VALUE ENGINEERING MANUAL

WEST VIRGINIA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
ENGINEERING DIVISION
January 1, 2004
with revisions to June 2014

VALUE

ENGINEERING

MANUAL

Prepared by:

Technical Section
Engineering Division
Division of Highways
West Virginia Department of Transportation

January 1, 2004

PRINTED BY: WVDOH OFFICE SERVICES DIVISION

TABLE OF CONTENTS

SECTION 10: INTRODUCTION

10.1 EXECUTIVE SUMMARY:

The West Virginia Division of Highways (WVDOH) recognizes the need for the prudent use of diminishing resources and revenues while providing a quality transportation program. Value Engineering (VE) is a function-oriented technique that has proven to be an effective management tool for achieving improved design, construction, and cost-effectiveness in various transportation program elements. It is anticipated that the successful implementation of a VE program will result in additional benefits beyond design and cost savings; for example, constant updating of standards and policies, accelerated incorporation of new materials and construction techniques; employee enthusiasm from participation in agency decisions; increased skills obtained from team participation.

Value Engineering is one of the most effective techniques known to identify and eliminate unnecessary costs in product design, testing, manufacturing, construction, operations, maintenance, data, procedures and practices. This manual provides guidelines for the implementation and application of a VE program for the WVDOH.

The following are the core elements of the WVDOH VE program:

- A firm commitment of resources and support by executive management to assure the success of the VE program.

- All levels of management must understand and support Value Engineering.

- A commitment to provide some degree of VE training or program familiarization at appropriate levels within the WVDOH organization.

- The establishment of a Value Engineering Coordinator position to administer and monitor the VE program.

- For optimum results in the project development phase, VE should be performed:

  - Early in the planning-design process to maximize potential improvements and cost savings.
  - On high-cost and/or complex projects (as defined in Section 20).
  - By a multi-discipline team of professionals utilizing VE techniques.

- A Value Engineering Change Proposal (VECP) program to encourage contractors to develop VE proposals to allow the State to benefit from a contractor's design and construction ingenuity, experience, and ability to work through or around restrictions.

Some important elements of the VECP program are:

- Processing of proposals will be kept simple and performed quickly.
- Cost Savings are shared with the contractor.
- Change proposals become the property of the State. The concept may be used on future projects.

  - Change proposals should not compromise any essential design criteria or preliminary engineering commitments.
  - Change proposals cannot be the basis for a contract claim.

- All VE team recommendations and contractor proposals will be fairly reviewed and expeditiously evaluated for implementation.

- VE techniques may be used to improve productivity in other areas of the State's transportation program, including traffic operations, maintenance, procedures and operations, standard plans and specifications, and design criteria and guidelines.

- VE programs will be closely monitored, evaluated, and modified to assure the program's effectiveness.

10.2 VALUE ENGINEERING FOR HIGHWAYS:

The history of highway development is full of instances where inspiration has produced noteworthy contributions to the financial and operational betterment of highway transportation. The state of our national and State economy, with rising costs and unemployment, provides an opportunity to encourage such inspiration. Value Engineering is one tool that can make things happen. It is an engineer's means to force the development of, and use of, "bright ideas."

Value Engineering is predicated on the fact that people spend their money to accomplish functions rather than simply to obtain ownership. With today's well-established concern for our environment, energy, and rising costs, the functional needs of safe and efficient accommodation of vehicular and pedestrian traffic must be carefully and independently analyzed, so that we may obtain these functions in the most economical manner, with minimal disturbance to the environment.

10.3 DEFINITION OF VALUE ENGINEERING:

Value Engineering is the systematic application of recognized techniques by multi-disciplined team(s) that identifies the function of a product or service; establishes a worth for that function; generates alternatives through the use of creative thinking; and provides the needed functions, reliably, at the lowest overall cost.

Value Engineering may be defined in other ways, as long as the definition contains the following three basic precepts:

- An <u>organized review</u> to improve value by using multi-disciplined teams of specialists knowing various aspects of the problem being studied.

- A <u>function oriented approach</u> to identify the essential functions of the system, product, or service being studied, and the cost associated with those functions.

- <u>Creative thinking</u> using recognized techniques to explore alternative ways of performing the functions at a lower cost, or to otherwise improve the design.

10.4 WHAT VALUE ENGINEERING ISN'T:

Value Engineering is not just "good engineering." It is not a suggestion program and it is not routine project or plan review. It is not typical cost reduction in that it doesn't "cheapen" the product or service, nor does it "cut corners." Value Engineering simply answers the question "what else will accomplish the purpose of the product, service, or process we are studying?"

It stands to reason that any technique so useful should be applied to every product, and at each stage of the normal day-to-day development of a highway product. **This is not the case.** The practice of VE entails a certain amount of expense, that must be justified by potential cost savings. Accordingly there must be a recognized need for change and a distinct opportunity for financial benefit to warrant the added cost of a VE effort.

10.5 ROADBLOCKS TO COST EFFECTIVENESS:

The practice of VE doesn't imply that there may be intentional "gold plating," conscious neglect of responsibility, or unjustifiable error or oversight by the design team. VE simply recognizes that social, psychological, and economic conditions exist that may inhibit good value. The following are some of the more common reasons for poor value:

- Lack of information, usually caused by a shortage of time. Too many decisions are based on feelings rather than facts.

- Wrong beliefs, insensitivity to public needs or unfortunate experience with products or processes used in unrelated prior applications.

- Habitual thinking, rigid application of standards, customs, and tradition without consideration of changing function, technology, and value.

- Risk of personal loss, the ease and safety experienced in adherence to established procedures and policy.

- Reluctance to seek advice, failure to admit ignorance of certain specialized aspects of project development.

- Negative attitudes, failure to recognize creativity or innovativeness.

- Over specifying, costs increase as close tolerances and finer finishes are specified. Many of these are unnecessary.

- Poor human relations, lack of good communication, misunderstanding, jealousy, and normal friction between people are usually a source of unnecessary cost. In complex projects, requiring the talents of many people, costs may sometimes be duplicated and redundant functions may be provided.

10.6 HISTORY OF VALUE ENGINEERING:

Value Engineering has been applied by many private industries, and local, state, and federal agencies. VE had its origin during World War II, at General Electric, when innovation was required because of material shortages. Some critical materials were difficult to obtain, and a great many of substitutions had to be made. Mr. Harry Erlicker, a vice president, made the observation that many times these changes resulted in lower costs and improved products. This encouraged him to seek an approach to intentionally improve a products value. He assigned Lawrence D. Miles, a staff engineer, the task of finding a more effective way to improve a product's value.

In 1947, Mr. Miles and his team developed a step-by-step system, called Value Analysis (VA), to analyze a product's cost and function to ferret out unnecessary costs. As a result of substantial investment, the new methodology, VA, was developed, tested, and proven to be highly effective. However, it wasn't until 1952 that VA began its growth throughout industry.

