and the way it is used in the Air Force.

Conclusion

Motor vehicles are of tremendous importance to the U.S. Air Force because of their cost and the missions they support. A vehicle, like an aircraft, is a system of components subject to failure. The probability of failure, as well as maintenance costs, increases as it wears out. The cost to operate and maintain a vehicle over its service life can easily exceed the initial purchase price. Therefore, management policies should be based on life cycle costs. The problem is to identify what these costs are in a way that will make it easier to make better procurement, operational, and maintenance decisions.

This thesis was an attempt to take a step towards reducing the uncertainty in managing vehicles without increasing the amount of data required; i.e., to improve the quantity and quality of information current data provides. Incorporating a life cycle model in the VIMS system is probably not feasible today, but it is an indication of what might be accomplished with an on-line system that would allow frequent updates and sensitivity analysis of the variables with little effort. Expanding information system capabilities are rapidly making what was previously impractical, possible. The opportunities for improving the management of the Air Force motor vehicle fleet invite further exploration.

Appendix A: Data Set

OBS	REG NBR	AGE	CUM HRS	COST/HR	REL INDEX	CUR HRS
1	84E0424	3	2339	172	5.1	441
2	84E0425	3	1691	31	2.1	279
3	84E0426	3	3251	184	2.9	570
4	84E0427	3	3026	-207	6.7	344
5	84E0428	3	3238	161	6.1	468
6	84E0429	3	3282	110	3.3	558
7	84E0430	3	2602	222	3.8	477
8	84E0431	3	2162	191	6.4	337
9	84E0432	3	1872	97	3.6	466
10	84E0433	3	1771	153	5.1	402
11	84E0434	3	1552	17	1.1	398
12	84E0435	3	2268	65	2.9	546
13	84E0436	3	1529	36	2.4	325
14	84E0437	3	791	97	4.2	349
15	84E0438	3	1563	152	2.2	289
16	84E1046	3	892	35	2.3	209
17	84E1066	3	868	43	3.0	277
18	84E1067	3	1237	53	2.3	398
19	84E1068	3	869	116	5.5	256
20	84E1040	3	1116	319	9.0	289
21	84E1041	3	1447	27	1.6	620
22	84E0439	3	4314	116	3.4	747
23	84E0440	3	3815	292	5.0	669
24	84E0441	3	3947	141	5.8	773
25	82E0510	5	5419	42	2.3	521
26	82E0511	5	4483	90	4.0	613
27	82E0512	5	4500	30	1.9	688
28	82E0513	5	3587	225	8.4	592
29	82E0514	5	1724	122	6.4	250
30	82E0515	5	2171	59	3.9	278
31	82E0516	5	590	177	11.4	79
32	82E0517	5	2545	19	1.2	468
33	82E0518	5	2438	28	1.7	478
34	82E0751	5	1805	158	8.2	358
35	80E0052	7	6566	48	2.1	748
36	80E0077	7	6724	88	3.5	291
37	80E0078	7	5215	62	4.0	197
38	80E0329	7	3210	116	5.1	235
39	80E0332	7	7344	68	3.2	459
40	80E0333	7	2733	29	1.7	521
41	80E0334	7	5610	84	1.2	631
42	80E0335	7	5001	89	2.6	627
43	80E0347	7	3684	31	2.3	240
44	80E0348	7	2430	21	1.5	195
45	82E0506	7	2098	27	2.0	298

