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Pollution Reduction and Emission Prevention Automated Rule-based Expert (PREPARE) System for Operation and Maintenance of Pollution Control Equipment

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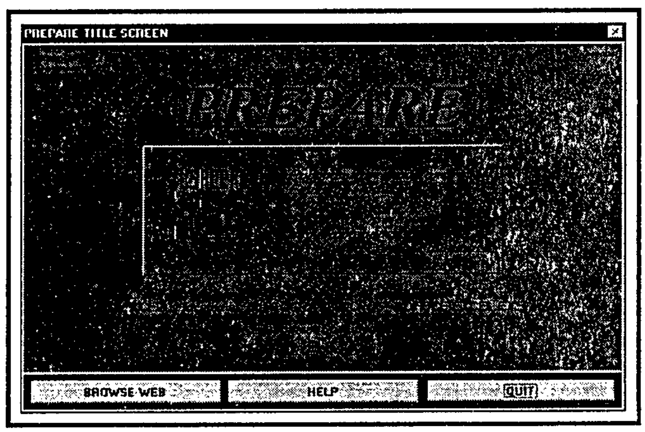

The maintenance of pollution control equipment (PCE) at Army installations is of critical importance. If PCE breaks downs, hazardous materials may be introduced into the environment. This may lead to unfavorable health and safety consequences for workers and people living in the area, and may also incur heavy fines on the installation responsible for the emissions. This study provided an expert system (PREPARE) for the operation and maintenance (O&M) of PCE. PREPARE helps combine the expertise of on-site personnel to information collected by researchers to help optimize decisionmaking on how O&M dollars can be spent most effectively.

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Foreword

This study was conducted for HQ Industrial Operations Command under Project 4A162720D048, "Industrial Operations Pollution Control Technology"; Work Unit UL-U47, "Enhanced D&M Pollution Control Equipment." The technical monitor was Ricky Peer, SMCPB-EM.

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Contents

List of Figures and Tables

Figures

Tables

1 Introduction

Background

Due to their mission, many Army installations are faced with controlling hazardous and nonhazardous emissions resulting from manufacturing processes. It is important that these industrial manufacturing installations reduce the levels of emissions to the environment by using the correct pollution control equipment (PCE) and by ensuring that the PCE is well maintained.

The importance of PCE maintenance cannot be over-emphasized. When PCE does not function at its optimal rating, emission of hazardous wastes creates health and safety problems and may lead to costly fines for the offending installation. To avoid emission problems, installations must develop an operation and maintenance (O&M) plan that covers all pollution control devices. The plan must document proposed inspection and maintenance methods, and must include a listing of the components that were inspected, the date of inspection, the actions taken, and the occurrence of any scheduled or nonscheduled downtime.

Generally, installations base their O&M plan on any one (or combination) of four maintenance strategies: (1) Run-to-Failure, (2) Predictive Maintenance (PDM), (3) Preventive Maintenance (PM), or (4) Proactive Maintenance (PAM). Run-to-Failure maintenance means the equipment is run until it breaks down. When failure occurs, the equipment is either repaired or replaced. Run-to-Failure is not always a cost-effective maintenance strategy. For example, at many military installations, Run-to-Failure maintenance has become the norm, simply as a way to cope with decreasing funds and manpower reductions. Under these circumstances, Run-to-Failure maintenance can result in huge expenditures for equipment replacements. Over the past few years, industry has used predictive and preventive maintenance for equipment. PDM is based on detecting warning signs of failure once they have already begun. PM relies on a periodic schedule in which components are checked and replaced. PAM takes a macro view on machine damage, concentrating on the causes instead of the symptoms of wear.

Maintenance is one of the largest single controllable expenditures in a manufacturing plant, but in some cases, maintenance costs have exceeded annual net profit in private industry. Current trends indicate that a change in philosophy has occurred toward machine maintenance. In many worldwide major industries, the cost-saving trend is toward a maintenance program that points out the root causes of machine wear and failure. The root cause, failure, and effects analyses are properties of PAM. This strategy requires a large, well-trained maintenance staff.

It can be a costly mistake to over-apply any single maintenance strategy. Calendar-based PM is not optimal for all types of equipment. Repeat trips to perform PM on a piece of equipment that does not really need consistent monitoring is a waste of labor, time, and maintenance dollars. National Aeronautics and Space Administration (NASA) research shows that each type of maintenance has its place — under specific circumstances. For example, Run-to-Failure maintenance may be appropriate if backup equipment is readily available, or if a particular piece of equipment is to be replaced by newer equipment that will accomplish a mission more efficiently. PM is an option when failure patterns of components are known and the replacement components are inexpensive relative to the costs involved with loss of service (downtime). Still, one should not maintain equipment on a PM schedule indefinitely if PM costs exceed expected resale costs.

Determining the correct maintenance strategy (or mix of strategies) in an O&M plan should be made on the basis of quantified experience with specific equipment. However, such decisions are often based on such rules of thumb as: "Cleanliness is important; even the smallest particles can cause a machine to stop functioning. Field and laboratory tests have shown that fluid contamination is the number one cause of equipment failure." Although the statement is true, it may not be the root cause in a particular analysis. If it were the cause of an immediate problem, it would make good monetary sense to use maintenance personnel to ensure cleanliness, to reduce fluid contamination.

If maintenance managers could set a value for the different maintenance strategies applied to specific tasks, situations, and equipment in present value dollars, they could choose between maintenance strategies based on cost. Such an evaluation would also need to include the cost of the equipment over its entire life cycle. Ideally, an installation could conduct a study to collect data and assess the probability of equipment failure — especially when predicted failure time according to the manufacturer and the actual failure time do not correlate. The results of such a study would allow one to predict the optimal time interval between service events. However, few installations have the personnel to do such a study on all equipment before obvious warning signs of impending failure occur.

The problem is to *efficiently* determine the correct type of maintenance and appropriate maintenance intervals for any given equipment. One way to resolve this problem is by applying "Reliability Centered Maintenance" (RCM). RCM is an approach that combines professional intuition ("rules of thumb") and a rigorous statistical approach to determine an optimal mix of differing maintenance strategies (Run-to-Failure, PDM, PM, and PAM) that accomplish the facility mission without wasting maintenance labor.

Objectives

This study undertook to design software that allows the user to calculate the cost of performing preventive maintenance and to compare that cost with the cost of Run-to-Failure and loss of service.

Approach

The PREPARE system was designed and developed as follows:

1. The fundamentals of expert systems were studied.
2. O&M of PCE reports from industry and military installations were studied, evaluated, and used as guidance in this project.
3. Models based on life cycle costs (LCCs) were developed to convert expenditures for the designated study period to present values.
4. The variables for the expert system were chosen and defined. Specifically, EOP-OMB Circular No. A-94 was used as a guide for Discount Rate variable.
5. Finally, algorithms were designed to produce the required reports for the various options in the program and incorporated into the system.

Scope

This report covers model development and how to use the software tool. Appendix A to this report includes the data used for limits in the software. This information was used to develop a hierarchical expert system to allow facility managers to make decisions regarding continued use of in-situ PCE or purchase of new equipment. The expert system includes elements of several approaches to solving problems of the engineer/manager working with inadequate data for maintenance or job order contracts for pollution control equipment. Run-to-Failure Maintenance and Preventive Maintenance (PM) were included in the development of the Pollution Reduction and Emission Prevention Automated Rule-based Expert (PREPARE) software. It is anticipated that Proactive Maintenance and Predictive Maintenance will be included in later work.

Mode of Technology Transfer

It is anticipated that the PREPARE manual and application will be made available for download from the CERL web page: http://www.cecer.army.mil/

2 Maintenance Methods for PCE

Losses due to poor operation and maintenance of equipment cost the U.S. industrial community billions of dollars annually. This chapter explains the different approaches to PCE maintenance. RCM, as described in the *NASA Facilities RCM Guide* (December 1996) has been used as a basis for this report and program. RCM recognizes four maintenance methods: (1) Run-to-Failure, (2) Predictive Maintenance (PDM), (3) Preventive Maintenance (PM), and (4) Proactive Maintenance (PAM). Run-to-Failure Maintenance and Preventive Maintenance (PM) were included in the development of the Pollution Reduction and Emission Prevention Automated Rule-based Expert (PREPARE) software. Proactive Maintenance (PAM) was not included in this version because it was assumed to be either a redesign of the equipment before purchase, or a redundant purchase. It is anticipated that Proactive Maintenance and Predictive Maintenance will be included in future work.

Run-to-Failure Maintenance

This maintenance strategy is a minimalist approach to maintenance. Very little or no surveillance or monitoring of equipment is performed. The equipment is run until it breaks down. On failure, the equipment is repaired or replaced. This strategy works best for equipment that is relatively inexpensive to replace, for example, in cases where the work stoppage caused by the failure is of small consequence to the mission operation, or where a backup system is present.

Predictive Maintenance (PDM)

Predictive Maintenance is characterized by careful and thorough system monitoring. Sensory equipment is used to either spot-check system functions or to continuously monitor system performance. By careful analysis of system readouts, potential equipment failures may be predicted before total breakdown. PDM can be justified when the costs of monitoring equipment can be offset by the costs of a catastrophic system failure.

Preventive Maintenance (PM)

Preventive Maintenance is a strategy in which equipment is monitored and replaced before it fails. Checks are performed at regular calendar intervals. Replacements of parts and routine maintenance such as oiling, cleaning, and tuning are performed as recommended by the equipment manufacturer. This strategy works best for equipment in which there are tasks that can be performed to minimize failure and in systems in which failure will have a serious adverse effect on mission operations.

Proactive Maintenance (PAM)

Proactive Maintenance is perhaps the most comprehensive approach to system maintenance. Long range trends in system maintenance are evaluated over the lifetime of the equipment. When a piece of equipment fails, the technician will evaluate historical records and/or related systems in an effort to determine contributing factors and causes for failure. System components are optimized to minimize chances for failure.

3 Pollution Reduction and Emission Prevention Automated Rule-based Expert (PREPARE) System

Overview of Expert Systems

Conventional programming languages, such as FORTRAN and C, are designed and optimized for the procedural manipulation of data (such as numbers and arrays). Humans, however, often solve complex problems using abstract, symbolic approaches that are not well adapted for implementation in conventional programming languages. Although abstract information can be modeled in these languages, considerable-programming effort is required to transform the information to a format that is usable with procedural programming paradigms.

One of the results of research in the area of artificial intelligence has been the development of techniques that allow the modeling of information at higher levels of abstraction. These techniques are embodied in languages or tools that allow programs to be built that closely resemble human logic in their implementation and are therefore easier to develop and maintain. These programs, which emulate human expertise in well-defined problem domains, are called "expert systems."

Rule-based programming is one of the most commonly used techniques for developing expert systems. In this programming paradigm, rules are used to represent heuristics, or "rules of thumb," which specify a set of actions to be performed for a given situation. A rule is composed of an "if" portion and a "then" portion. The "if" portion of a rule is a series of patterns that specify the facts (or data) that cause the rule to be applicable. The process of matching facts to patterns is called pattern matching. The expert system tool provides a mechanism, called the "inference engine," which automatically matches facts against patterns and determines which rules are applicable. The "then" portion of a rule is the set of actions to be executed when the rule is applicable. The actions of applicable rules are executed when the inference engine is instructed to begin execution. The inference engine selects a rule, and then the actions of the selected rule are executed (which may affect the list of applicable rules by adding or removing facts). The inference engine then selects another rule and executes its actions. This process continues until no applicable rules remain.

Pollution Reduction and Emission Prevention Automated Rule-based Expert (PREPARE) System

PREPARE is an expert system that allows the user to compare the LCCs involved in using different maintenance strategies on pollution control equipment. The LCC models convert all expenditures for the designated study period to present values for ease of comparison.

Life Cycle Cost (LCC)

LCC analysis is a method of calculating the total cost of ownership over the life span of the asset and takes into account initial costs, expected costs of significance, disposal value, and qualified benefit value. LCC is justified when a decision is made on the acquisition of an asset that will require substantial operating and maintenance costs over its life span.

LCC analysis is applied within the U.S. Department of Defense (DOD) to every new weapon system proposed or under development. The impact of LCC on the defense and aerospace industries has been so great that those industries now design their products in terms of LCC objectives.

LCC has also worked its way into the health care field. The operating costs of a hospital in its first 3 to 5 years typically exceeded the entire construction costs. This has stimulated interest in cost-effective technologies, and the U.S. Department of Health, Education, and Welfare has initiated a project to formalize an LCC model for the health field.

The building industry has been slow to adopt LCC, but escalating operating costs and government prompting have made builders aware of the advantages of LCC. U.S. General Services Administration (GSA) and American Institute of Architects (AIA) have cooperated to develop a costing framework – UNIFORMAT – for both public and private work.

Life cycle costing should not be used for every acquisition, as LCC itself carries a cost. If you know that purchasing a new piece of equipment will save dollars, analysis is unnecessary.

In PREPARE, the "Life Cycle Cost Analysis" pull-down menu allows you to run analyses and comparisons for new equipment, equipment with maintenance, and equipment without maintenance. When performing analyses and comparisons, you should take into account that the replacement of old equipment can yield energy savings in addition to lower maintenance costs. Together, these savings can further offset the cost of using maintenance-demanding equipment. The analyses and comparisons mentioned above are run in present value dollars, that is, dollars at a specific point in time. When calculating LCC, it is important to carefully choose the discount and escalation factors so as not to skew the results. The difference due to escalation factors is not significant over a short time period, at about 5 years, the curves diverge (Figure 1).

Time Value of Money

Sometimes the term "opportunity cost" shows up in LCC analysis. Opportunity cost is the cost sacrificed by not investing in an alternative project. If capital can be employed in other projects and earns a return, it has an opportunity cost. The opportunity cost of capital means that it has a time value. If \$100 can be invested today at a 6 percent annual rate, it will be worth \$100 X 1.06 = \$106, 1 year from now. If the investment continues for a second year, it will be worth \$100 X 1.06^2 = \$112.36 (or \$106 X 1.06). The process, called compounding, affects the present value of money due in the future that is calculated by a process called discounting (Brown and Yanuck 1980, p 13). See Appendix A for formulas relating to the time value of money.