The Federal-Aid Highway Act of 1970 made the first Federal Highway reference to VE, requiring that "in such cases that the Secretary determines advisable plans, specifications, and estimates for proposed projects on any Federal-Aid system shall be accompanied by a value engineering or other cost reduction analysis."

Congress extended the federal value engineering role with the passage of the National Highway Systems Act of 1995. This act included a value engineering provision (later codified in Section 106 of Title 23, U.S.C.) requiring the U.S. Secretary of Transportation to "establish a program to require states to carry out a value engineering analysis for all projects on the National Highway System with an estimated total cost of $25,000,000 or more." FHWA published its regulation (23 CFR Part 627) establishing this program on February 14, 1997.

In addition, the Office of Management and Budget's (OMB) Value Engineering Circular A-131, dated May 21, 1993, states "Each agency shall report fiscal year results of using VE annually to OMB, except those agencies whose total budget is under $10 million or whose total procurement obligations do not exceed $10 million in a given fiscal year." This circular provides the basis for FHWA's request for year-end VE data. The Federal-Aid Policy Guide was revised in September 1998 to include a VE chapter to provide guidance on the application of value engineering in the federal-aid highway system.

10.7 APPLICABILITY OF VALUE ENGINEERING:

As shown in Figure 10.7-1, the design effort verses the total project costs as expended over the life cycle of a typical project are the smallest expenditure. Usually, all of the initial costs of a project add up to less than 50% of the total life cycle cost.

Total Project Costs		
Design Cost	Construction Cost	Operation & Maintenance Cost

Figure 10.7-1 - Life Cycle Cost Distribution

Figure 10.7-2, Influence on Cost, shows which decision-makers have the most influence over the total cost of ownership during the life cycle of a project. Operations and maintenance personnel, although often responsible for the majority of the projects total costs, have very little influence on decisions that add to life cycle costs. Two things can be observed here: 1) the earlier VE is performed, the greater its potential savings; and 2) the design process should take life cycle costs into account.

All phases of VE involve the search for answers to the question, "what else will accomplish the function of a system, process, product, or component at a reduced cost?" Obviously, cost savings diminish as time progresses from inception to completion of a project, leaving few, if any, identifiable cost savings for operation and maintenance without compromise.

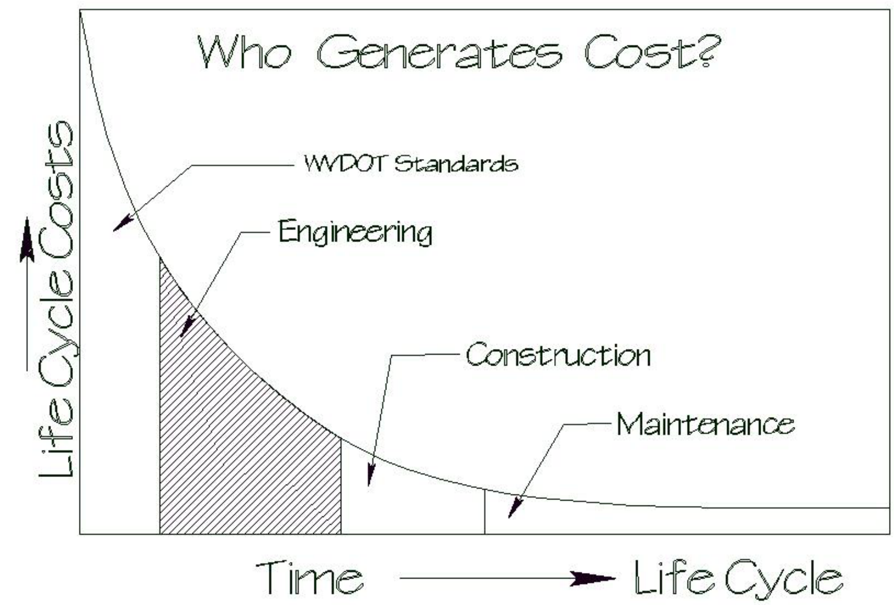


Figure 10.7-2 – Influence on Costs

What makes VE effective is the use of creative techniques at the proper time. Value Engineering is not just good engineering, it is not a suggestion program, and it is not a routine plan review, but it is an independent approach to the project. Therefore, the user must also recognize that VE entails a certain amount of expense that must be justified by potential cost savings. Accordingly, the need for change in standards, concepts or plans must be recognized and a distinct opportunity for financial rewards in terms of life cycle cost savings must warrant the added project engineering cost of a VE effort.

10.8 EFFECT OF VALUE ENGINEERING:

Value Engineering doesn't nibble at costs to make the item "cheaper", as occurs in normal cost reduction. Instead, the VE approach determines the worth of the basic function, without regard to its applications, sets a target cost, and finds the design alternative(s) meeting all needs at a lower overall cost.

Typically, a VE study may generate recommendations to eliminate ten to thirty percent of the project's construction costs. The designer usually accepts about half of these recommendations, providing savings of at least five percent. The cost of the VE effort (including any redesign) is usually less than ten percent of the implemented savings.

10.9 FUNDAMENTALS OF VALUE ENGINEERING:

10.9.1 PRINCIPLES: The principles of VE can be applied by anyone; e.g. a systems analyst, a shopkeeper, an engineer, or a homemaker. Value Engineering is often considered a management tool to control costs; but, should be understood in a broader context as a problem-solving tool that anyone can use.

By definition and nature VE is far more than a means of simply reducing existing costs. VE is a tool whose strength lies in the ability to clearly delineate design alternatives and to suggest choices based on the necessity or desirability of the function, on the availability of economic means of archiving that function, and on the cost-worth relationships that assure growth and prosperity.

No single phase of a VE study is apt to show anything startling to new VE team members. Rather, it is the arrangement and application of the segments of the VE methodology, the use of creative techniques at the proper time, and the general philosophy that are new and unique. Value Engineering is a procedure enabling one to exercise underutilized human creative potential to solve problems. This is accomplished through adherence to a sequence of steps known as the Value Engineering Job Plan.

10.9.2 VALUE ENGINEERING JOB PLAN: The "systematic application of recognized techniques", referred to in the definition of VE, is embodied in the Value Engineering Job Plan (Figure 10.9.2-1). The Job Plan is an organized plan of action for accomplishment of VE studies.

The key features that separate the VE Job Plan from other methods used to solve routine engineering problems are: 1) analysis of function; 2) specific creative effort to develop many design alternatives; 3) the principle of not degrading the required performance; and 4) assigning costs to perform each function.

Among the many techniques used to solve problems, only the VE approach calls for function analysis followed by the application of creative thinking techniques.

The VE Job Plan procedural steps (referred to as "phases") each include multiple tasks (see Figure). A melding of tasks and techniques, coupled with finesse in their application, is the art of Value Engineering. Its trajectory is controlled by the Job Plan.