46	82E0500	7	2104	69	5.1	151
47	80E0062	7	2306	29	1.0	227
48	80E0063	7	2938	225	11.2	272
49	80E0064	7	3304	120	6.1	209
50	80E0336	7	1340	50	2.9	70
51	80E0337	7	4000	60	3.7	243
52	80E0346	7	4045	353	10.3	210
53	80E0049	7	620	100	6.7	156
54	80E0051	7	907	30	1.9	106
55	80E0072	7	1029	222	0.6	226
56	79E0133	8	5326	250	4.2	330
57	79E0120	8	4213	223	6.5	309
58	78E0144	9	2710	216	2.7	207
59	78E0146	9	5050	10	1.2	600
60	78E0155	9	3046	33	2.2	179
61	78E0157	9	4034	34	2.3	511
62	78E0158	9	5153	35	2.3	462
63	78E0159	9	6492	15	1.0	453
64	78E0160	9	7916	103	1.5	423
65	78E0161	9	6660	20	2.9	746
66	78E0162	9	5000	147	4.2	341
67	78E0164	9	4152	70	4.0	309
68	78E0165	9	5154	47	3.1	305
69	78E0166	9	4109	14	0.9	316
70	78E0026	9	4960	22	1.6	231
71	78E0027	9	2372	61	4.5	67
72	78E0020	9	4933	25	1.0	372
73	78E0029	9	8003	357	2.0	465
74	78E0030	9	1537	591	4.5	146
75	78E0031	9	2673	225	3.7	174
76	78E0032	9	7164	595	4.0	368
77	78E0034	9	4071	215	0.3	201
78	78E0035	9	5042	12	0.9	615
79	78E0036	9	6201	332	9.0	229
80	78E0038	9	6464	31	2.3	342
81	78E0039	9	6694	261	4.5	252
82	78E0040	9	8510	35	2.6	416
83	78E0041	9	5077	34	2.5	304
84	78E0042	9	6679	460	9.2	158
85	78E0043	9	4061	84	6.2	259
86	78E0047	9	3048	139	10.3	101
87	78E0049	9	8282	146	7.7	482
88	78E0051	9	3260	430	5.0	110
89	78E0086	9	1417	12	0.9	422
90	78E0087	9	1925	7	0.5	460
91	78E0107	9	1553	430	3.6	190
92	78E0004	9	3718	113	6.1	321
93	78E0010	9	7249	43	2.6	505
94	78E0053	9	2956	47	2.8	641
95	78E0084	9	2589	1392	37.8	116
96	78E0085	9	4589	210	7.7	194
97	78E0151	9	6629	432	11.9	191

98	78E0163	9	3594	190	10.9	289
99	78E0100	9	2655	79	2.5	484
100	78E0102	9	1276	248	11.5	282
101	77E0061	10	4593	618	2.6	336
102	77E0062	10	4531	26	1.7	350
103	77E0063	10	8362	19	1.3	647
104	77E0064	10	4708	22	1.4	368
105	77E0065	10	4476	32	2.1	520
106	77E0066	10	691	23	1.5	67
107	77E0067	10	4894	25	1.1	389
108	77E0068	10	2078	1983	7.7	104
109	77E0069	10	8839	237	7.8	190
110	77E0070	10	6579	1018	9.6	139
111	77E0251	10	3360	53	3.7	172
112	77E0252	10	7149	599	9.9	77
113	77E0253	10	5543	62	4.1	209
114	77E0255	10	5967	559	3.2	622
115	77E0257	10	5961	67	4.4	154
116	77E0258	10	3624	39	2.5	267
117	77E0259	10	1900	368	8.1	183
118	77E0260	10	3302	34	2.3	230
119	77E0261	10	4847	12	0.8	456
120	77E0231	10	9306	332	5.6	245
121	77E0232	10	6293	67	4.9	184
122	77E0071	10	399	363	22.0	150
123	77E0072	10	9906	15	0.9	483
124	77E0073	10	7502	210	6.6	474
125	77E0074	10	8587	105	4.3	738
126	77E0075	10	8425	48	2.9	451
127	77E0076	10	9543	44	2.7	637
128	77E0077	10	7951	134	8.1	442
129	77E0239	10	4646	60	1.6	407
130	77E0240	10	2895	64	2.4	642
131	77E0241	10	3490	33	2.0	673
132	77E0242	10	2361	273	16.3	206
133	77E0243	10	2495	165	9.9	111
134	77E0079	10	2852	13	0.9	234
135	77E0082	10	5292	204	12.9	98
136	77E0083	10	5970	121	7.7	167
137	77E0228	10	6002	132	5.0	274
138	77E0230	10	7339	110	5.2	454
139	75E0334	12	5992	247	8.0	205
140	75E0335	12	3575	196	5.7	196
141	75E0638	12	11873	827	5.9	377
142	75E0639	12	6893	113	5.7	449
143	75E0640	12	4656	121	5.5	297
144	75E0641	12	3684	608	5.4	235
145	75E0642	12	4149	87	5.7	253
146	75E0337	12	2994	19	1.4	259
147	75E0339	12	4633	45	2.3	432
148	75E0644	12	5416	1479	23.8	92
149	75E0646	12	5706	81	4.1	208