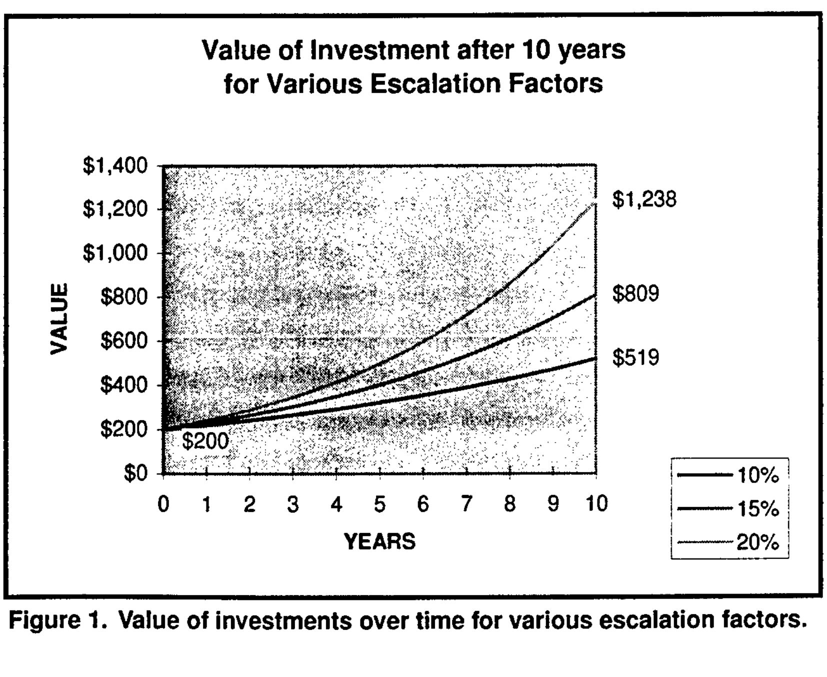

Figure 1. Value of investments over time for various escalation factors.

Description of Variables Used in PREPARE Reports

Initial Cost of Equipment

This is the list or purchase price of new equipment.

Annual Energy Cost of New Equipment

This is the cost for energy (electricity or fuel) to operate new equipment for one year.

Annual Surveillance Costs

Surveillance costs as used in PREPARE include the cost of labor to inspect equipment or to perform tests to ascertain if maintenance is required in the course of 1 calendar year. Surveillance costs also include the costs of travel time to and from the equipment location and maintenance of the vehicle used to transport the inspection crew.

Annual Maintenance Costs

Maintenance costs as used in PREPARE include the actual cost of labor to perform maintenance to improve the operation of the equipment and any replacement parts needed. The time period is 1 calendar year.

Occasional Replacement Costs

In PREPARE, occasional replacement costs include any costs incurred for the removal of old equipment and replacement costs for installing new equipment.

Number of Years between Occasional Replacements

This is the expected number of years between equipment replacements due to normal usage and wear.

Occasional Repair Costs

In PREPARE, occasional repair costs include the cost of labor and parts necessary to repair equipment and return it to operational status after an equipment or part failure.

Number of Years between Occasional Repairs

This is the expected number of years between equipment repair due to normal usage and wear.

Number of Years in Study Period

This includes the number of years in the life of equipment that will be included in the maintenance study.

Discount Rate

This is a rate used to relate present and future dollars. It is expressed as a percentage used to translate the value of future ("tomorrow") dollars to present ("today") dollars. For this reason, the discounting process is important in LCC analysis.

EOP-OMB Circular No. A-94 "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs" provides guidance for discounting using a real discount found in Appendix C of Circular No. A-94. Appendix C is updated each January. The Real Discount Rates are listed in Table 1. Real Discount Rates are based on the economic assumptions from the budget. These real rates must be used for discounting real (constant-dollar) flows, as required in cost-effectiveness analysis. Circular No. A-94 is accessible on the internet at the following World Wide Web (WWW) address:

http://www2.whitehouse.gov/WH/EOP/OMB/html/circulars/a094/a094.html

Note: Analyses of programs with terms that differ from those in Table 1 may use a linear interpolation. For example, one can evaluate a 4-year project with a rate equal to the average of the 3- and 5-year rates. Programs of duration greater than 30 years may use the 30-year interest rate.

Energy Escalation Rate

This is the expected rise in cost over time for the purchase of energy due to inflation.

Table 1. Real interest rates based on treasury notes and bonds of specified maturates (in percent).

3-Year	5-Year	7-Year	10-Year	30-Year
3.4	3.5	3.5	3.6	3.8

Maintenance/Repair Escalation Rate

Escalation rate is the expected rise in cost over time for labor needed to maintain or repair equipment due to inflation.

Replacement Escalation Rate

This is the expected rise in cost over time for labor needed to replace equipment as well as replacement parts due to inflation.

Loss of Service (LOS) Costs

The LOS is the summation of all costs incurred due to equipment failure and shutdown. It may include loss of revenue, fines for noncompliance, labor for idle personnel, or other miscellaneous resulting costs.

True Payback in Years

This is the period of time (in years) necessary to recover the initial investment of a project or purchase.

Total Present Value of All Costs

This cost includes all expenditures incurred for the maintenance of equipment during the study period converted to present day dollar value.

Average Annualized Present Value Costs

This includes all expenditures incurred for the maintenance of equipment during the study period converted to present day dollar value and then estimated for each year of the study period.

Cost Benefit Ratio

In PREPARE, the cost benefit ratio is the ratio of the total LCC costs with preventive maintenance to the savings (benefits) derived from the difference between LCC with preventive maintenance and LCC without preventive maintenance. The more negative the ratio, the more costly Run-to-Failure is for the system. The driving factor here is the loss of service costs. The more positive the number, the more costly the preventive maintenance is compared to Run-to-Failure.

Overview of Calculations for PREPARE Reports

Brief discussions of the calculations underlying PREPARE reports follow. Appendix A contains the formulas used in the calculations. Appendix B includes samples of PREPARE reports in Figures B21 through B26.

LCC Report for Existing Equipment – Basic Model

(Brown and Yanuck 1980)

LCC = Initial Cost of Equipment (PV) + Annual Energy Cost (PV) + Annual Surveillance Cost (PV) + Annual Maintenance Cost (PV) + Occasional Repairs (PV).

Average Annual Cost is calculated by using the Average Annual Cost formula found in Appendix A.

LCC Report for New Equipment

LCC = Initial Cost of Equipment (PV) + Annual Energy Cost (PV) + Annual Surveillance Cost (PV) + Annual Maintenance Cost (PV) + Occasional Repairs (PV).

Average Annual Cost is calculated by using the Average Annual Cost formula found in Appendix A.

LCC Report without Preventive Maintenance on Equipment or Run-to-Failure

LCC = Initial Cost of Equipment (PV) + Annual Energy Cost (PV) + Loss of Service (LOS) + Occasional Repairs (PV).

Average Annual Cost is calculated by using the Average Annual Cost formula found in Appendix A.

LCC Report with Preventive Maintenance on Equipment

LCC = Initial Cost of Equipment (PV) + Annual Energy Cost (PV) + Annual Surveillance Cost (PV) + Annual Maintenance Cost (PV).

Average Annual Cost is calculated by using the Average Annual Cost formula found in Appendix A.

LCC Report – Comparison of LCC of New Equipment vs. Existing Equipment

LCC for Existing Equipment

LCC = Initial Equipment Cost (PV) + Annual Energy Cost (PV) + Annual Surveillance Costs (PV) + Annual Maintenance Costs (PV) + Occasional Repairs (PV).

Average Annual Cost is calculated by using the Average Annual Cost formula found in Appendix A.

Calculations and formulas for True Payback and Cost Benefit Ratio are also found in Appendix A.

LCC for New Equipment

LCC = Initial Equipment Cost (PV) + Annual Energy Cost (PV) + Annual Surveillance Costs (PV) + Annual Maintenance Costs (PV) + Occasional Repairs (PV).

Average Annual Cost is calculated by using the Average Annual Cost formula found in Appendix A. Calculations and formulas for True Payback and Cost Benefit Ratio are also found in Appendix A.

Comparison of Equipment Costs: PM Performed vs. No PM Performed

LCC for Equipment with PM

LCC = Initial Equipment Cost (PV) + Annual Energy Cost (PV) + Annual Surveillance Costs (PV) + Annual Maintenance Costs (PV).

Average Annual Cost is calculated by using the Average Annual Cost formula found in Appendix A.

LCC for Equipment with No PM

(LCC) = Initial Equipment Cost (PV) + Annual Energy Cost (PV) + Occasional Repairs (PV) + LOS (PV).

Average Annual Cost is calculated by using the Average Annual Cost formula found in Appendix A. See Appendix A also for Cost Benefit calculations.

Table 2 lists the various options in using PM or Run-to-Failure.

Assumptions Made in Report Models

The on-site person will have to decide how much PM will be done per year. As the equipment ages, PM costs will rise and the purchase of new equipment may be justified. Table 2 illustrates the further assumptions used in the report development. If preventive maintenance is used, there are no occasional replacement or repair costs and no loss of service. If Run-to-Failure is adopted, there are no maintenance or surveillance costs.

Table 2. Preventive Maintenance vs. Run-to-Failure.

Options	Preventive Maintenance (PM)	Run-to-Failure
Maintenance Costs	Yes	No
Surveillance Costs	Yes	No
Occasional Replacements	No	Yes
Occasional Repairs	No	Yes
Loss of Service (LOS)	No	Yes

4 Conclusion

The PREPARE program provides Army installations with an "expert system" to compare the LCCs of using different maintenance strategies on pollution control equipment. PREPARE provides methodologies for performing cost analyses when trading off alternatives. To assist the user, some information on motors and sensors is included in the program. However, the variety of motors, sensors, and filters used in pollution control equipment is too great for a comprehensive list to be included in PREPARE at this time. Also the costs of equipment change rapidly over time. The program requires the user to have prior knowledge of initial costs of equipment, energy costs for equipment, and the cost of surveillance and maintenance. The program includes some default discount and escalation rates that the user may change. The user can take advantage of the links to the web browsers to put together a comprehensive list of web sites that will provide relevant information on pollution control equipment for a particular installation. The general nature of the PREPARE program offers the user guidelines and decisionmaking mechanisms to manage the maintenance of pollution control equipment.

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Appendix A: Calculations and Formulas Used in the PREPARE Program

Glossary of Symbols Used in the PREPARE Formulas

AAC	=	Average Annualized Cost
C	=	Cost
C/S	=	Simple Payback in years
CY	=	Repair or Replacement Cycle in years
DR	=	Discount Rate
e	=	Generic Escalation Rate
EC	=	Annual Energy Costs
ER	=	Energy Escalation Rate
i	=	Generic Discount Rate
IC	=	Initial Costs
LCC_existing	=	Total Life Cycle Costs of Using Existing Equipment
LCC_new	=	Total Life Cycle Costs of Purchasing New Equipment
LCC_w/oPM	=	Total Life Cycle Costs without Preventive Maintenance
LCC_w/PM	=	Total Life Cycle Costs with Preventive Maintenance
LOS	=	Loss of Service Costs
MC	=	Annual Maintenance Costs
MR	=	Maintenance/Repair Escalation Rate
N	=	Number of Years in Study Period
n	=	Year of Occurrence within Study Period (1,2,3 ...)
NEC	=	Annual Energy Costs of New Equipment
NIC	=	Initial Costs of New Equipment
NMC	=	Annual Maintenance Costs of New Equipment
NOC	=	Occasional Repair Costs of New Equipment
NOR	=	Occasional Replacement Costs for New Equipment
NYR	=	Number of Years between Occasional Repairs for New Equipment
NYS	=	Number of Years between Occasional Replacements for New Equipment
OC	=	Occasional Repair Cost
OR	=	Occasional Replacement Cost

PB	=	True Payback in years
PV	=	Present Value
RR	=	Replacement Escalation Rate
S	=	Annual Savings in dollars
SC	=	Annual Surveillance Costs
SPV	=	Single Present Value Multiplier
TPV	=	Total Present Value of All Costs
UPV	=	Uniform Present Value Multiplier
YR	=	Number of Years between Occasional Repairs
YS	=	Number of Years between Occasional Replacements
ZEC	=	Present Value of Annual Energy Costs
ZMC	=	Present Value of Annual Maintenance Costs
ZNEC	=	Present Value of Annual Energy Costs of New Equipment
ZNMC	=	Present Value of Annual Maintenance Costs of New Equipment
ZNOC	=	Present Value of Occasional Repair Costs of New Equipment
ZNOR	=	Present Value of Occasional Replacement Cost of New Equipment
ZNSC	=	Present Value of Annual Surveillance Costs of New Equipment
ZOC	=	Present Value of Occasional Repair Costs
ZOR	=	Present Value of Occasional Replacement Costs
ZSC	=	Present Value of Annual Surveillance Costs
Z	=	Number of Occurrences of an Occasional Repair or Replacement that fall Within the Study Period

General Formulas

GENERAL FORMULA FOR SINGLE PRESENT VALUE MULTIPLIER:

(Used for Calculating Present Value of a One-time Cost or a Non-Annually Recurring Cost)

i = Discount Rate

e = Escalation Rate

n = Year of Occurrence

$$SPV = \left(\frac{1+e}{1+i}\right)^n$$

GENERAL FORMULA FOR UNIFORM PRESENT VALUE MULTIPLIER:

(Used for Calculating Present Value of Uniform Annual Costs over a Study Period)

i = Discount Rate

e = Escalation Rate

N = Number of Years in Study Period

$$UPV = \frac{\frac{1+e}{1+i}\left[1-\left(\frac{1+e}{1+i}\right)^{N}\right]}{1-\left(\frac{1+e}{1+i}\right)}$$

GENERAL FORMULA FOR TRUE PAYBACK:

PB = Payback Years C = Cost

i = Discount Rate S = Annual Savings

e = Escalation Rate C/S = Simple Payback

$$PB = \frac{\log_{10}\left[1+\left(\frac{C}{S}\right)\left(1-\frac{1}{\left(\frac{1+e}{1+i}\right)}\right)\right]}{\log_{10}\left(\frac{1+e}{1+i}\right)}$$

Present Value Formulas

PRESENT VALUE FOR ANNUAL ENERGY COSTS OVER STUDY PERIOD:

DR	=	Discount Rate	UPV	=	Uniform Present Value Multiplier
ER	=	Energy Escalation Rate	EC	=	Annual Energy Costs
N	=	Number of Years in Study Period	ZEC	=	Present Value of Annual Energy Costs

$$UPV = \frac{\frac{1+ER}{1+DR}\left[1-\left(\frac{1+ER}{1+DR}\right)^{N}\right]}{1-\left(\frac{1+ER}{1+DR}\right)}$$

$$ZEC = EC \times UPV$$

PRESENT VALUE FOR ANNUAL SURVEILLANCE COSTS OVER A STUDY PERIOD:

DR = Discount Rate

MR = Maintenance/Repair Escalation Rate

N = Number of Years in Study Period

UPV = Uniform Present Value Multiplier

SC = Annual Surveillance Costs

ZSC = Present Value of Annual Surveillance Costs

$$UPV = \frac{\frac{1+MR}{1+DR}\left[1-\left(\frac{1+MR}{1+DR}\right)^{N}\right]}{1-\left(\frac{1+MR}{1+DR}\right)}$$

$$ZSC = SC \times UPV$$

PRESENT VALUE FOR ANNUAL MAINTENANCE COSTS OVER A STUDY PERIOD:

DR = Discount Rate

MR = Maintenance/Repair Escalation Rate

N = Number of Years in Study Period

UPV = Uniform Present Value Multiplier

MC = Annual Maintenance Costs

ZMC = Present Value of Annual Maintenance Costs

$$UPV = \frac{\frac{1+MR}{1+DR}\left[1-\left(\frac{1+MR}{1+DR}\right)^{N}\right]}{1-\left(\frac{1+MR}{1+DR}\right)}$$

$$ZMC = MC \times UPV$$

PRESENT VALUE FOR OCCASIONAL REPAIR COSTS:

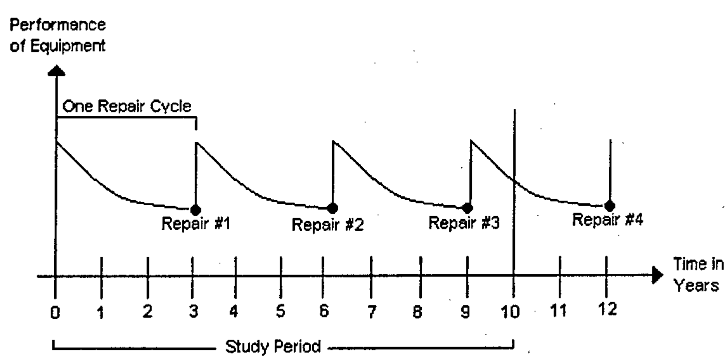
To determine the total for repair costs over a set study period, the number of repair occurrences must be determined. This is best illustrated using two examples. The general case will be discussed later.

Example 1:

Study Period	$= N$	= 10 years
Repair Cycle	$= CY$	= 3 years
Occasional Repair Cost	$= OC$	= $1000
Discount Rate	$= DR$	= 3 %
Maintenance/Repair Escalation Rate	$= MR$	= 5 %
Year at which cost occurs	$= YR$	
Single Present Value Multiplier	$= SPV$	

The formula for the single present value multiplier for a given year is:

$$SPV = \left(\frac{1+MR}{1+DR}\right)^{YR}$$



Repair #1 occurs at Year 3: $OC \times \left(\frac{1+MR}{1+DR}\right)^{YR} = \$1000 \times \left(\frac{1+0.05}{1+0.03}\right)^{3} = \$\ 1059$

Repair #2 occurs at Year 6: $OC \times \left(\frac{1+MR}{1+DR}\right)^{YR} = \$1000 \times \left(\frac{1+0.05}{1+0.03}\right)^{6} = \$\ 1122$

Repair #3 occurs at Year 9: $OC \times \left(\frac{1+MR}{1+DR}\right)^{YR} = \$1000 \times \left(\frac{1+0.05}{1+0.03}\right)^{9}$ = $ 1189

1/3 of a Repair occurs at Year 10: $\frac{1}{3} \times OC \times \left(\frac{1+MR}{1+DR}\right)^{YR} = \frac{1}{3} \times \$1000 \times \left(\frac{1+0.05}{1+0.03}\right)^{10}$ = $ 404

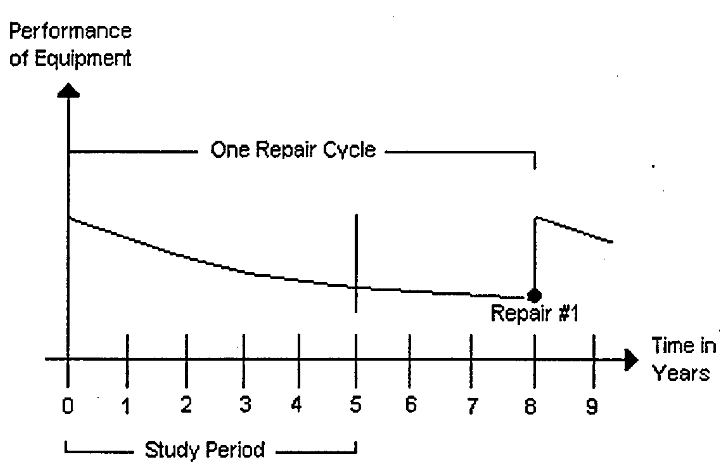
Total Present Value of Repair Costs for Study Period for Example #1: $ 3774

Example 2:

Study Period	= N = 5 years
Repair Cycle	= CY = 8 years
Occasional Repair Cost	= OC = $2000
Discount Rate	= DR = 3 %
Maintenance/Repair Escalation Rate	= MR = 5 %
Year at which cost occurs	= YR
Single Present Value Multiplier	= SPV

The formula for the single present value multiplier for a given year is:

$$SPV = \left(\frac{1+MR}{1+DR}\right)^{YR}$$



Repair #1 would occur at Year 8, which is beyond the scope of the study period. However for planning purposes, money should be set aside for an inevitable repair. Assume that ...

5/8 of a Repair occurs at Year 5: $\frac{5}{8}\times OC\times\left(\frac{1+MR}{1+DR}\right)^{YR} = \frac{5}{8}\times\$2000\times\left(\frac{1+0.05}{1+0.03}\right)^{5}$ = $\underline{\$\ 1376}$

Total Present Value of Repair Costs for Study Period, for Example #2: $ 1376

GENERAL CASE FOR CALCULATING THE PRESENT VALUE FOR OCCASIONAL REPAIR COSTS:

Study Period	$= N$
Repair Cycle	$= CY$
Occasional Repair Cost	$= OC$
Discount Rate	$= DR$
Maintenance/Repair Escalation Rate	$= MR$
Total PV of Occ. Repair Costs	$= ZOC$

The formula for the single present worth multiplier for a given year is:

$$SPV = \left(\frac{1+MR}{1+DR}\right)^{YR}$$

If the study period is shorter than the repair cycle (i.e., $N < CY$), then prorate the repair costs over the study period using this formula:

$$ZOC = \frac{N}{CY}\times OC\times\left(\frac{1+MR}{1+DR}\right)^{N}$$

If the repair cycle is shorter or equal to the study period (i.e., $CY \le N$), then proceed as follows:

Determine how many occurrences of an occasional repair will fall within the study period by dividing the study period by the repair cycle and *rounding* the quotient down to the nearest integer. The "remainder" portion of the quotient will be dealt with in section D:

$$Z_{int} = N \div CY \qquad \text{example: N = 25; CY = 3}$$

$$25 \div 3 = 8\frac{1}{3} \qquad Z_{int} = 8$$

(B) Determine at which year each occurrence of an occasional repair will fall within the study period:

$$YR_1 = CY \times 1 \qquad \text{example: } YR_1 = 3 \times 1 = 3$$

$$YR_2 = CY \times 2 \qquad YR_2 = 3 \times 2 = 6$$

$$YR_3 = CY \times 3 \qquad YR_3 = 3 \times 3 = 9$$

$$\ldots \qquad \ldots$$

$$YR_Z = CY \times Z_{int} \qquad YR_Z = 3 \times 8 = 24$$

(C) Calculate the Present Worth Value of each repair occurrence:

$$ZOC_x = OC \times \left(\frac{1+MR}{1+DR}\right)^{YR_X} \qquad \text{where x = 1, 2, 3 ... } Z_{int}$$

(D) Determine a present value for the portion of a repair cycle that may remain in the study period. If $YR_Z \neq N$, then this partial value can calculated using this formula:

$$ZOC_{partial} = \left(\frac{N-(Z_{int} \times CY)}{N}\right) \times OC \times \left(\frac{1+MR}{1+DR}\right)^N$$

(E) Sum the Present Worth Values of each repair occurrence:

$$ZOC = ZOC_1 + ZOC_2 + ZOC_3 + \ldots + ZOCz + ZOC_{partial}$$

<u>PRESENT VALUE FOR OCCASIONAL REPLACEMENT COSTS:</u>

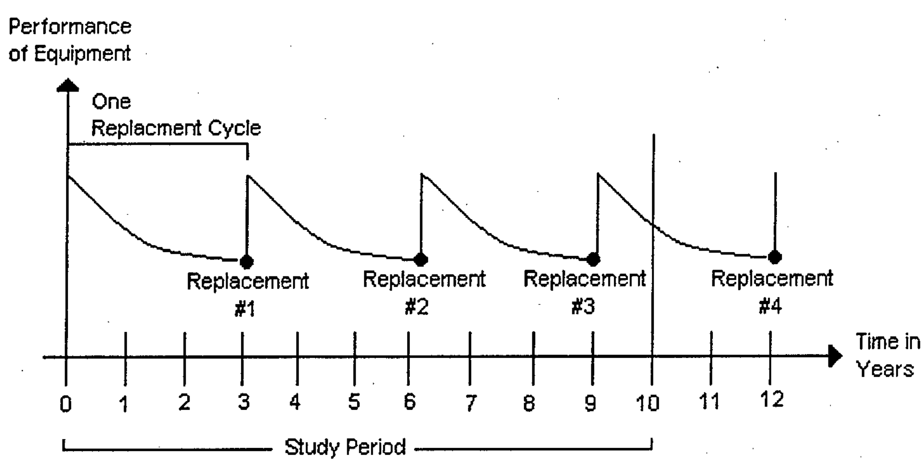
To determine the total for replacement costs over a set study period, the number of replacement occurrences must be determined. This is best illustrated using two examples. The general case will be discussed later.

Example 1:

Study Period	= N	=	10 years
Replacement Cycle	= CY	=	3 years
Occasional Replacement Cost	= OR	=	$ 1000
Discount Rate	= DR	=	3 %
Replacement Escalation Rate	= RR	=	5 %
Year at which cost occurs	= YR		
Single Present Value Multiplier	= SPV		

The formula for the single present value multiplier for a given year is:

$$SPV = \left(\frac{1+RR}{1+DR}\right)^{YR}$$



Replacement #1 occurs at Year 3: $OR \times \left(\frac{1+RR}{1+DR}\right)^{YR} = \$1000 \times \left(\frac{1+0.05}{1+0.03}\right)^{3}$ = $ 1059

Replacement #2 occurs at Year 6: $OR \times \left(\frac{1+RR}{1+DR}\right)^{YR} = \$1000 \times \left(\frac{1+0.05}{1+0.03}\right)^{6}$ = $ 1122

Replacement #3 occurs at Year 9: $OR \times \left(\frac{1+RR}{1+DR}\right)^{YR} = \$1000 \times \left(\frac{1+0.05}{1+0.03}\right)^{9}$ = $ 1189

1/3 of a Replac. occurs at Year 10: $\frac{1}{3} \times OR \times \left(\frac{1+RR}{1+DR}\right)^{YR} = \frac{1}{3} \times \$1000 \times \left(\frac{1+0.05}{1+0.03}\right)^{10} = \$404$

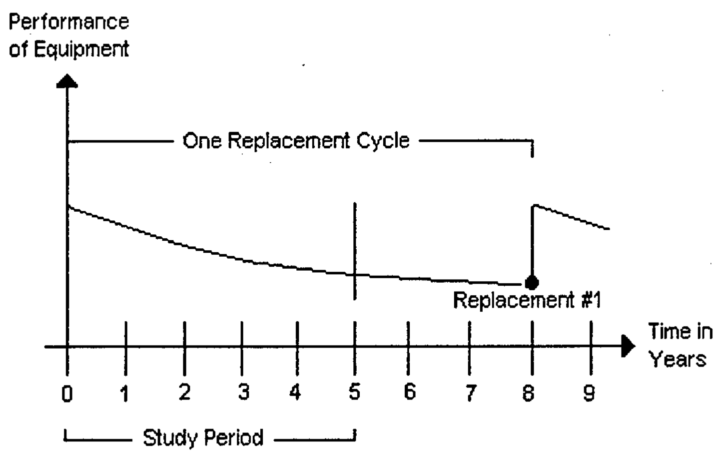
Total Present Value of Replac. Costs for Study Period for Example #1: $ 3774

Example 2:

Study Period	= N = 5 years
Replacement Cycle	= CY = 8 years
Occasional Replacement Cost	= OR = $ 2000
Discount Rate	= DR = 3 %
Replacement Escalation Rate	= RR = 5 %
Year at which cost occurs	= YR
Single Present Value Multiplier	= SPV

The formula for the single present value multiplier for a given year is:

$$SPV = \left(\frac{1+RR}{1+DR}\right)^{YR}$$



Replacement #1 would occur at Year 8, which is beyond the scope of the study period. However for planning purposes, money should be set aside for an inevitable replacement. Assume that ...