To apply the VE Job Plan, two important factors must be recognized:

- An effective VE effort must consider all phases of the Job Plan. Omissions of any one of the phases will hamper accomplishment of the objectives. The amount of attention given to each phase, however, may differ from one project to another.

- Execution of the plan requires a team effort. The cooperation and active participation of several people produces the most effective results. Group dynamics play an important role, and illustrate that results of a team of professionals is greater that the sum of individual team member efforts.

In VE, as in other problem-solving methods, a systematic approach produces better results than undisciplined ingenuity. Strict adherence to the Job Plan provides:

- A vehicle to carry the study from inception to conclusion.

- A convenient basis for maintaining a written record of the effort as it progresses.

- Assurance that consideration has been given to the facts that may have been neglected in the creation of the original design or plan.

- A logical separation of the study into units that can be planned, scheduled, budgeted, and assessed.

The VE Job Plan is a systematic approach that has been used, tested, and proven to work. The application of this plan may produce results in reducing costs and simplifying design.

During normal cost reduction, one is inclined to analyze an item from the standpoint of how to reduce the cost of the elements that make up the item. One "cheapens" the parts until quality and performance are sacrificed. Use of the VE Job Plan and its associated techniques of analysis of function and application of creativity often yields more cost reduction without adversely affecting performance. In many cases, through design simplification, reliability, maintainability and quality are improved.

Finally, the Job Plan concludes with specific recommendations, the necessary data supporting them, the required implementing actions, and a proposed implementation schedule.

If the greatest benefits are to be realized, follow-up action must be taken to assure implementation. Audit of VE accomplishments is necessary to provide historical supportive data to promote or improve on future designs and VE projects. The Division will realize the greatest benefits from its VE program when the process facilitates feedback into the design phase. So, even if a VE recommendation is implemented on an individual project the VE team must decide if the idea should be considered as part of the normal design process, and if so the VE team must play a key role to implement the idea.

	Objective	Key Questions	Responsibility	Techniques	Tasks
Selection	Select Project	What is to be Studied? Who is Best Able to Study the Problem? What must be Known to Start?	Responsible Division	Solicit Project Ideas Identify High Cost/Low Value Areas Plan the Project Obtain Authorization to Proceed Allocate Resources	Speculate on Sources of Projects Develop Plan to Identify Project Analyze Projects for Applying VE Evaluate Projects for Potential Present Project to Management Select Projects for VE Study Implement Study Plan
Investigation	Investigate Project Analyze Function and Cost	What is the Project? What is the Problem? What is the Cost? What is now Accomplished? What is the Basic Function Worth? What are the Secondary Functions Worth? What are the High Cost Areas? Can Any Function be Eliminated?	Project Manager / VE Team	Get Information From Best Sources Get all Facts & Available Costs Work with Specifics Identify the Function Challenge Everything Evaluate by Comparison Put $ on Specs. & Requirements Put $ on Key Tolerances & Finishes Put $ on Key Standards	Speculate on Sources of Proj. Data Dev. Plan to Gather Proj. Data Implement Data Search Plan Investigate the Proj., Audit Data Speculate on Functions Performed Analyze Cost Analyze Functions Evaluate Function Cost/Worth Evaluate Project Potential Select Specific Study Areas
Speculation (Creative)	Speculate on Alternatives	What Else will Perform the Function? Where Else may the Function be Performed? How Else may the Function be Performed?	Project Manager / VE Team	List Everything, be imaginative Use Creative Techniques Defer Judgement, don't criticize Be Courageous	Select Techniques to be Used Speculate Alternatives Select the Best Alternatives
Evaluation (Judgement)	Evaluate Alternatives	How Might Each Idea Work? What Might be the Cost? Will Each Idea Perform the Basic Function?	Project Manager / VE Team	Weigh Alternatives Choose Evaluation Criteria Refine Ideas Put $ on Each Main Idea Evaluate by Comparison	Speculate on Evaluation Criteria Evaluate Alternatives Select the Best Alternatives
Development	Develop Alternatives	How will the new Idea Work? How Can Disadvantages be Overcome? What will be the Total Cost? Why is the New Way Better? Will it Meet the Requirements? What are the Life Cycle Costs?	Project Manager / VE Team	Use Search Techniques Get Information for Best Sources, Specialists & Suppliers Consider Specialty Materials, Products & Processes Consider Standards Use New Information Compile all Costs - Work with Specifics Gather Convincing Facts	Speculate on Information Needed Speculate on Information Sources Develop a Plan of Investigation Develop Selected Alternatives Select Preferred Alternative Develop Implementation Plan Audit Data
Presentation	Present Alternative	Who Must be Sold? How Should the Idea be Presented? What was the Problem? What is the New Way? What are the Benefits? What are the Savings? What is needed to Implement Proposal?	Project Manager / VE Team	Make Recommendations Use Selling Techniques Be Factual Be Brief Give Credit Provide an Implementation Plan	Develop a Written Proposal Speculate on Possible Roadblocks to Acceptance Present Recommended Alternative
Approval	Approval of Alternatives	Management Questions Resolved? Impacts on Schedules?	DOH Management and/or FHWA	Strategic Planning Economic Development Coordination	Further definition of costs Alternative Performance Definition Alternative effects on long-term planning
Implementation	Implement Alternative	Who is to Implement the Change How Will Plans/Contract be Changed? Is There Money for the Change?	Project Manager	Translate Plan Into Action Overcome Problems, Expedite Action Monitor Project	Develop Change Documents Implement Approved Alternative Evaluate Process
Audit	Audit Results	Did the New Idea Work? How Much did it Cost? How Much Money Was Saved? Did the Change Meet Expectations? Who is to Receive Recognition?	VE Coordinator	Verify Accomplishments Obtain copies of VE Studies Gather VE Information Report to Management	Audit Results of Implementation Evaluate Project Results Present Project Results Prepare Annual VE Report to FHWA

Figure 10.9.2-1 – Value Engineering Job Plan

10.10 VALUE ENGINEERING PRINCIPLES:

Value Engineering principles consist of key questions, techniques, and procedural tasks used in pursuing the objective of the VE Job Plan. The objective is to achieve design excellence. These principles are explained in subsequent chapters, where each phase of the Job Plan is discussed.

Certain VE techniques are applicable throughout the formal VE study. They are of significant importance in the area of decision-making and problem-solving.

- Use Teamwork. A fundamental principal of VE is to employ teamwork. In a complex design, with many different functions and people contributing to project cost, cost-effectiveness is enhanced when the team blends their talents toward that common objective.

- Although Value Engineering can be accomplished, minimally, through concentrated individual effort, the results can be magnified several times with teamwork. Further discussion on team structuring and team operation will be found in Section 20.

- Overcome Roadblocks. Roadblocks are obstacles in the path of progress, often occurring whenever a change is proposed. Some roadblocks are real (those of others), and some are imaginary (those of your own). Roadblocks are an expression of resistance to change.