150	75E0647	12	3602	182	10.2	537
151	75E0651	12	5264	26	6.4	135
152	75E0654	12	3713	62	3.9	97
153	74E0557	13	6749	373	18.0	93
154	74E0564	13	2743	117	7.7	95
155	73E0841	14	4048	168	8.2	195
156	72E1548	15	7635	93	4.7	426
157	70E1135	17	6538	277	3.4	195
158	70E1133	17	7077	2589	34.3	84

REG NBR: registration number of the vehicle

AGE: age of the vehicle in years

CUM HRS: cumulative engine hours

COST/HR: maintenance cost (in cents) per operating hour

R INDEX: reliability index (maint. hrs/100 operating hrs)

CUR HRS: current hours for the six month period

Appendix B: Economic Life Model for Vehicles (Spreadsheet)

PART 1: The Amortized Acqusition Cost Function

AQ = P * B/(B + An^3)

where:

AQ = amortized acquisition cost
P = current price for a new replacement asset
B = basic maint. hr/operating hr efficiency when asset is new
A = parameter for years-cubed
n = age in years

Enter data for P, B, and A below:

P = 23335 B = 3.112 A = 0.00255

PART 2: The Maintenance Cost Function

Function is in the form Y = (R1n^3 + R2n^2 + S) * H where:

Y = annual maintenance cost
R1 = regression line parameter for years-cubed
R2 = regression line parameter for years-squared
n = age in years
S = initial maintenance rate (y-intercept of regression line)
H = average number of hours per year vehicles are used

Enter data for variables R, S, and H below:

R1 = 0.00508 S = 2.1674 H = 657.02
R2 = -0.0536

PART 3: The Cost Model

End of Year:	Period Value	Yrly Maint$	Total Cost
0	23335.00	1424.025	24759.02
1	23315.89	1392.146	24708.04
2	23183.03	1309.861	24492.89
3	22829.91	1197.195	24027.10
4	22172.24	1074.175	23246.41
5	21166.95	960.826	22127.77
6	19825.96	877.174	20703.13
7	18215.42	843.246	19058.66
8	16438.36	879.066	17317.52
9	14608.58	1004.662	15613.24
10	12825.60	1240.059	14065.65
11	11161.69	1605.283	12766.97
12	9658.77	2120.361	11779.13
13	8333.21	2805.317	11138.52
14	7183.41	3680.179	10863.58
15	6197.04	4764.971	10962.01
16	5356.61	6079.721	11436.33
17	4643.08	7644.453	12287.53
18	4038.04	9479.195	13517.23
19	3524.75	11603.97	15128.72
20	3088.57	14038.80	17127.38

Appendix C: Economic Life Model for Vehicles (Spreadsheet Template)

PART 1: The Amortized Acqusition Cost function

AQ = P * B/(B + An^3)

where:

AQ = amortized acqusition cost
P = current price for a new replacement asset
B = basic maint. hr/operating hr efficiency when asset is new
A = parameter for years-cubed
n = age in years

Enter data for P, B, and A below:

P = B16   B = D16   A = F16

PART 2: The Maintenance Cost Function

Function is in the form Y = (R1n^3 + R2n^2 + S) * H where:

Y = annal maintenance cost
R1 = regression line parameter for years-cubed
R2 = regression line parameter for years-squared
n = age in years
S = initial maintenance rate (y-intercept of regression line)
H = average number of hours per year vehicles are used

Enter date for variables R, S, and H below:

R1 = B32   S = D32   H = F32
R2 = B33

PART 3: The Cost Model

End of Year:	Period Value	Yrly Maint$	Total Cost
0	*	**	***
1	*	**	***
2	*	**	***
3	*	**	***
4	*	**	***
5	*	**	***
6	*	**	***
7	*	**	***
8	*	**	***
9	*	**	***
10	*	**	***
11	*	**	***
12	*	**	***
13	*	**	***
14	*	**	***
15	*	**	***
16	*	**	***
17	*	**	***
18	*	**	***
19	*	**	***
20	*	**	***

*   (D16/(D16 + F16 * A#^3)) * B16

** (D32 + B32 * A#^3 + B33 * A#^2) * F32

*** C# + E#

Notes: # = appropriate row number in column A for vehicle age.

Other varialbes listed by row and column number wre entered in parts 1 and 2 of the spreadsheet.

Bibliography

1. Andrew, Arthur A. "The Proactive Approach to Reducing Lift Truck Maintenance Cost," Material Handling Engineering: 89-93 (March 1987).

2. -----. "When to Replace Your Lift Trucks and How to Make the Program Pay Off!" Material Handling Engineering: 46-50 (July 1980).

3. Armour, Rodney F. "An Economic analysis of Transit Bus Replacement," Transit Journal: 41-54 (Winter 1980).

4. Cardy, SMSgt. WR-ALC/MMC. Telephone Interview. WR-ALC/MMV, Warner Robins AFB GA, 26 March 1987.

5. Claypool, Scott K., and Jeffery B. Webb. A Life Cycle Cost Analysis for the Procurement of General Purpose Vehicles. MS thesis, LSSR 19-82. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1982 (AD-A122 883).

6. Colson, Frank J. and others. "Evaluation of the Air Force Replacement Model." Air Force Logistics Management Center, Gunter AFS AL, 1978.

7. Department of the Air Force. Acquisition, Management and Use of Motor Vehicles. AFM 77-310, Volume I. Washington: HQ USAF, 1981.

8. -----. Maximum Repair Allowances, Replacement Codes and Priority Buy Program for USAF Vehicles. TO 00-25-249. Washington: HQ USAF, 1979.

9. -----. Vehicle Maintenance Management. AFM 77-310, Volume II. Washington: HQ USAF, 1983.

10. ----- Vehicle Management Index File. TO 36A-1-1301. Washington: HQ USAF, December 1985.

11. Economic Analysis of Industrial Lift Trucks. Exide Battery Pamphlet. EBS Incorporated, Philadelphia PA 1977.

12. Fabrycky, W. J. and G. J. Theusen. Economic Decision Analysis (Second Edition). Englewood Cliffs NJ: Prentice-Hall, Inc., 1980.

13. Friedl, Capt Raymond. Vehicle Replacement, Expectancy, and Repair Allowance Improvement Final Report. Air Force Logistics Management Center, Gunter AFS AL, 1982.

14. Gill, Leroy. "Life Cycle Cost." Handout for AMGT 559, Life Cycle Cost and Reliability. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFb OH, undated.

15. Gladden, Maj, WR-ALC/MMC. Telephone Interview. Warner-Robins AFB GA, 10 July 1987.

16. Goldon, John H. An Application on Linear Regression to the Allocation of General Purpose Vehicles. MS thesis, 86S-26. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1986 (AD-A174 566).

17. Harris, Michael G. A Life Cycle Cost Analysis of the Eruopean Vehicle Buy Program. MS thesis, 84S-28. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1986 (AD-A148 446).

18. Karsten, Ernst R., and Larry T. McDaniel. Suggested Methods for Implementation of Life Cycle Costing Techniques in the Procurement of Air Force General Purpose Commercial Vehicles. MS thesis, SLSR 9-74A. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, January 1974 (AD-777 249).

19. Maze, T. H., and Allen R. Cook. "Life Cycle Costing in the Transit Industry: A Good Idea Turned Sour and What to do Abot it," Transportation Quaterly, 40:397-309 (July 1986).

20. McAllister, HQ USAF/LETN. "Background Paper on Motor Vehicle Funding Programs." Vehicle Management Division, directorate of Transportation, Headquartes USAF, Washington, 6 January 1987.