5/8 of a Replac. occurs at Year 5: $\frac{5}{8} \times OR \times \left(\frac{1+RR}{1+DR} \right)^{YR} = \frac{5}{8} \times \$2000 \times \left(\frac{1+0.05}{1+0.03} \right)^{5}$ =\$1376

Total Present Value of Replac. Costs for Study Period for Example #2: \$ 1376

GENERAL CASE FOR CALCULATING THE PRESENT VALUE FOR OCCASIONAL REPLACEMENT COSTS:

Study Period	= N
Replacement Cycle	= CY
Occasional Replacement Cost	= OR
Discount Rate	= DR
Replacement Escalation Rate	= RR
Total PV of Occasional Replacement Costs	= ZOR

The formula for the single present worth multiplier for a given year is:

$$SPV = \left(\frac{1+RR}{1+DR} \right)^{YR}$$

If the study period is shorter than the replacement cycle (i.e., $N < CY$), then prorate the replacement costs over the study period using this formula:

$$ZOR = \frac{N}{CY} \times OR \times \left(\frac{1+RR}{1+DR} \right)^{N}$$

If the replacement cycle is shorter or equal to the study period (i.e., $CY \leq N$), then proceed as follows:

Determine how many occurrences of an occasional replacement will fall within the study period by dividing the study period by the replacement cycle and *rounding* the quotient down to the nearest integer. The "remainder" portion of the quotient will be dealt with in section D:

$Z_{\text{int}} = N \div CY$ example: N = 25; CY = 3

$$25 \div 3 = 8\frac{1}{3} \qquad Z_{\text{int}} = 8$$

(B) Determine at which year each occurrence of an occasional replacement will fall within the study period:

$YR_1 = CY \times 1$ example: $YR_1 = 3 \times 1 = 3$

$YR_2 = CY \times 2$ $YR_2 = 3 \times 2 = 6$

$YR_3 = CY \times 3$ $YR_3 = 3 \times 3 = 9$

. . . . . .

$YR_Z = CY \times Z_{\text{int}}$ $YR_Z = 3 \times 8 = 24$

(C) Calculate the Present Worth Value of each replacement occurrence:

$ZOR_x = OR \times \left(\frac{1+RR}{1+DR}\right)^{YR_X}$ where x = 1, 2, 3 ... Z_{int}

(D) Determine a present value for the portion of a replacement cycle that may remain in the study period. If $YR_Z \neq N$, then this partial value can calculated using this formula:

$$ZOR_{partial} = \left(\frac{N-(Z_{\text{int}} \times CY)}{N}\right) \times OR \times \left(\frac{1+RR}{1+DR}\right)^N$$

(E) Sum the Present Worth Values of each replacement occurrence:

$$ZOR = ZOR_1 + ZOR_2 + ZOR_3 + \ldots + ZORz + ZOR_{partial}$$

<u>TOTAL PRESENT VALUE OF ALL COSTS</u>:

IC = Initial Costs

ZEC = Present Value of Annual Energy Costs

ZSC = Present Value of Annual Surveillance Costs

ZMC =Present Value of Annual Maintenance Costs

ZOC = Present Value of Occasional Repair Costs

ZOR = Present Value of Occasional Replacement Cost

TPV = Total Present Value of All Cost

$$TPV = IC + ZEC + ZSC + ZMC + ZOC + ZOR$$

Average Annualized Cost Formula:

AAC = Average Annualized Cost

TPV = Total Present Value of All Costs

DR = Discount Rate

N = Number of Years in Study Period

$$AAC = TPV \times \frac{DR \times (1+DR)^N}{(1+DR)^N - 1}$$

Formulas for Cost Benefit

<u>COST BENEFIT OF PERFORMING PREVENTIVE MAINTENANCE</u>:

IC = Initial Costs

ZEC = Present Value of Annual Energy Costs

ZSC = Present Value of Annual Surveillance Costs

ZMC =Present Value of Annual Maintenance Costs

ZOC = Present Value of Occasional Repair Costs

ZOR = Present Value of Occasional Replacement Cost

LOS = Loss of Service Costs

LCC_w / PM =Total Life Cycle Costs with Preventive Maintenance

LCC_w / oPM = Total Life Cycle Costs without Preventive Maintenance

$$LCC\_w/PM = IC + ZEC + ZSC + ZMC$$

$$LCC\_w/oPM = IC + ZEC + LOS + ZOC + ZOR$$

$$Cost\ Benefit\ Ratio = \frac{(LCC\_w/PM)}{(LCC\_w/PM) - (LCC\_w/oPM)}$$

<u>COST BENEFIT OF PURCHASING NEW EQUIPMENT</u>:

IC = Initial Costs of Existing Equipment

ZEC = Present Value of Annual Energy Costs using Existing Equipment

ZSC = Present Value of Annual Surveillance Costs using Existing Equipment

ZMC =Present Value of Annual Maintenance Costs using Existing Equipment

ZOC = Present Value of Occasional Repair Costs using Existing Equipment

ZOR = Present Value of Occasional Replacement Cost using Existing Equipment

Note: If Preventative Maintenance is done on existing equipment, then:

ZOC = 0

ZOR = 0

If No Preventative Maintenance is performed on existing equipment, then:

ZSC = 0

ZMC = 0

NIC = Initial Costs of New Equipment

ZNEC = Present Value of Annual Energy Costs using New Equipment

ZNSC = Present Value of Annual Surveillance Costs using New Equipment

ZNMC =Present Value of Annual Maintenance Costs using New Equipment

ZNOC = Present Value of Occasional Repair Costs using New Equipment

ZNOR = Present Value of Occasional Replacement Cost using New Equipment

LCC_new = Total Life Cycle Costs of Purchasing New Equipment

LCC_existing = Total Life Cycle Costs of Using Existing Equipment

$$LCC\_new = NIC + ZNEC + ZNSC + ZNMC + ZNOC + ZNOR$$

$$LCC\_existing = IC + ZEC + ZSC + ZMC + ZOC + ZOR$$

$$Cost\ Benefit\ Ratio = \frac{(LCC\_new)}{(LCC\_new) - (LCC\_existing)}$$

ANNUAL ELECTRICAL COSTS FOR RUNNING A FAN MOTOR:

	unit = KW/horsepower	
gas flow rate	unit = CFM	range =
pressure drop	unit = in. of water, GGE	range = 1" - 10"
specific gravity		range = 1.0
operating rate	unit = hour/year	range = 0 - 8760
electricity cost	unit = $/KWH	range = $.06 - $.10
efficiency	unit = %	range = 60% - 70%
6356.0	unit conversion factor	
Cost	unit = $/year	

$$Cost = \frac{(0.746)(flowrate)(pressdrop)(specgrav)(operrate)(elect\cos t)}{(6356)(fanmotor\_efficiency)}$$

Appendix B: PREPARE System User Guide

B1. Introduction

The Prevention Reduction and Emission Prevention Automated Rule-based Expert (PREPARE) System allows the user to calculate the cost of performing preventive maintenance (PM) and comparing it with the cost of "Run-to-Failure" and loss of service. The expert system includes several approaches to solving problems for maintenance of pollution control equipment.

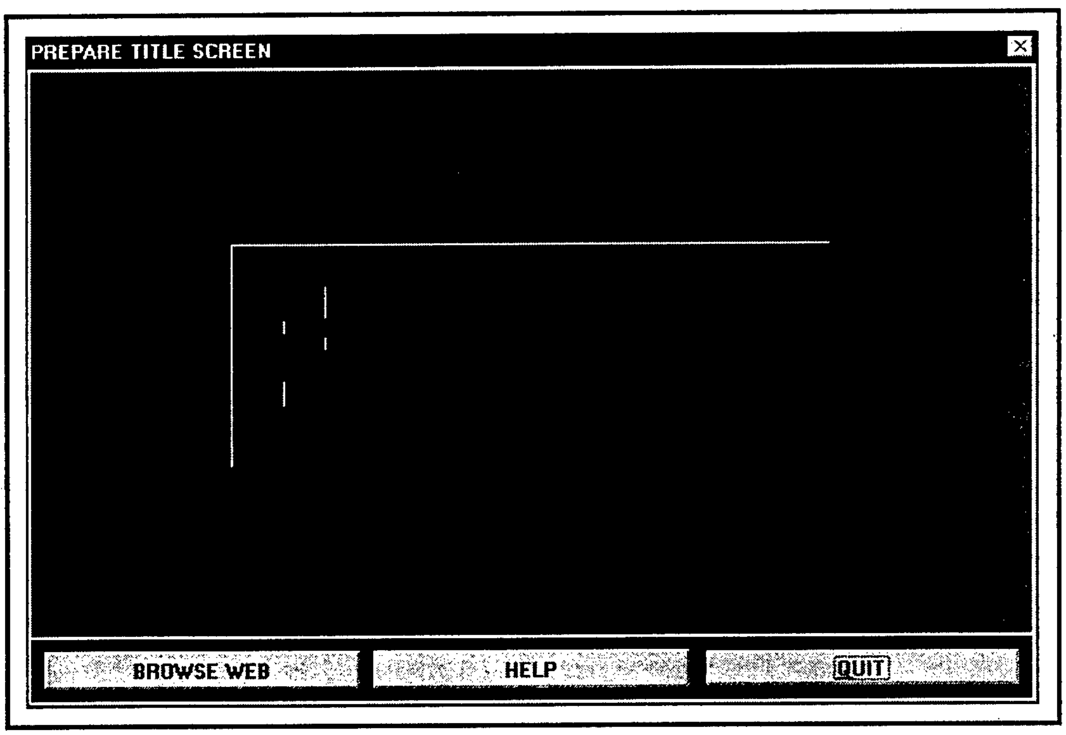


Figure B1. PREPARE opening screen.

B2. Program Installation

System Requirements

IBM 386 compatible PC or greater; 4 MB RAM or greater; Windows 95/NT

Due to the large amount of information on the form screens, the display mode must be at least 800 x 600 pixels in size. The default 640 x 480 pixels screen resolution will not show the entire entry form. The program is also expecting a 256-color mode for the display. Although the program will work with a 16-color mode, the screen display will not be optimal. Most modern desktops and portables will have the 256-color mode available. The user should also select Small Font to fit the program on the screen.

Software Setup

- Insert CD-ROM or floppy disk in the appropriate drive.
- Double click the *setup.exe* file and PREPARE will automatically begin installation.
- Select the suggested directory in which to set up the PREPARE files in order to run the program or make your own directory.
- Click the computer icon to complete the installation of PREPARE onto the machine.

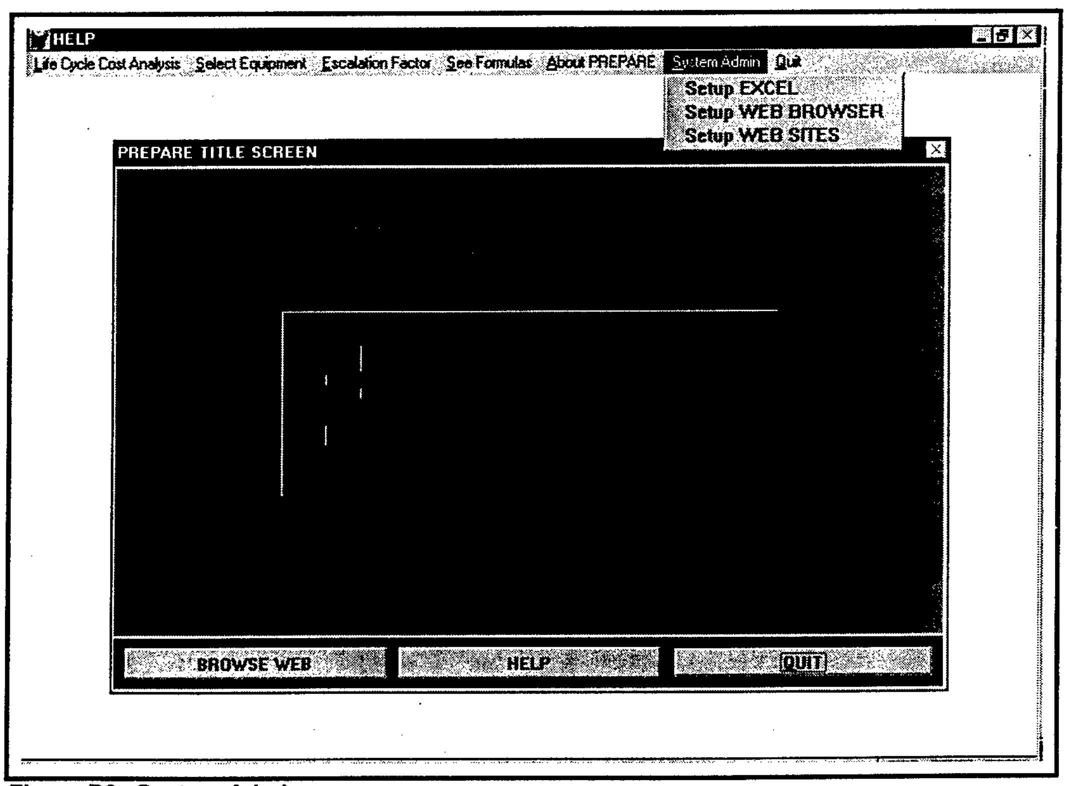


Figure B2. System Admin menu.

B3. Links to Outside Applications

Setup Links to Outside Applications

Click *System Admin.* on the toolbar.

Click *Setup Excel* to set up path for launching Microsoft Excel.

Click *Edit*.

Type in DOS path name and program file name.

Click *Save*. Then, click *OK* to return to main menu.

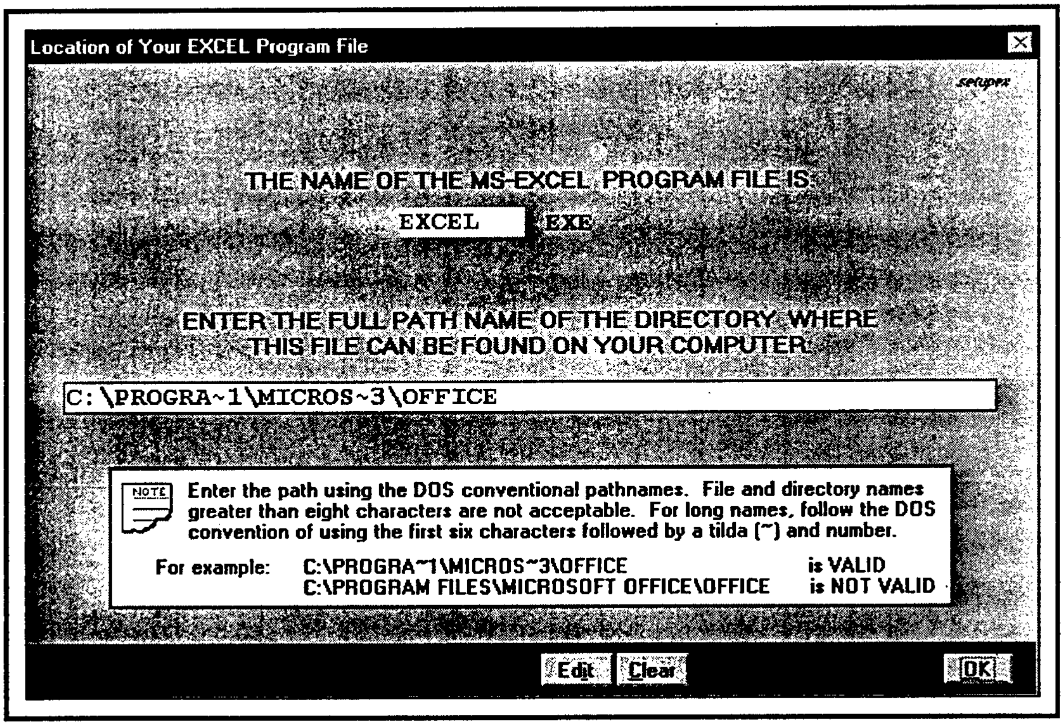


Figure B3. Setup Excel screen.