- Value Engineering techniques are designed to help "overcome roadblocks," therefore; existence of roadblocks should be recognized. Be prepared to refute roadblocks when encountered.

- Use Good Human Relations. Because VE is concerned with creating change, concern is with human relations. In VE, there is a high degree of dependence on cooperation with other people. Therefore, good or poor human relations can relate directly to success or failure of the project.

The effectiveness of a VE study may depend upon the amount of cooperation the engineer is able to obtain from managers, engineers, designers, etc. If engineers are sensitive in their approach, diplomatic when resolving opposing viewpoints, and tactful in questioning a design requirement or specification, they will minimize the problem of obtaining the cooperation needed to perform effectively.

Convince the people with whom you work that you are asking, not demanding; suggesting, not criticizing; helping, not hindering; and interested, not bored with them.

Some of the areas where good human relations must be employed are:

- In Fact-Finding: getting good information from people requires their cooperation.

- In Creativity: good ideas come from people who are properly motivated. Get all team members involved. Don't let anyone dominate the team.

- In Implementation: receptivity to ideas has to be generated.

- Be a Good Listener. Listen attentively when explanations are made concerning problems that arise. The explanations almost always provide clues that otherwise would require hours of investigation and research. The experience of the team members might enable them to detect the true problem if the person making the explanation is given every opportunity to express their ideas. Also, the person who objects to a proposal may give an indication as to how it may be improved or modified to enable approval.

- Use Key Questions. The Value Engineering approach is a QUESTIONING approach. In order to get answers, questions must be asked.

- Use Checklists. As an aid to the practicing VE - Team, the key questions of the VE Job Plan have been incorporated into checklists found in the chapters describing each phase. The checklists are not all-inclusive. The lists do, however, provide a good minimum of questions to ask.

- Record Everything. Don't trust your memory. During all phases of the study, record the information you have gained through interview; write down your ideas, the questions that need to be answered, and the details of your developed ideas. You will need this data in each succeeding step of the VE Job Plan and in preparing the workbook, the study summary, and your recommendations.

10.11 VALUE ENGINEERING COORDINATOR:

An integral part of the overall VE program for the WVDOH is the designation of an individual to serve as the "VE Coordinator" for VE activities. This individual's duties will consist of the following:

a. Primary responsibility for Audit Phase of VE program per Section 90 of this manual.

b. Preparation and submittal of "Annual VE Report to FHWA".

c. Collection and filing of all Final Value Engineering Reports.

d. Serve as the primary contact for implementing programmatic activities with FHWA.

- In Creativity: good ideas come from people who are properly motivated. Get all team members involved. Don't let anyone dominate the team.

- In Implementation: receptivity to ideas has to be generated.

- Be a Good Listener. Listen attentively when explanations are made concerning problems that arise. The explanations almost always provide clues that otherwise would require hours of investigation and research. The experience of the team members might enable them to detect the true problem if the person making the explanation is given every opportunity to express their ideas. Also, the person who objects to a proposal may give an indication as to how it may be improved or modified to enable approval.

- Use Key Questions. The Value Engineering approach is a QUESTIONING approach. In order to get answers, questions must be asked.

- Use Checklists. As an aid to the practicing VE - Team, the key questions of the VE Job Plan have been incorporated into checklists found in the chapters describing each phase. The checklists are not all-inclusive. The lists do, however, provide a good minimum of questions to ask.

- Record Everything. Don't trust your memory. During all phases of the study, record the information you have gained through interview; write down your ideas, the questions that need to be answered, and the details of your developed ideas. You will need this data in each succeeding step of the VE Job Plan and in preparing the workbook, the study summary, and your recommendations.

10.11 VALUE ENGINEERING COORDINATOR:

An integral part of the overall VE program for the WVDOH is the designation of an individual to serve as the "VE Coordinator" for VE activities. This individual's duties will consist of the following:

a. Primary responsibility for Audit Phase of VE program per Section 90 of this manual.

b. Preparation and submittal of "Annual VE Report to FHWA".

c. Collection and filing of all VE studies performed including the final approved recommendations. The VE Coordinator shall establish and maintain a set of files on all VE studies.

d. Serve as the primary contact for implementing programmatic activities with FHWA.

e. Serve as the primary source for implementing policy and technology changes for the WVDOH VE program.

f. Serve as a resource for VE Teams as requested by the team leaders.

SECTION 20: SELECTION PHASE

20.1 OBJECTIVE:

The objective of the Selection Phase is to establish the identity of candidate projects for VE analysis, and to select specific projects to achieve maximum monetary savings, energy savings, or other benefits, such as a shorter construction schedule. In addition, an important part of this phase is the selection of the VE team members.

Proper study selection is vital to the success of the entire VE Program. Because VE resources are limited, a major criterion in project selection should be the potential benefit to be derived for the resources invested.

This phase relates to the identification of study projects and their evaluation, selection, planning and authorization.

There are generally two primary reasons why a project is considered for a VE study.

1. The item or project is required to undergo a VE analysis per WVDOH policy, Section 20.2 of this manual.

2. The item or project is a high-cost or high-volume (specifications, standards, policies, design methods, etc.) item, i.e., there must be enough potential savings to make the analysis worthwhile.

When a project has been identified as one in which a VE analysis will be conducted, the Project Manager shall immediately notify the "Program Administration Division" as indicated in DD-816 Value Engineering. The Program Administration Division shall then include the appropriate notes in the project tracking system.

20.2 PROJECTS REQUIRING VE ANALYSIS:

The WVDOH may initiate a VE analysis on any project or process when it is felt that there are sufficient potential cost savings to justify the cost of the analysis. The National Highway System Act of 1995 required the establishment of a program for value engineering analysis for all projects on the National Highways System and this requirement has been updated by MAP-21, effective October 1, 2012. The following criteria shall be used by the WVDOH to determine which projects require the performance of a VE analysis.

20.2.1 CRITERIA:

Projects on the National Highway System (NHS) -

All projects on the NHS, receiving federal assistance, with an estimated total cost greater than $50,000,000, shall undergo a VE analysis.

Bridge Projects on the NHS –

All bridge projects on the NHS, receiving federal assistance, with an estimated total cost greater than $40,000,000, shall undergo a VE analysis.

All required VE analyses shall be performed, per this manual, prior to Final Design.

A project meeting the above criteria, to be delivered by the design-build method, shall not be required to have a value engineering analysis performed.

A "project" will be defined by the limits shown in the controlling environmental document.

The Total Project Cost includes all the cost associated with the environmental clearance, engineering, right of way, utilities, and construction phases of a project.