21. Parsons, F. J. An Analysis of the Economic Life and Maintenance Cost Prediction for the Truck, Cargo/Van, 1-1/14 Ton, 4x4. Directorate of Land Engineering Support, Department of National Defence Canada, Ottawa, July 1983 (AD-B086 256).

22. SAS Institute Inc. SAS Users Guide: Statistics (Version 5 Edition). Cary NC: SAS Institute Inc., 1985.

23. Strosser, Skip, Miami Industrial Trucks. Telephone Interview. Miami Industrial Trucks, Inc., Dayton OH, 25 June 1987.

24. Streilein, James J. Economic Lives of Administrative Use Vehicles. U.S. Army Materiel Systems Analysis Acivity, Aberdeen Proving Ground MD, August 1979 (AD-073 399).

25. Weiss, W. H. "When Should Lift Trucks Be Replaced?", Plant Engineering: 60-62 (23 August 1984).

26. Whyte, Paul C. "Reduce High Cost of Aging Lift Trucks," Industrial Engineering: 24-27 (January 1980).

VITA

Captain Paul Scott Albert was born in Detroit, Michigan on 26 December 1955. Upon graduation from Plymouth Salem High School, he attended Central Michigan University and earned a Bachelor of Science degree in Education in May 1979. He completed Officers Training School and received his commission in the United States Air Force in December 1980. He served as a Staff Transportation Officer at Headquarters Air Force Systems Command, as a Vehicle Operations Officer, and was the Vehicle Maintenance Officer at the Air Force Flight Test Center, Edwards AFB, California, prior to entering the School of Systems and Logistics, Air Force Institute of Technology, in May 1986.

Permanent address: 1380 Elm
Plymouth, Michigan 48170

6c. ADDRESS (City, State, and ZIP Code)
Air Force Institute of Technology
Wright-Patterson AFB OH 45433-6583

7b. ADDRESS (City, State, and ZIP Code)

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code)

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)
A MODEL TO DETERMINE THE ECONOMIC LIFE OF AIR FORCE MOTOR VEHICLES

12. PERSONAL AUTHOR(S)
Paul S. Albert, B.S., Capt, USAF

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
MS Thesis	FROM ______ TO ______	1987 September	94

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
15	05	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Vehicles
Replacement
Cost Models
Forklift Vehicles
Life Cycle Costs

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

THESIS ADVISOR: Bruce P. Christensen, Lt Col, USAF
Assist Prof of Logistics Management

Approved for public release: IAW AFR 190-1.
24 Sept 87
JOHN E. WOLAVER
Dean for Research and Professional Development
Air Force Institute of Technology (AFSC)
Wright-Patterson AFB OH 45433

Block 19. Abstract

The purpose of this thesis was to develop a model to determine optimum service lives for Air Force motor vehicles. The scope was limited to the model's feasibility on one type of vehicle. The vehicle selected was the 4K electric forklift, National Stock Number 3930-00-053-9175.

The sample consisted of 158 vehicles out of a population of 742. Operations and maintenance data were extracted from VIMS reports from four Air Force Logistics Command installations. Age was not distributed normally; only 6 of the 158 vehicles were more than 12 years old.

Linear regression was used to develop a maintenance cost function with age as the independent variable. The function was not linear, and heteroscedasticity was present. A weighting technique was applied to correct for heteroscedasticity, and the model was transformed to account for the curvilinear relationship.

An "amortized acquisition cost" function was also obtained by linear regression. Depreciation was derived from the amount maintenance hour per operational hour increased as the vehicles aged.

The total cost curve was found by summing the amortized acquisition and the maintenance cost functions. The economic service life was found to be 14 years; however, given the distribution of the sample, the results were not considered conclusive enough to dispute the current 15 year service life.

The overall utility of the model was demonstrated - with limitations. Data requirements would preclude its use for some types of vehicles, but it could prove useful for many others. The author recommneded incorporating the model in a VIMS upgrade with the admonition that it be used only where appropriate, and in conjunction with other management indicators.