Click *Setup Web Browser* to set up path for launching the web browser.

Click *Edit*.

Type in DOS path name and program file name.

Click *Save*. Then, click *OK* to return to main menu.

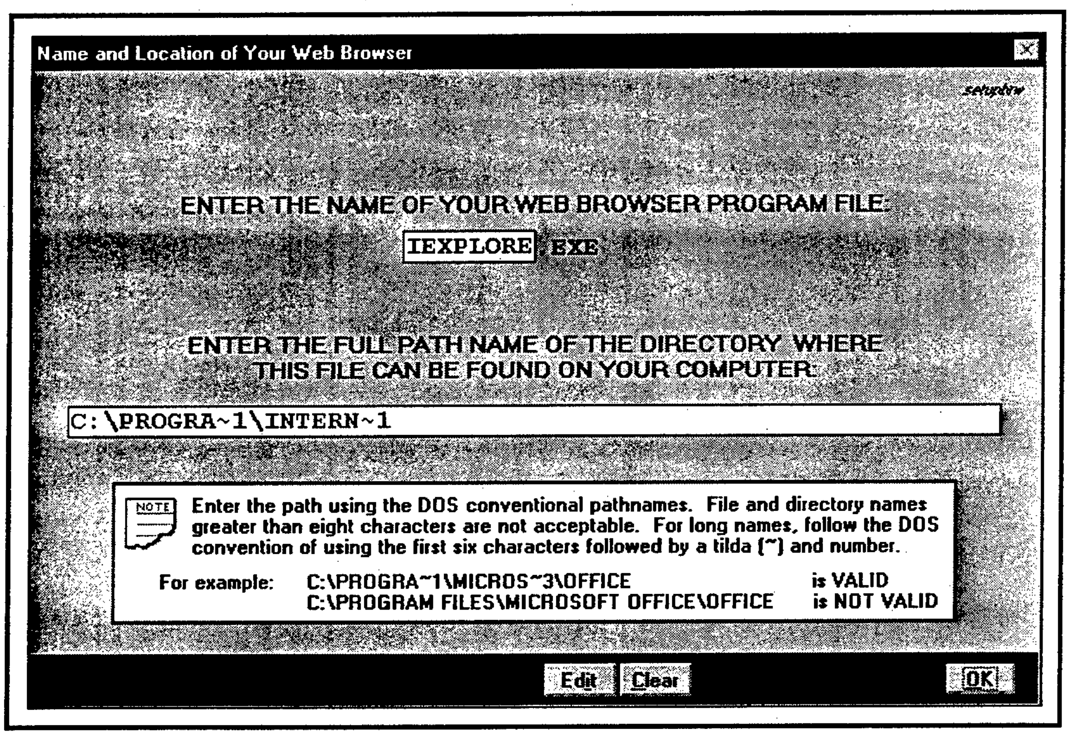


Figure B4. Setup web browser screen.

Click *Setup Web Sites* to set up path for a web site designation.

Click *Edit*.

Type in web site designation.

Type in a search label.

Assign a search category.

Click *Save*. Then, click *Close* to return to main menu.

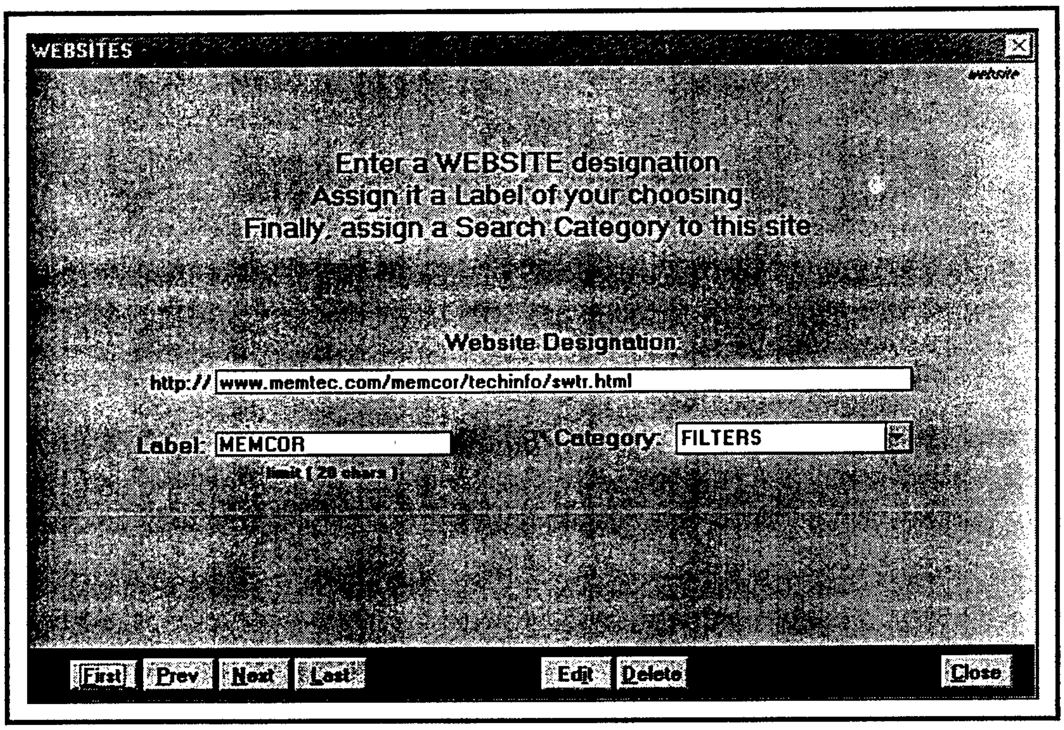


Figure B5. Setup web sites.

B4. PREPARE: Step By Step

Click *About PREPARE* on the toolbar.

Click *Overview* to read the objective of the PREPARE program.

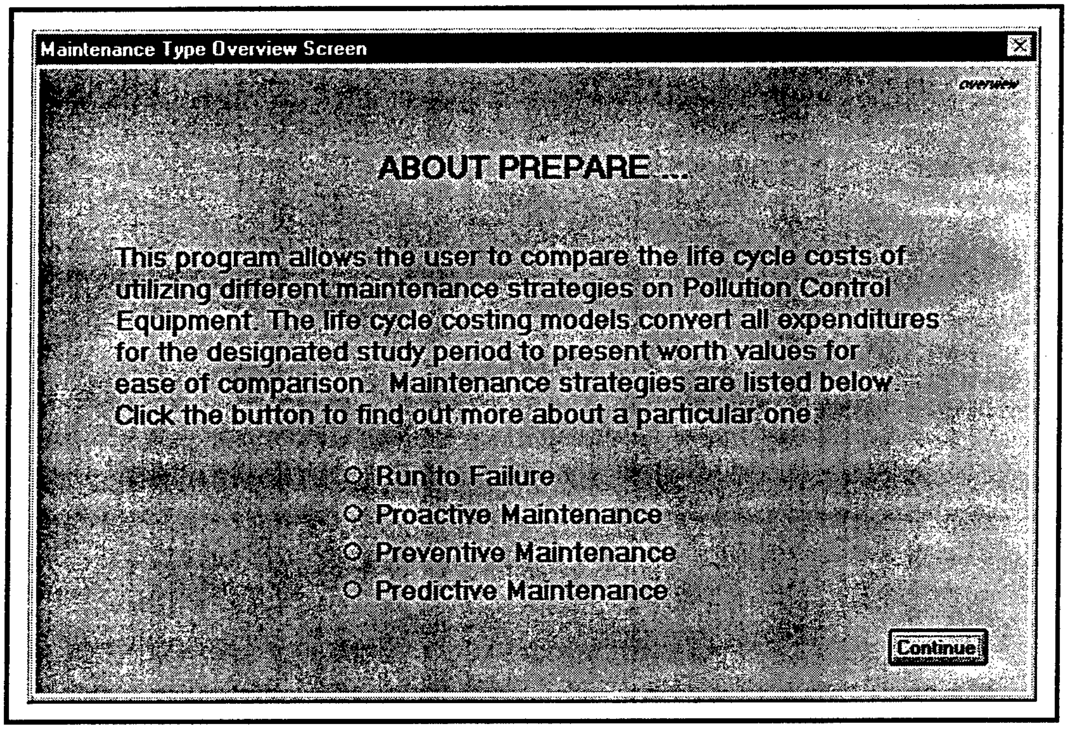


Figure B6. Overview of PREPARE program.

Click *Logic Tree* to determine the type of maintenance/RCM that should be used on a piece of equipment.

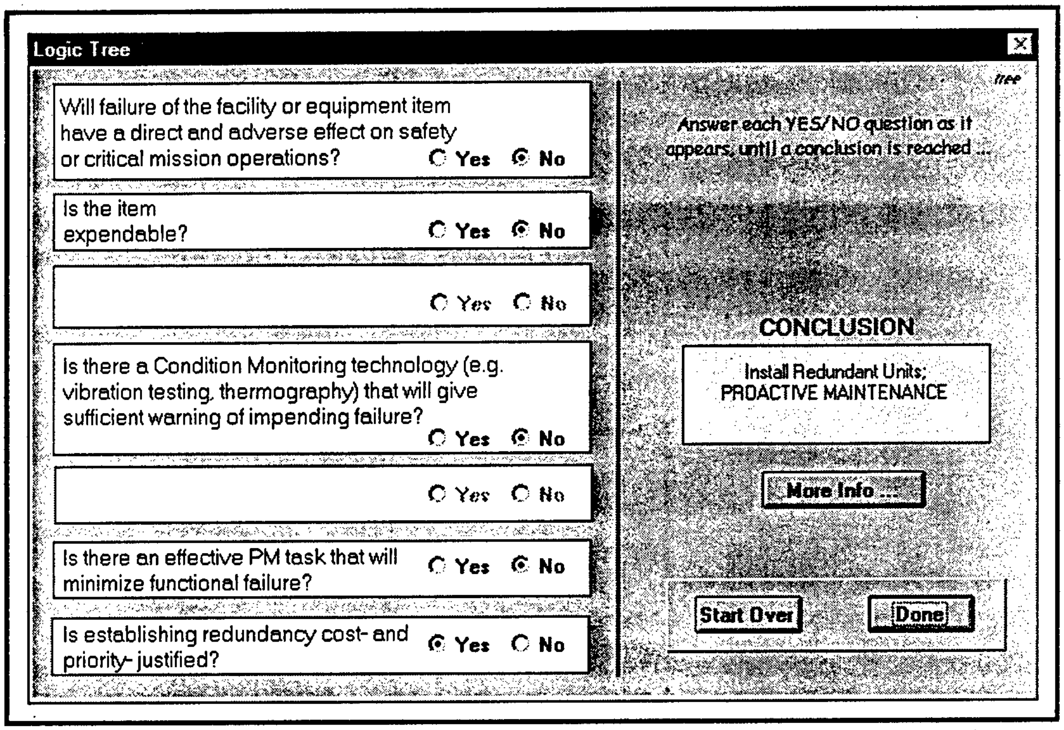


Figure B7. Logic tree.

Click *More Info* to read the definitions of the maintenance/RCM categories.

Click *Start Over* to run another trial or *Done* to exit logic tree.

Click *Select Equipment* on the toolbar.

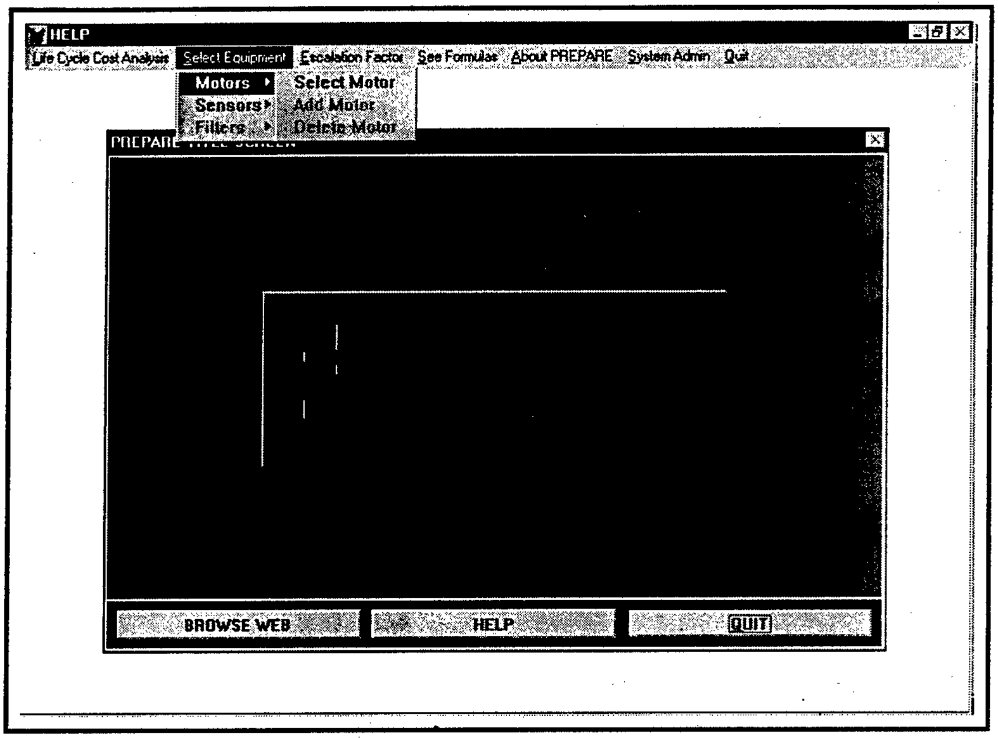


Figure B8. Select equipment menu.