20.2.2 REPRESENTATIVE PROJECT CONCEPT: When a project, as defined in Section 20.2.1 above, is required to undergo a VE analysis, the WVDOH may employ a "Representative Project" approach. This type of VE analysis approach may be used on projects where the contract plan development within the limits of the environmental document is subdivided into several design projects. The use of a Representative Project approach will require prior approval per Section 20.4 of this manual.

The "Representative Project" approach utilizes a VE study that is performed on one or several contract plan development segments of the complete environmental project. This approach requires the Project Manager along with the Responsible Division to consider the entire environmental project (per Section 20.2.1 of this manual) and determine if contract design segments are similar in design attributes. Those parts of the environmental project that can be considered to be represented by a single design segment may utilize the "Representative Project" approach. This may involve performing a VE study on a single design segment of the entire environmental project or on a number of design segments for large or complex environmental projects. The "Representative Project(s)" may serve as the VE study for the entire project provided the following two conditions are met:

1. The contract plan segment(s) is reasonably "representative" of the entire project.

2. The results of the VE study are applied, where appropriate, equally on the remaining contract plan segments of the complete environmental project.

20.2.3 VE STUDY TIMING: VE studies may be conducted at any time during project development when so directed by the WVDOH management. However, on projects requiring a VE study the value engineering will be conducted at one of two project milestones.

20.2.3.1 <u>Contract Plans</u>: Projects that are part of an environmental project meeting the requirements of Section 20.2.1 of this manual, will undergo a VE study immediately following and/or in conjunction with the Preliminary Field Review on the project. This may be eliminated if the design segment is part of an approved "Representative Project" per Section 20.2.2 of this manual, or a VE study was conducted per Section 20.2.3.2 of this manual.

20.2.3.2 <u>Design Report</u>: Projects that require a VE study per Section 20.2.1 of this manual may also meet this requirement by conducting the study immediately following and/or in conjunction with the office review of the design report plans on the project.

20.3 HIGH COST OR HIGH VOLUME ITEMS OR PROJECTS:

The WVDOH encourages the use of VE studies and methodologies to improve high cost or high volume items or projects. Any functional unit may initiate a request for a VE study per the approval process outlined in Section 20.4 of this manual. These studies will typically involve an item or process of state-wide or district-wide implications. Studies originating from functional units usually do not involve specific highway projects.

20.4 VE STUDY SELECTION APPROVAL:

SECTION 20: SELECTION PHASE

20.1 OBJECTIVE:

The objective of the Selection Phase is to establish the identity of candidate projects for VE study, and to select specific projects to achieve maximum monetary savings, energy savings, or other benefits, such as a shorter construction schedule. In addition, an important part of this phase is the selection of the VE team members.

Proper study selection is vital to the success of the entire VE Program. Because VE resources are limited, a major criterion in project selection should be the potential benefit to be derived for the resources invested.

This phase relates to the identification of study projects and their evaluation, selection, planning and authorization.

There are generally two primary reasons why a project is considered for a VE study.

1. The item or project is required to undergo a VE study per WVDOH policy, Section 20.2 of this manual.

2. The item or project is a high-cost or high-volume (specifications, standards, policies, design methods, etc.) item, i.e., there must be enough potential savings to make the study worthwhile.

When a project has been identified as one in which a VE study will be conducted, the Project Manager shall immediately notify the "Program Administration Division" ad indicated in DD-816. The Program Administration Division shall then include the appropriate notes in the Project Tracking System.

20.2 PROJECTS REQUIRING VE STUDY:

The WVDOH may initiate a VE study on any project or process when it is felt that there are sufficient potential cost savings to justify the cost of the study. The National Highway System Act of 1995 required the establishment of a program for value engineering analysis for all projects on the National Highways System with an estimated total cost of $25,000,000 or more. The following criteria shall be used by the WVDOH to determine which projects require the performance of a VE study.

20.2.1 CRITERIA: All projects on the National Highway System, with an estimated total cost greater than $25,000,000 dollars, shall undergo a VE study, performed per this manual, prior to construction authorization. Total cost shall include engineering, right-of-way, and construction costs. A project will be defined by the limits shown in the controlling environmental document for the project.

20.2.2 REPRESENTATIVE PROJECT CONCEPT: When a project, as defined in Section 20.2.1 above, is required to undergo a VE study, the WVDOH may employ a "Representative Project" approach. This type of VE study approach may be used on projects where the contract plan development within the limits of the environmental document is subdivided into several design projects. The use of a Representative Project approach will require prior approval per Section 20.4 of this manual.

The "Representative Project" approach utilizes a VE study that is performed on one or several contract plan development segments of the complete environmental project. This approach requires the Project Manager along with the Responsible Division to consider the entire environmental project (per Section 20.2.1 of this manual) and determine if contract design segments are similar in design attributes. Those parts of the environmental project that can be considered to be represented by a single design segment may utilize the "Representative Project" approach. This may involve performing a VE study on a single design segment of the entire environmental project or on a number of design segments for large or complex environmental projects. The "Representative Project(s)" may serve as the VE study for the entire project provided the following two conditions are met:

1. The contract plan segment(s) is reasonably "representative" of the entire project.

2. The results of the VE study are applied, where appropriate, equally on the remaining contract plan segments of the complete environmental project.

20.2.3 VE STUDY TIMING: VE studies may be conducted at any time during project development when so directed by the WVDOH management. However, on projects requiring a VE study the value engineering will be conducted at one of two project milestones.

20.2.3.1 Contract Plans: Projects that are part of an environmental project meeting the requirements of Section 20.2.1 of this manual, will undergo a VE study immediately following and/or in conjunction with the Preliminary Field Review on the project. This may be eliminated if the design segment is part of an approved "Representative Project" per Section 20.2.2 of this manual, or a VE study was conducted per Section 20.2.3.2 of this manual.

20.2.3.2 Design Report: Projects that require a VE study per Section 20.2.1 of this manual may also meet this requirement by conducting the study immediately following and/or in conjunction with the office review of the design report plans on the project.

20.3 HIGH COST OR HIGH VOLUME ITEMS OR PROJECTS:

The WVDOH encourages the use of VE studies and methodologies to improve high cost or high volume items or projects. Any functional unit may initiate a request for a VE study per the approval process outlined in Section 20.4 of this manual. These studies will typically involve an item or process of state-wide or district-wide implications. Studies originating from functional units usually do not involve specific highway projects.

20.4 VE STUDY SELECTION APPROVAL:

The Project Manager shall initiate approval of the VE study selections and the VE study timing.

All projects utilizing the "Representative Project" (Section 20.2.2) approach to meet the VE study requirements will be approved in writing by the Deputy State Highway Engineer Development and FHWA. The results of the study will be applied to all applicable segments of the environmental project.

The approvals described above will be obtained by the Project Manager prior to conducting the VE study.

20.5 VE JOB PLAN:

All VE Job Plans should contain the following minimal essential features:

- Description of the objectives and scope of the project in enough detail to assure direction of the study.
- Goals for the study,
- Selection of team members.
- Designation of the project leader.
- Schedule for completion of each phase of the VE Job Plan. Including the anticipated VE study timing.
- Establishment of a target date for formal presentation of project results.