Click *Life Cycle Cost Analysis* on the toolbar.

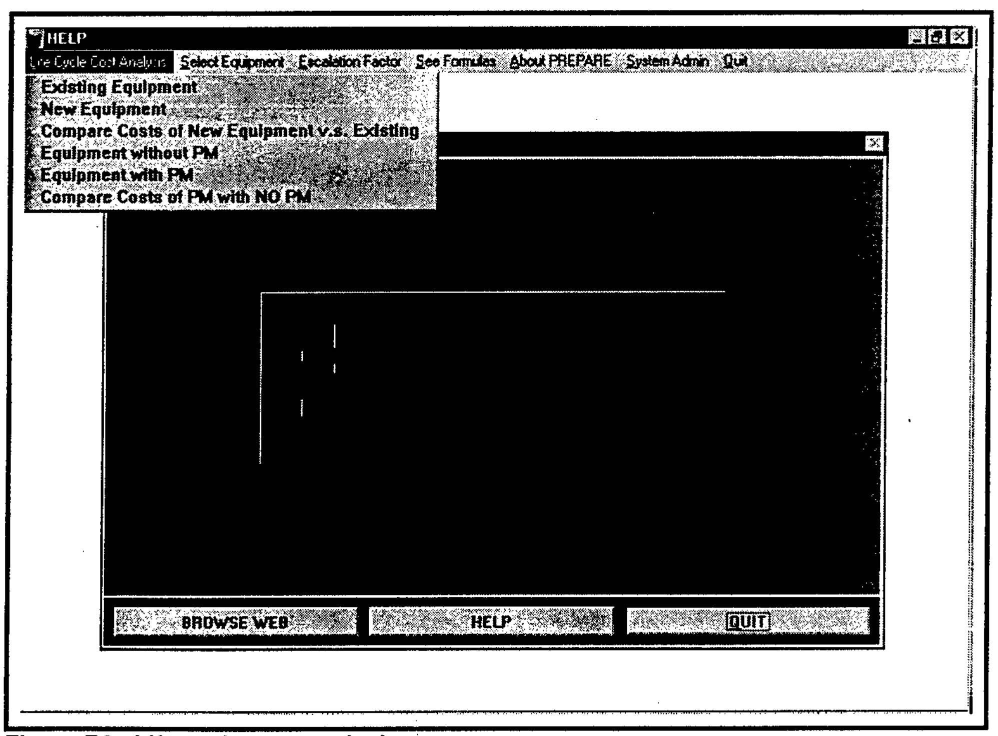


Figure B9. Life cycle cost analysis menu.

Select an option from the Life Cycle Cost Analysis menu and the following screen appears. From this screen the user selects a study set or adds a new set. A study set is a set of data inputs that you may save and reuse at a later time.

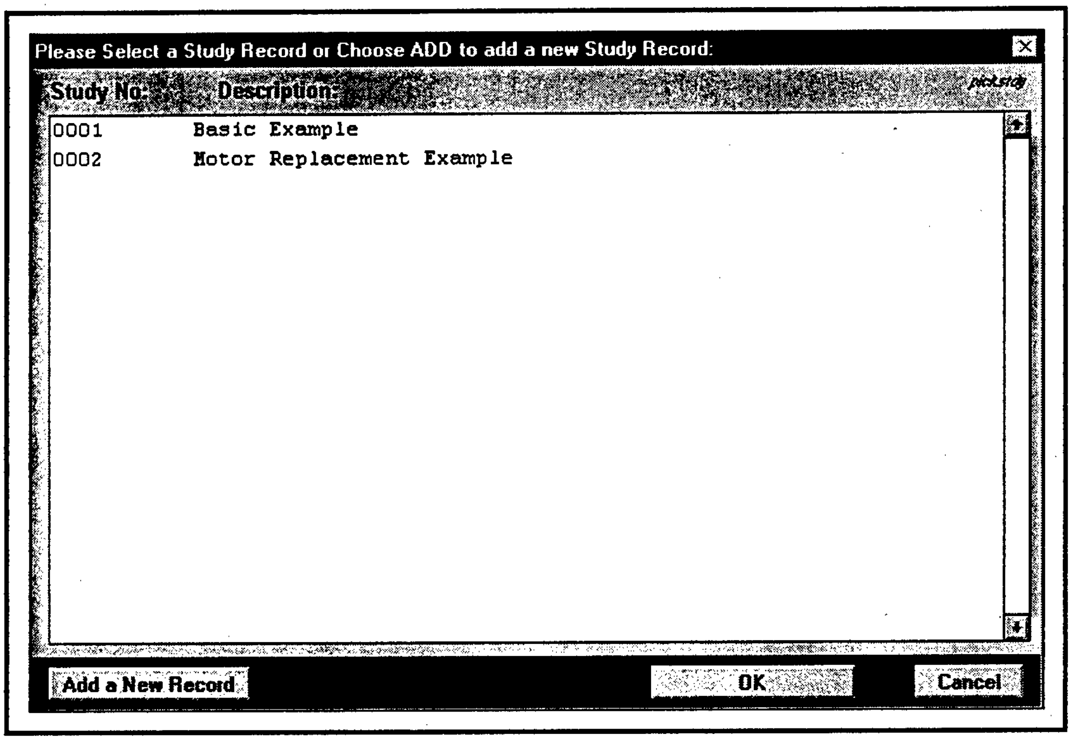


Figure B10. Study record screen.

Figures B11 through B16 show the individual screens from the Life Cycle Cost Analysis menu.

Discount rates used in PREPARE are taken from EOP-OMB Circular No. A-94 *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. This document is accessible on the internet at the following website http://www2.whitehouse.gov/WH/EOP/OMB/html/circulars/a094/a094.html

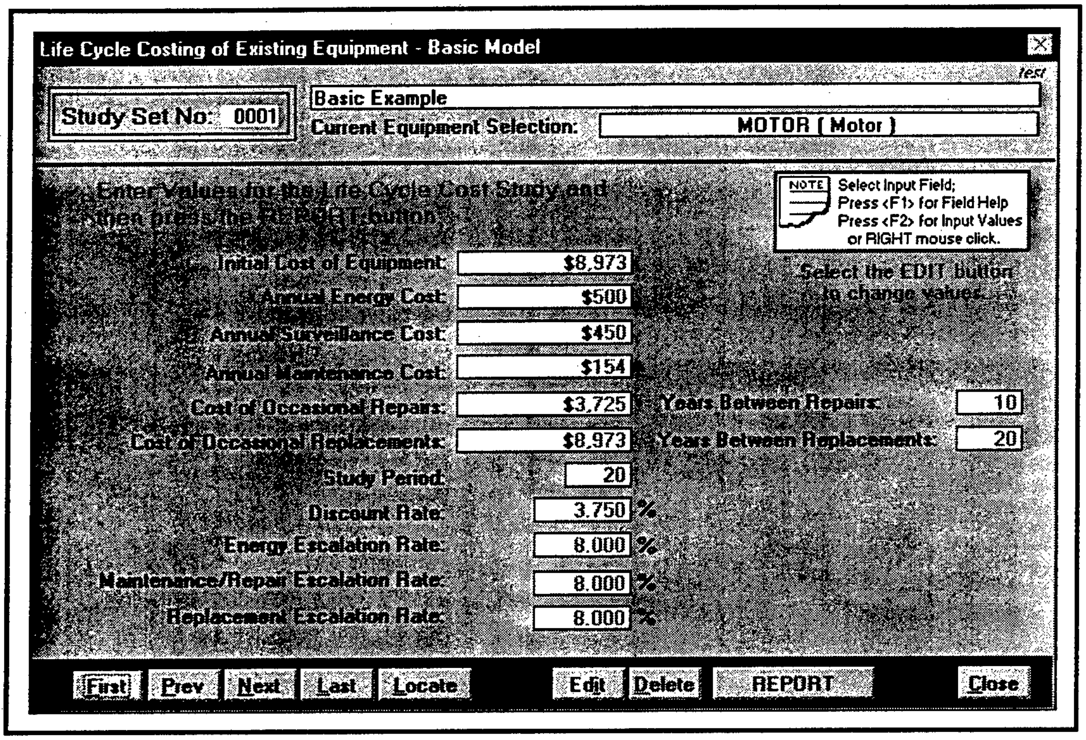


Figure B11. LCC analysis of existing equipment.

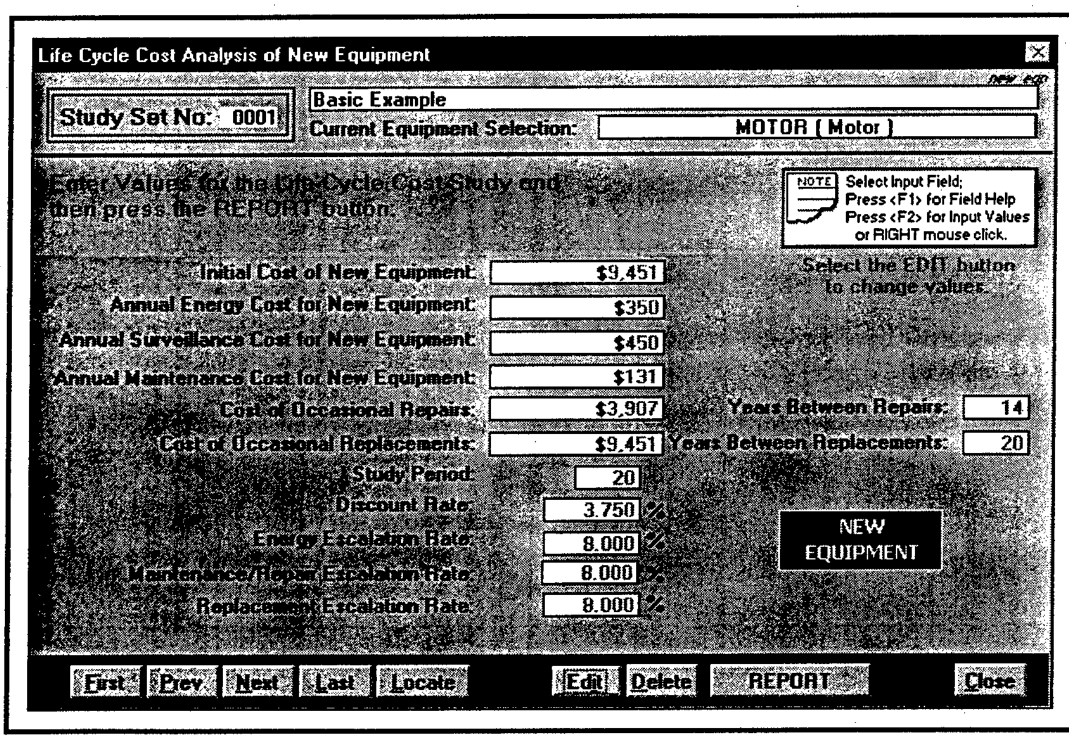


Figure B12. LCC analysis of new equipment.

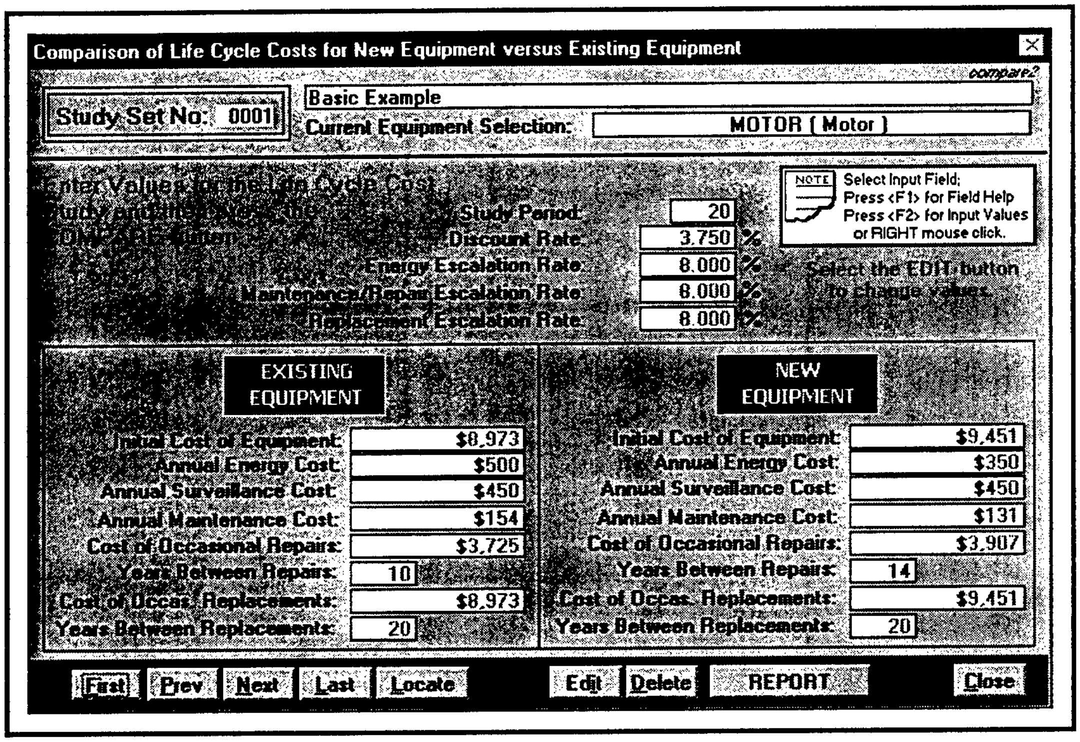


Figure B13. Comparison of LCC analyses for new vs. existing equipment.