20.6 VE TEAM STRUCTURE:

20.6.1 GENERAL: Depending on the scope of the project and the time restraints for completing it, VE studies can vary from a one-man effort (studies involving specific operational or repetitive tasks) to a team effort (projects requiring VE study, Section 20.2 of this manual), and may also have several people assigned to support the team if and when their particular skills are needed. Although there is no specific size required for an efficient VE team, five persons, supported on a part-time basis by other elements of the organization, is usually a sufficient number. Selection of members to perform the team study should be based on the following criteria, if possible:

- The VE study leader should have attended an appropriate VE Workshop training seminar, preferably with additional experience as a team member on one or more VE projects.
- Other team members should have some familiarity with the VE process, perhaps through a one-day VE orientation course. If such

experience is unavailable, suitable orientation may be included during the conduct of the study. All WVDOH employees, who are requested and approved to serve on a VE Team, are reminded that they are to commit their time and resources to the VE study.

- Identify work experience or background of the team members related to the particular project under study.

- A mix of talent is desired to achieve different points of view. Typical team members might include a soils engineer, right-of-way specialist, materials specialist, environmental specialist, structural engineer, design engineer, traffic operations, maintenance, or construction engineer. An experienced cost estimator can be valuable to the team.

- Emphasis should be placed on using the best talent available, rather than obtaining only those who can be spared.

20.6.2 TEAM MEMBERS FOR PROJECTS REQUIRING VE STUDY: The Project Manager will normally serve as the VE study leader on most projects. Team members will be comprised of the project review team. The VE study leader may ask for personnel with special knowledge about the project to serve on the team.

20.6.3 TEAM OPERATIONS:

- Each member must contribute to the study. The team leader should determine each person's talents and allocate tasks that make the best use of those skills.

- In each phase of the Job Plan, the team should carry out both individual and group actions. One member can obtain and organize costs, one analyze the specifications and identify problem areas, one can get the equipment information, etc. Each can summarize and document the information so that the team can plan, create, and act to solve the problem.

20.6.4 DATA REQUIRED FOR A VE STUDY: It is important to any VE study to have certain data available for the team prior to commencement of the study. The VE study team leader will be responsible to gather the appropriate data. The following data are required for a VE Study, much of which is available from research done during the Selection Phase:

- Complete graphic data, including drawings, sketches, photographs and standards pertinent to the study.

- Specifications and technical manuals.

- Up-to-date cost estimates for the project.

- Historical data, status of design, schedules, public requirements.

- Design engineer(s) and approval authority names and contact points.

20.7 SELECTION PHASE CHECKLIST

The following areas or causes of high cost, that may indicate poor value, should receive the majority of the VE effort:

- Great complexity in the design. Generally, the more complex the design, the more opportunity there is to improve value and performance.

- An advancement in the state-of-the-art. Those aspects of design that reach beyond the state-of-the-art will usually offer potential VE savings.

- High degree of time compression in the design cycle. A project having an accelerated design program will usually contain elements of over design.

- A component or material that is critical, exotic, hard-to-get or expensive.

- Intricate shapes, deep excavations, high embankments, steep slopes, etc.

- Components that appear to be difficult to construct.

- Overly long material haul: Excessive borrow; excessive waste. Expensive construction traffic control.

- Long foundation piles.

- Excessive reinforcement.

- Cofferdam dewatering.

- Architectural embellishment.

- Record seeking design (longest span, highest piers, deepest cut, etc.).

- Large safety factors.

- Curb, gutter and sidewalk (rural).

- Specially designed components that appear to be similar to low-cost off-the - shelf items.

- Components that include non-standard fasteners, bearings, grades and sizes.

- Sole-source materials or equipment.

- Processes or components that require highly-skilled or time-consuming labor. Items with poor service or cost history.

- Items that have maintenance and field operation problems.

- Project costs that exceed the amount budgeted.

- Standard plans in use more than 3 or 4 years.

- Will a change to the existing method solve any problems or have any benefits other than cost, in such areas as?

noise	reliability	aesthetics
safety	fire protection	simplification
maintainability	standardization	vibration
time	performance	air quality
quality	weight	employment rate
energy use	water quality	

SECTION 30: INVESTIGATION

30.1 OBJECTIVE:

The objective of the Investigation Phase of the Value Engineering Job Plan is to acquire knowledge of the design to be studied and to assess its major functions, cost and relative worth.

30.2 INVESTIGATION PHASE OUTLINE:

- Collect detailed information and data.
  - Gather all types of information from the best sources.
  - Obtain complete, pertinent information
  - Get the facts.
  - Get all available costs.
  - Gather all Environmental Constraints and Commitments.
  - Gather other constraints.

- Determine the functions.
  - Identify and define functions
  - Classify functions
  - Determine function relationships.

- Determine function cost.
  - Determine cost of each function.
  - Determine overall cost of project.
  - Identify high-cost functions.

- Determine worth of each function.
  - Determine worth of each function.
  - Determine overall worth of project.

- Determine function value.
  - Determine value opportunity index for each function.
  - Determine overall value opportunity index.
  - Identify areas of poor value.

- Analyze project potential.
  - Review life cycle cost aspects.
  - Establish target costs for areas of low value.
  - Choose specific elements to be studied.

30.3 DISCUSSION:

This phase is intended to provide a thorough understanding of the system, operation, or item under study by an in-depth review of all of the pertinent factual data. Complete information is essential to provide the foundation upon which the entire Value Engineering study is based. The complexity of the VE project, the amount of information available, and the study schedule will all impact on the level of effort devoted to the Investigation Phase.

The second intent of this Phase is to determine the functions that are being performed and those that must be performed by the item or system under study. Value Engineering is concerned with two classes of functions: The use function and the esteem or aesthetic function. The use function of a design element satisfies the user's need for having an action performed, while an aesthetic function fulfills a desire for something more than what is needed. These two functions are not mutually exclusive and are frequently present in designs. Good value occurs when the user is provided with the functions he needs, with the aesthetics he desires, for a reasonable cost.

30.3.1 GATHER ALL TYPES OF INFORMATION: The VE team should gather all relevant information, regardless of how disorganized or unrelated it may seem when gathered. The data should be supported by credible evidence, where possible. Where supported facts are not obtainable, the opinions of knowledgeable persons should be obtained.

The information sought is seldom found in comprehensive form in one place. The by-words for any VE study are **"RECORD EVERYTHING."** Information gathering may be subdivided into separate tasks and assigned to individual team members. Various types of data that may be obtained are:

- Physical data, such as shape, dimensions, material, skid resistance, color, weight, density, fire resistance, weather resistance, sound absorption capability, deflection resistance, and horizontal and vertical alignment.

- Methods data, about how it is operated, constructed, fabricated, developed, installed, maintained, and replaced.

- Performance data, concerning present performance requirements and actual performance needs in areas of design, operation, maintenance, safety, and utility.

- Restrictions, (relating to detailed specifications) concerning methods, performance, procedures, operations, schedule, and cost.

- Cost data, including a detailed breakdown of costs of labor, material, and markups for both construction and other elements of life cycle cost.

- Quantity data, relating to the anticipated volume or repetition of use for this project and future uses.

30.3.2 GO TO THE BEST INFORMATION SOURCE: Information should be obtained from credible sources. There are two basic principles in this area. First, is to seek information from multiple sources; and, second, to seek the best source for the information desired. Typical of the various sources from which the required information might be obtained are the following:

- **People Sources --** Project managers, design engineers, operators, maintenance personnel, contractors, fabricators, suppliers, expert consultants.

- **Data Sources** -- Planning documents, environmental documents, design studies, traffic studies, drawings, computations, design analyses and calculations, WVDOH Standard Specifications and Standard Drawings, material lists, cost estimates, schedules, scope of work, handbooks, engineering and maintenance manuals, American Association of State Highway and Transportation Officials' Policy on Geometric Design of Highways and Streets (the Green Book) and the Roadside Design Guide, test and maintenance reports, user feedback, catalogs, technical publications, previous study data files, management information systems, conference and symposium proceedings, universities.

NOTE: It is important that the names, addresses, and telephone numbers of persons contacted during the course of the study be **RECORDED** and keyed to the information they supplied.

30.3.3 OBTAIN COMPLETE PERTINENT INFORMATION: The type of data available will depend upon the status of the design in its overall life cycle, i.e., whether it is in Concept Phase, Design Phase, or under construction.

A set of design objectives and a statement of requirements may be all that is available early in a project cycle. For an older, standard design, such useful data as performance under use, maintenance characteristics, failure rates, and operational costs may be available. In addition to specific knowledge of the project, it is essential to have all relevant available information concerning the technologies involved, and to be aware of the latest applicable technical developments. The more factual information brought to bear on the problem, the more likely the possibility of a substantial cost reduction.

30.3.4 WORK WITH SPECIFICS/FACTS: Get specific information about the item; generalities serve only to protect the status quo. You must work on each function individually before attempting to combine them into a single multi-functioning project. The danger inherent in a generalized statement is that if one exception can be found, the statement is proven wrong. If the proposal depends upon a generalized statement, the validity of the entire study could be doubted.

30.3.5 GET ALL AVAILABLE COSTS: To make a complete analysis of any project, the total cost of the item, the cost of each component, and a breakout of the cost of each design component are needed. Accurate and itemized cost estimates should be obtained for each proposed design to determine the alternative offering the greatest cost reduction. These costs are normally obtained from the designer or design consulting firm.

30.4 DETERMINE THE FUNCTIONS:

A user purchases an item or service because it will provide certain functions at a cost he is willing to pay. If something does not perform as it is intended to, it is of no use to the user, and no amount of cost reduction will improve its value.

Actions that sacrifice needed utility of an item actually reduce its value to the user. On the other hand, functions beyond those that are needed also are of little value to the user. Thus, anything less than performance of needed functions is unacceptable; anything more is unnecessary and wasteful. To achieve the best value, functions must be carefully defined so that their associated costs may be determined and properly assigned.

Many times there is a temptation to look at an item and say that the function it performs is the required function. But this is not always true. By defining the function, one learns precisely which characteristics of the design are required.

The determination of functions should take place as soon as possible to permit determination of true needs. All members of the VE study group should participate in function analysis because the determination of the required function(s) is vital to the successful application of the subsequent phases of the Job Plan.

After the functional description has been developed, the next step is to estimate the worth of performing each required function. The determination of worth should be compared against the estimate of the item's cost. This comparison indicates whether the study will provide an opportunity for large reductions in cost. The objective of the VE study is to develop a design that closely approaches the established worth.

30.5 DEFINING FUNCTIONS:

Attempts to identify and define the function(s) of an item can often result in several descriptions of many sentences. While this method may conceivably describe the function(s) satisfactorily, it is neither concise nor workable enough for the Value Engineering approach to function. In VE, function is best expressed using two words: a verb, and its noun object:

- The verb defines the action required (it may generate, support, control, restrain, pump, protect, transmit, etc.)

- The noun describes what is acted upon (electricity, load, temperature, force, liquids, surfaces, sound, etc.). This noun must be measurable, or at least understood in measurable terms, because a specific value will be assigned to it in the evaluation process, when cost is related to function. For example, the function of a water service line to a roadside rest area could be defined as "provides service." This service, not being readily measurable, does not enable us to seek alternatives intelligently. On the other hand, if we define the function as "transports water," the noun in the definition is measurable, and accepted alternatives, being dependent upon the quantity of water being transported, can be determined.

The system of defining a function in two words, a verb and a noun, is known as two-word abridgment. This abridgment represents a skeletal presentation of relative completeness. Advantages of this system are that it: (1) Forces conciseness and (2) Avoids combining functions or attempting to define more than one simple function at a time.

Some difference of opinion exists among Value Engineers as to how many words should be permitted to define the function. No one has a problem with the two-word definition, providing that a clear definition of the function is the end result. However, if an adjective, participle, or noun results in a better understanding of the function by the team members, then a third or forth word may be used. Examples of modifiers are shown below:

- Adjective: Generates electrical power
- Participle: Protects bridge deck
- Noun: Measures hydraulic rate

30.6 IDENTIFYING FUNCTIONS:

Considerations in assuring proper function identification are:

- A function should be identified so as not to limit the ways in which it could be performed. For example, consider the operation of fastening a simple nameplate to a piece of equipment. Rather than the specific instruction "screw nameplate", the function would be better identified as "label equipment," since attaching a nameplate with screws is only one of many ways of identifying equipment. Nameplates can also be riveted, welded, hung, cemented, or wired in place. On the other hand, the name may be etched, stenciled, or stamped on the equipment, thus entirely eliminating the need for the separate metal nameplate.

- Identification of function should concern itself with how something can be used, not just what it is. For example, the function of a wire could be "conduct current," "fasten part," "or transfer force", depending on the designer's intent. Consider the function of a box culvert that could be "convey water," "bridge unstable material," "convey cattle". A guardrail may "impede force," "deflect force," "absorb force," "redirect traffic," "or reassure motorist".

- Identifying the function in the broadest possible terms provides the greatest potential for value improvement because it gives greater freedom for creatively developing alternatives. Further, it tends to overcome any preconceived ideas of the manner in which the function is to be accomplished.

30.7 CLASSIFYING FUNCTIONS:

Functions of items or systems may be divided into two types: Basic and Secondary.