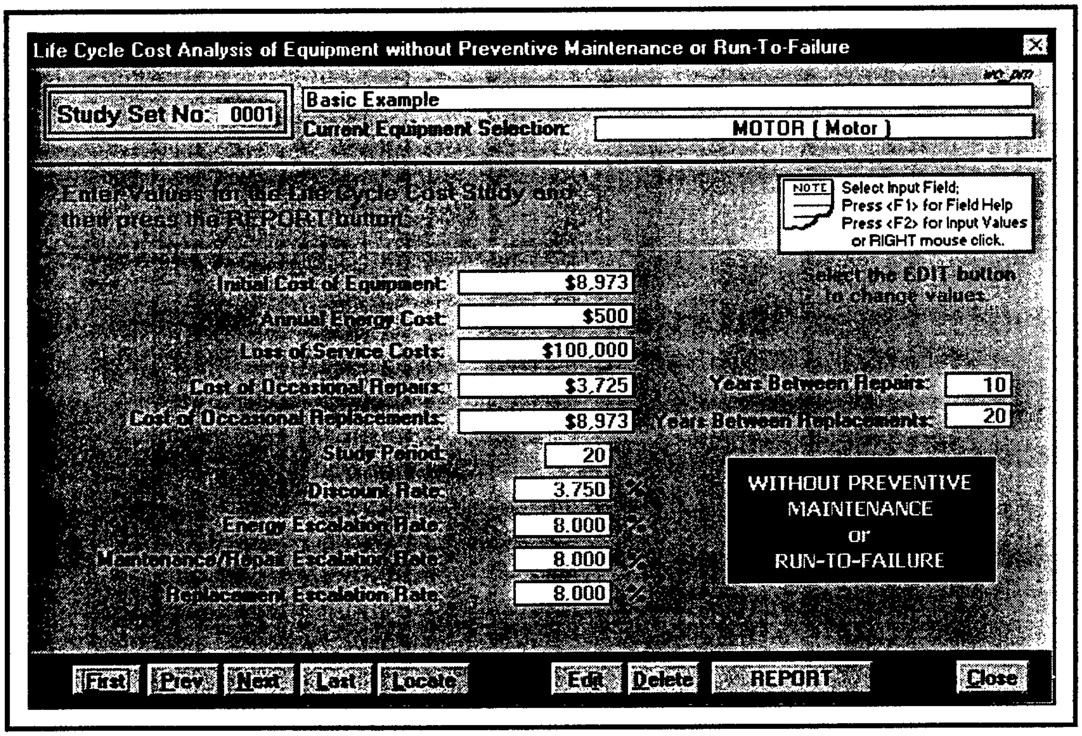


Figure B14. LCC analysis of equipment using Run-to-Failure.

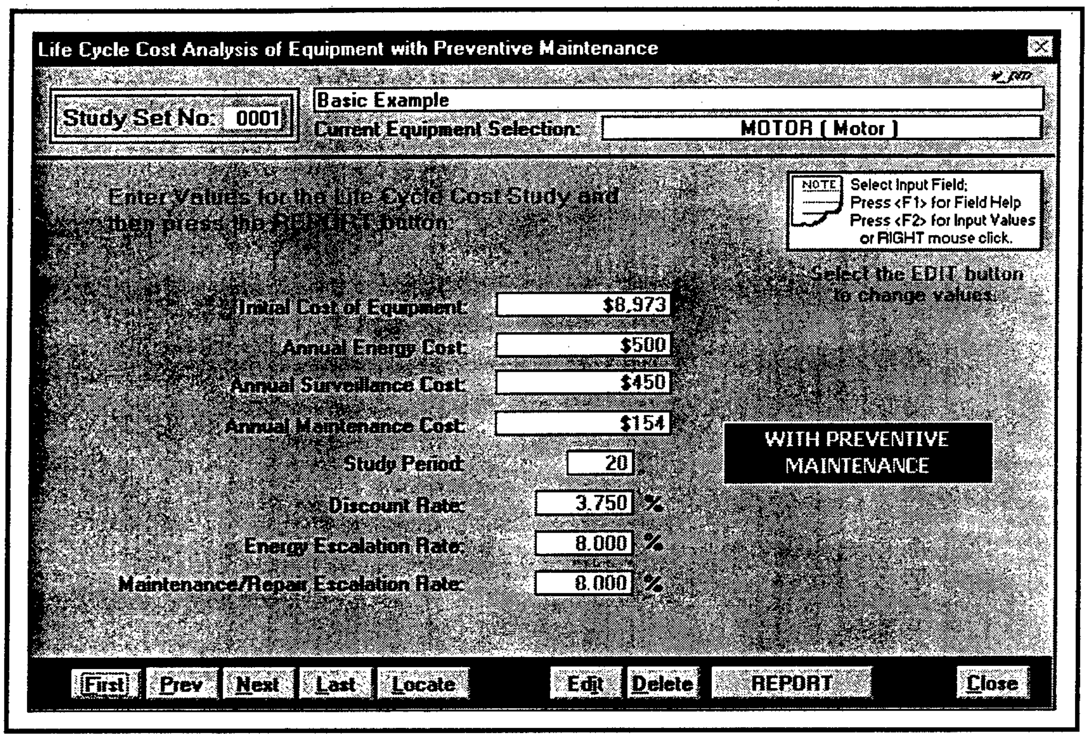


Figure B15. LCC analysis of equipment using Preventive Maintenance.

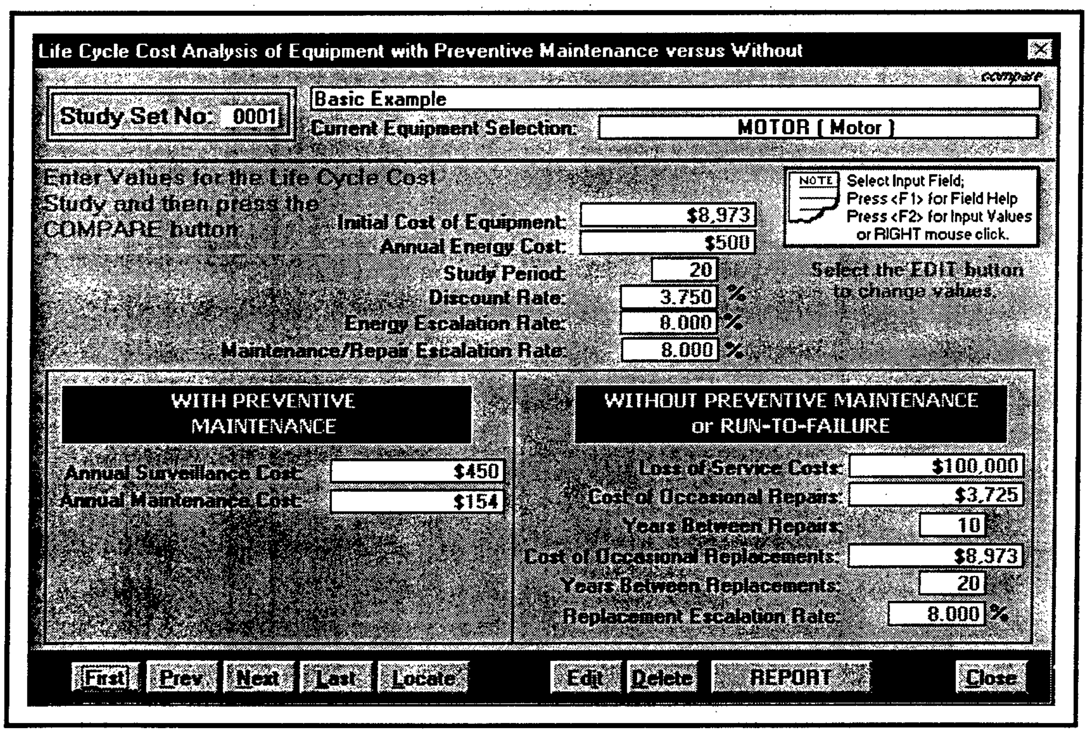


Figure B16. Comparison of LCC analyses of equipment using Preventive Maintenance vs. Run-to-Failure.

Click *Edit* to change values.

Press *F1* for the help screen once you place the cursor in a field.

Press *F2* to input values once you place the cursor in a field.

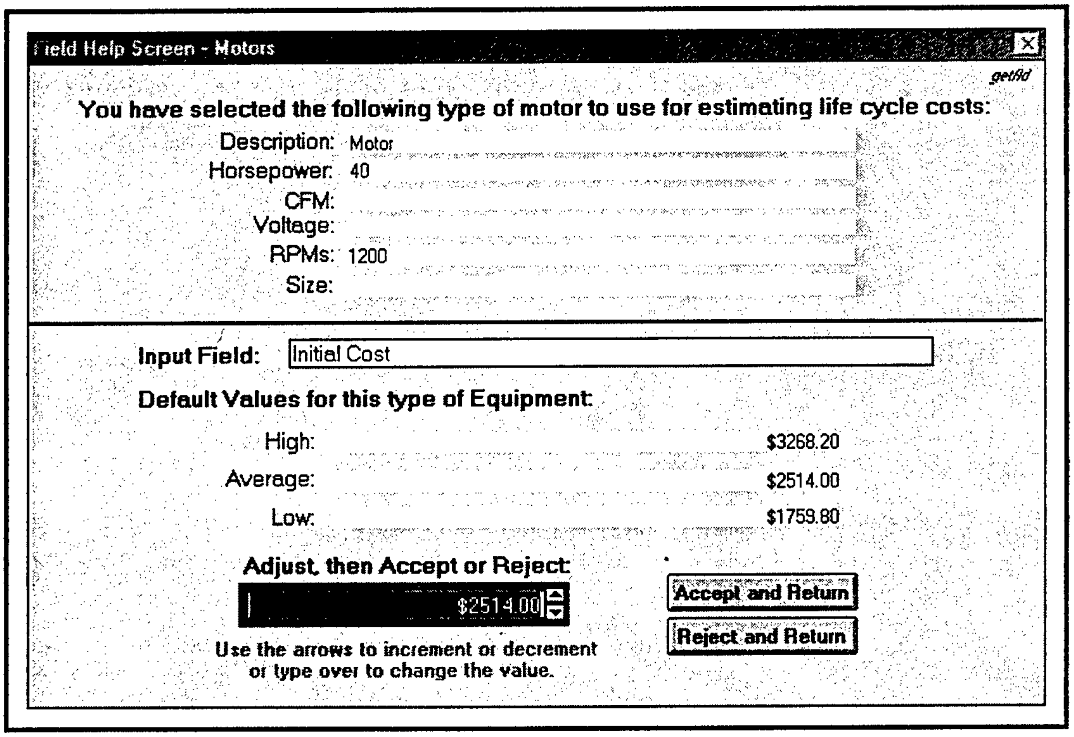


Figure B17. Screen to input values for motors.

Click *Save* or *Cancel* to exit the edit mode.

Click *Report* for a report. Click *OK* when done. Print report? *Yes/No.*

Click *Close* when finished.

Click *Escalation Factor* on the toolbar.

Click *Edit* to change values. (Click *F1* for help.)

Click *Save* or *Cancel* to exit the edit mode.

Click Chart/Excel (icon) button to launch charting tool in Excel. Excel will then launch and display the value of investment for 10 years. Low, average, and high values are shown color-coded for comparison.

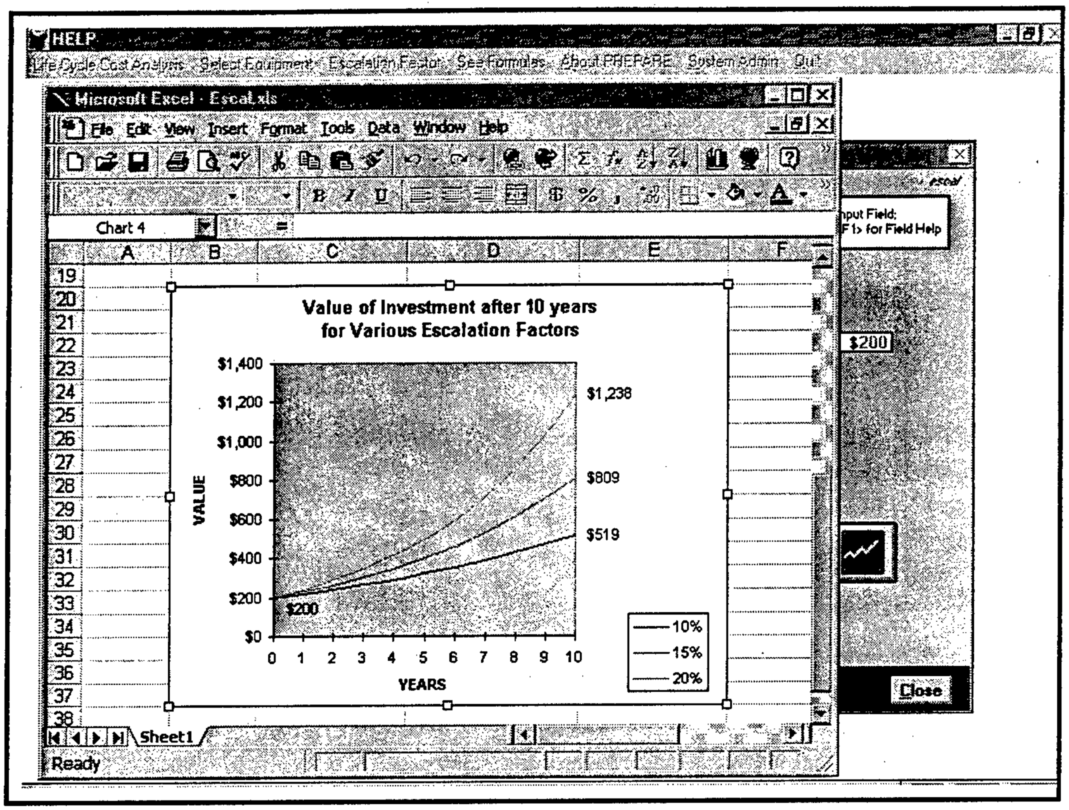


Figure B18. Excel chart for escalation factors.

Choose *File* → *Exit* to exit out of Excel.

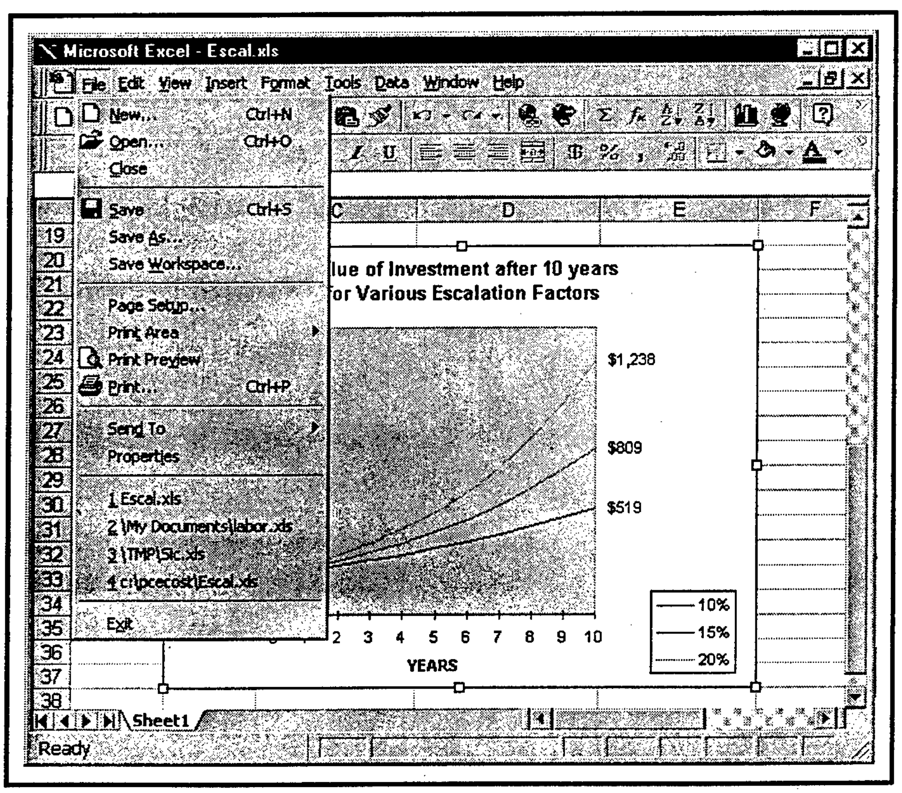


Figure B19. Exit out of Excel.

Choose *Close* in PREPARE to exit out of Escalation Factor.

Click *See FORMULAS* on the toolbar to see formulas used in calculations.

Click *Continue* to exit.

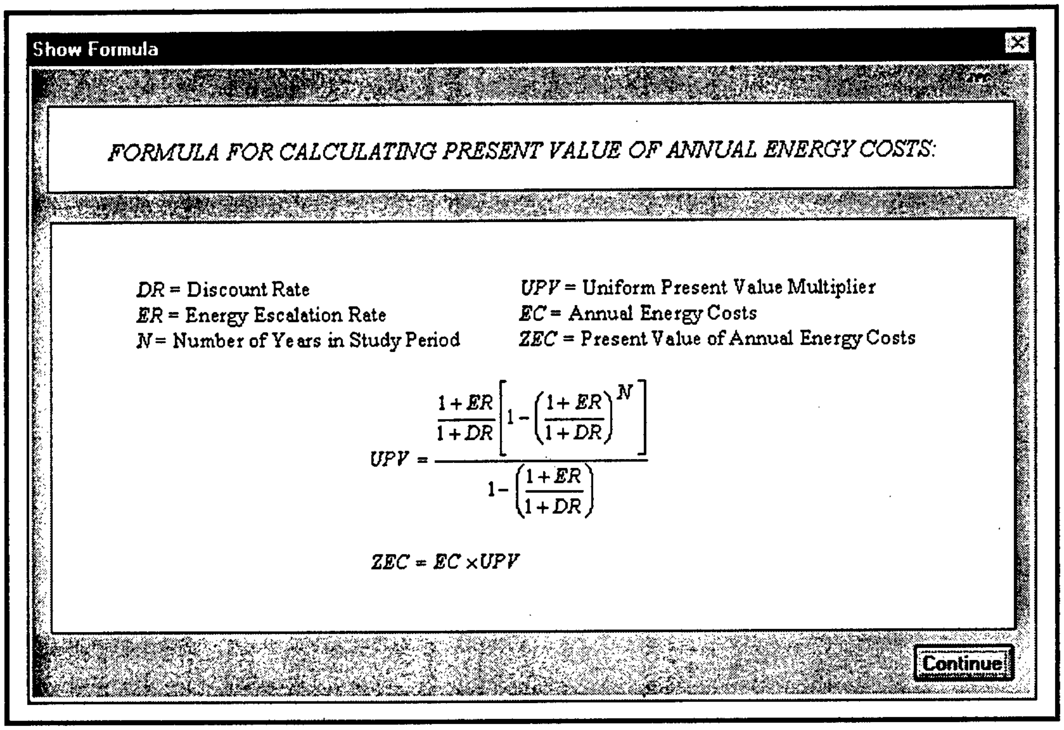


Figure B20. FORMULAS sample screen.

Click *Quit* to exit the PREPARE program.

B5. Reading the Report

Input Information

Initial Cost – Initial acquisition cost or sunk cost.

Annual Energy Cost – The yearly cost to run the equipment (present value of an annuity). Routine PM.

Annual Surveillance Cost – The yearly cost to monitor the equipment (present value of an annuity). Routine PM.

Annual Maintenance Cost – The yearly cost to maintain the equipment (present value of an annuity). Routine PM.

Occasional Repairs & Occasional Replacements – The cost in case of breakdowns (present value of the predicted breakdown cost per study period).

Study Period – Time period in which a piece of equipment is observed for maintenance and breakdowns.

Discount Rate – Interest rate that denotes market value and inflation/depreciation value of capital over time. Opportunity cost is taken into account here.

Energy Escalation Rate – A multiplier that takes into account energy rate fluctuations.

Maintenance/Repair Escalation Rate – A multiplier that takes into account maintenance/repair fee variations.

Replacement Escalation Rate – A multiplier that takes into account variable replacement rate costs.

Output Information

Initial Cost – Initial acquisition cost or sunk cost.

Present Value Energy Costs – Cost of energy to run equipment.

Present Value Surveillance Costs – Cost to monitor the equipment.

Present Value Maintenance Costs – Cost to maintain/repair the equipment.

Present Value Occasional Repair Costs – Cost to fix the equipment if there is a breakdown.

Present Value Occasional Replacement Costs – Cost to replace equipment and/or its parts in the case of a breakdown.

Total Present Value of Costs – The present value of total costs.

Average Annual Cost – Average cost per year to run and maintain the equipment.

Sample Reports

LIFE CYCLE COST REPORT
Existing Equipment - Basic Model

For Equipment: Basic Example

INPUT INFORMATION:

Initial Cost:	$8,973	
Annual Energy Cost:	$500	
Annual Surveillance Cost:	$450	
Annual Maintenance Cost:	$154	
Occasional Repair Costs:	$3,725	per 10 years
Occasional Replacement Costs:	$8,973	per 20 years
Study Period:	20	years
Discount Rate:	3.750 %	
Energy Escalation Rate:	8.000 %	
Maintenance/Repair Escalation Rate:	8.000 %	
Replacement Escalation Rate:	8.000 %	

OUTPUT INFORMATION:

Initial Cost:	$8,973
PV of Annual Energy Costs:	$15,654
PV of Annual Surveillance Costs:	$14,089
PV of Annual Maintenance Costs:	$4,821
PV of Occasional Repair Costs:	$13,879
PV of Occasional Replacement Costs:	$20,028
Total Present Value of Costs:	**$77,444**
Average Annual Cost:	**$5,573**

01/13/99

Figure B21. LCC report for existing equipment – basic model (Brown and Yanuck 1980).

LIFE CYCLE COST REPORT
New Equipment

For Equipment: Basic Example

INPUT INFORMATION:

Initial Cost of New Equipment:	$9,451		
Annual Energy Cost For New Equipment:	$350		
Annual Surveillance Cost for New Equipment:	$450		
Annual Maintenance Cost for New Equipment:	$131		
Occasional Repair Costs for New Equipment:	$3,907	per	14 year
Occasional Replacement Costs for New Equip.:	$9,451	per	20 year
Study Period:	20	years	
Discount Rate:	3.750 %		
Energy Escalation Rate:	8.000 %		
Maintenance/Repair Escalation Rate:	8.000 %		
Replacement Escalation Rate:	8.000 %		

OUTPUT INFORMATION:

Initial Cost of New Equipment:	$9,451
PV of Energy Costs for New Equipment:	$10,958
PV of Surveillance Costs for New Equipment:	$14,089
PV of Maintenance Costs for New Equipment:	$4,101
PV of Occ. Repair Costs for New Equipment:	$10,591
PV of Occ. Replac. Costs for New Equipment:	$21,095
Total Present Value of Costs of New Equipment:	**$70,285**
Average Annual Cost:	**$5,057**

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Figure B22. LCC report for new equipment.

LIFE CYCLE COST REPORT
(Comparison of Life Cycle Costs of New Equipment vs. Existing Equipment)

For Equipment: Basic Example

INPUT INFORMATION:

Initial Cost:	$8,973	Initial Cost:	$9,451
Annual Energy Cost:	$500	Annual Energy Cost:	$350
Annual Surveil. Costs:	$450	Annual Surveil. Costs:	$450
Ann. Maint. Costs:	$154	Ann. Maint. Costs:	$131
Occ. Repair Costs: every 10 yrs	$3,725	Occ. Repair Costs: every 14 yrs	$3,907
Occ. Replacement Costs: every 20 yrs	$8,973	Occ. Replacement Costs: every 20 yrs	$9,451

Study Period in Years:	20
Discount Rate:	3.750 %
Energy Escalation Rate:	8.000 %
Maintenance/Repair Escalation Rate:	8.000 %
Replacement Escalation Rate:	8.000 %

OUTPUT INFORMATION:

Initial Cost:	$8,973	Initial Cost:	$9,451
Energy Costs:	$15,654	Energy Cost:	$10,958
Surveillance Costs:	$14,089	Surveillance Costs:	$14,089
Maintenance Costs:	$4,821	Maintenance Costs:	$4,101
Occ. Repair Costs:	$13,879	Occ. Repair Costs:	$10,591
Occ. Replac. Costs:	$20,028	Occ. Replac. Costs:	$21,095
Total Present Value of Costs of Existing Equipment:	$77,444	Total Present Value of Costs of New Equipment:	$70,285
Average Annual Cost:	$5,573	Average Annual Cost:	$5,057

Life Cycle Cost Difference:	$7,159
Annual Cost Savings:	$516
Cost Benefit Ratio:	10.8177
True Payback in Years:	13.5195

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Figure B23. LCC report for comparison of new and existing equipment.

LIFE CYCLE COST REPORT
Without Preventive Maintenance on Equipment or "Run-To-Failure"

For Equipment: Basic Example

INPUT INFORMATION:

Initial Cost:	$8,973	
Annual Energy Cost:	$500	
Loss of Service Costs:	$100,000	
Occasional Repair Costs:	$3,725	per 10 years
Occasional Replacement Costs:	$8,973	per 20 years
Study Period:	20	years
Discount Rate:	3.750 %	
Energy Escalation Rate:	8.000 %	
Maintenance/Repair Escalation Rate:	8.000 %	
Replacement Escalation Rate:	8.000 %	

OUTPUT INFORMATION:

Initial Cost:	$8,973
PV of Annual Energy Costs:	$15,654
Loss of Service Costs:	$100,000
PV of Occasional Repair Costs:	$13,879
PV of Occasional Replacement Costs:	$20,028
Total Present Value of Costs:	**$158,534**
Average Annual Cost:	**$11,408**

01/13/99

Figure B24. LCC report for equipment without Preventive Maintenance or Run-to-Failure.

LIFE CYCLE COST REPORT
With Preventive Maintenance on Equipment

For Equipment: Basic Example

INPUT INFORMATION:

Initial Cost:	$8,973	
Annual Energy Cost:	$500	
Annual Surveillance Cost:	$450	
Annual Maintenance Cost:	$154	
Study Period:	20	years
Discount Rate:	3.750 %	
Energy Escalation Rate:	8.000 %	
Maintenance/Repair Escalation Rate:	8.000 %	

OUTPUT INFORMATION:

Initial Cost:	$8,973
PV of Annual Energy Costs:	$15,654
PV of Annual Surveillance Costs:	$14,089
PV of Annual Maintenance Costs:	$4,821
Total Present Value of Costs:	**$43,537**
Average Annual Cost:	**$3,133**

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Figure B25. LCC report for equipment with Preventive Maintenance.

LIFE CYCLE COST REPORT
(Comparison of Life Cycle Costs for equipment for which PM is performed vs. No PM is performed)

For Equipment: Basic Example

INPUT INFORMATION:

Initial Cost:	$8,973
Annual Energy Cost:	$500
Annual Surveillance Cost:	$450
Annual Maintenance Cost:	$154
Occasional Repair Costs:	$3,725 per 10 years
Occasional Replacement Costs:	$8,973 per 20 years
Study Period:	20 years
Discount Rate:	3.750 %
Energy Escalation Rate:	8.000 %
Maintenance/Repair Escalation Rate:	8.000 %
Replacement Escalation Rate:	8.000 %

OUTPUT INFORMATION:

Initial Cost:	**$8,973**	**Initial Cost:**	**$8,973**
Energy Costs:	**$15,654**	**Energy Costs:**	**$15,654**
Surveillance Costs:	**$14,089**	**Occ. Repair Costs:**	**$13,879**
Maintenance Costs:	**$4,821**	**Occ. Replac. Costs:**	**$20,028**
		Loss of Service Costs:	**$100,000**
Total Present Value of Costs Including Preventive Maintenance:	**$43,537**	**Total Present Value of Costs without Preventive Maintenance:**	**$158,534**
Average Annual Cost:	**$3,133**	**Average Annual Cost:**	**$11,408**

Life Cycle Cost Difference:	**$-114,997**
Annual Cost Savings:	**$-8,275**
Cost Benefit Ratio:	**-0.3785**

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Figure B26. LCC report for comparison of equipment with Preventive Maintenance and without.

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The maintenance of pollution control equipment (PCE) at Army installations is of critical importance. If PCE breaks downs, hazardous materials may be introduced into the environment. This may lead to unfavorable health and safety consequences for workers and people living in the area, and may also incur heavy fines on the installation responsible for the emissions. This study provided an expert system (PREPARE) for the operation and maintenance (O&M) of PCE. PREPARE helps combine the expertise of on-site personnel to information collected by researchers to help optimize decisionmaking on how O&M dollars can be spent most effectively.

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