- **A Basic Function:** defines a performance feature that must be attained. It reflects the primary reason for an item or system. In the case of the screwdriver, "transfer torque" would normally, but not necessarily, be the basic function. For example, if the desired application was to pry open lids of paint cans, the function would be defined in terms of the transfer of a linear force rather than a rotational force. Thus, a clear understanding of the user's need is necessary if an adequate definition of the basic function is to be developed.

  An item may possess more than one basic function. An example is the camper's hand ax, with a flat head for driving tent stakes, and a sharp blade for cutting firewood. A basic function answers the question, "What must it do?"

- **A Secondary Function:** also defines performance features of a system or item other than those that must be accomplished. It answers the question, "What else does it do?" For example, the basic function of exterior paint is "protect surface." Then a secondary function is "improve appearance."

  Secondary functions support, the basic function but generally exist only because of the particular design approach that has been taken to perform the basic function. For example, a valve on a radiator "restricts flow" and is necessary only because a hot water heating design was chosen. (No valve is needed with a forced air heating system). Many times, the presence of a secondary function depends on the method chosen to achieve a basic function and, if the method to achieve the basic function is changed, the secondary function may be eliminated.

30.8 FUNCTIONAL RELATIONSHIP:

It is common practice to describe systems (1) in terms of function and their relationship within the next larger assembly, (2) in terms of their own components or subparts, or (3) in terms of their indivisibility or uniqueness. The relative position that a system or item occupies in the scheme of the total assembly is called its "level of indenture."

In Value Engineering, the significance of level of indenture is that the designation of functions as basic or secondary depends upon the indenture level. A function that exists to support the method of performing the basic function is a secondary function. But when considered by itself and with respect to itself, it is a basic function.

Systems and items may have many levels of indenture. The rule of functional evaluation is to work from the top, down; and to consider the item or system under study as the top assembly. If the function of the top assembly is dependent upon the function of the indentured item the function of the indentured item is basic.

MANUAL FIRE ALARM SYSTEM

Level of Service	Component	Functions	Classification B=Basic S=Secondary
1	Fire Alarm System	Make Noise Detect Fire Protect Build.	B B S
2	Person Equipment	Detect Fire Pull Lever Make Noise Transfer Sign	B S B S
3	Pull Boxes Bells Panels Conduit & Wires	Break Circuit Make Noise Provide Power Control Circuits Transmit Signal Transmit Power	S B S S S S

Figure 30.8-1 - Functional Relationships

Figure 30.8-1 illustrates the first three levels of indenture for a manually operated fire alarm system. Observe that the system, as defined, must perform two basic functions. Rather than choosing the restrictive function of "ring bell," the broader term "make noise" was selected to permit greater freedom in developing alternative ways of making noise, i.e., horn, bell, siren, etc.

Both items in the second level of indenture have functions that are basic, because the function of the system is dependent upon them. All other functions in the second level of indenture are secondary, because they only exist to support the method or design selected to achieve the basic functions. Similarly, in the third level of indenture, only the bells perform a basic function. Another approach used for identifying and classifying the functional relationships of a study subject is FAST Diagramming.

30.9 DEVELOPING A FAST DIAGRAM:

In 1964, Mr. Charles W. Bytheway developed a system for function analysis that has become known as the Function Analysis System Technique (FAST). Mr. Bytheway, the Value Engineering and Cost Reduction Administrator for UNIVAC, was searching for a way to analyze, in depth, the functions of the Walleye Missile System.

The technique that he devised and refined was presented by him in 1965 to the Society of American Value Engineers at their National Conference in Boston. FAST diagramming has since been used by Value Engineers throughout the world as a tool to correctly identify the interrelationship of the functions under study.

As in the case with most Value Engineering tasks, the development of a FAST diagram is best accomplished as a team effort. The interplay of different viewpoints causes deeper thinking about the subject and, therefore, more thorough investigation.

The first step is to determine what the team considers to be the most general function of the item to be studied. This provides a starting point for what may resemble a game of "Dominoes." Expansion from that point occurs by asking the questions "HOW" and "WHY?"

Figure 30.9-1 depicts the method of graphically representing this technique. To develop a **FAST** diagram to the right, one asks the questions, **HOW** is (verb) (noun) actually accomplished, or How is it proposed to be accomplished. The blank is filled in with the function being contemplated. The team will make several suggestions and then decide on the most appropriate one. That answer, also expressed as a verb and a noun, is the next lower order function on the diagram.

The progression to the right is accomplished by continuing to ask **HOW** for each new function on the diagram. Items to the right of a function are required secondary functions, i.e., required, based on the system design chosen. The answer to the **HOW** questions are verified by asking the question **WHY** is it necessary to (verb) (noun)? The answer to that question should be the same as the function in the square to the left.

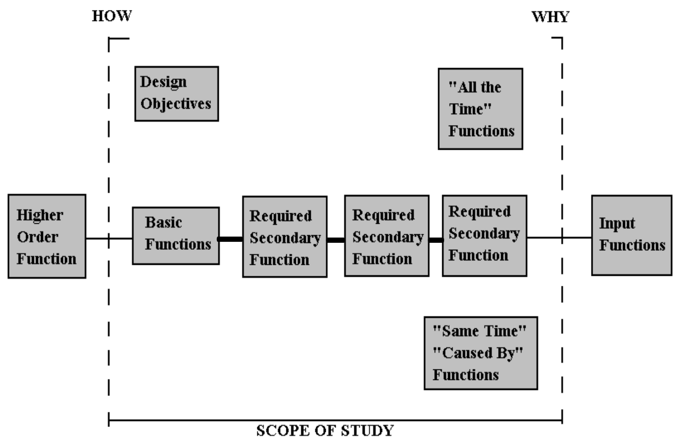


Figure 30.9.1 - Fundamentals of FAST Diagramming

To quote Mr. Bytheway, "when we ask 'How' we are looking for solutions and moving to lower levels of opportunity. When we ask 'WHY' we are looking for reasons and moving to higher levels of opportunity." By continuing to ask the **"WHY"** questions, one should progress to the left to increasingly higher order functions. Asking the **"WHY"** question can also extend the diagram further to the left, thus illustrating the fact that the starting function may not have been the basic or primary one after all. The line of functions from right to left is called the critical path. They are the functions that are critical to the performance of the basic function. If you take one of them away, the basic function of the system cannot be satisfied. If you try taking one away and find that the basic function can still be performed, then perhaps the function removed is a supporting function, and not critical.

Supporting Functions are those that happen: (1) all the time, (2) at the same time as, or (3) are caused by the critical functions. They occur as a result of the method chosen for accomplishing the basic function. These secondary functions are positioned vertically in the diagram.

The FAST diagram, that is developed during the Investigation Phase, uses the original design as a model. As can be seen from the above discussion, the diagram can be expanded almost endlessly to the left, even to the point of asking why the project is being designed. At some point along the critical sequence of functions, a "SCOPE" line defines the limits of the study. To its right lies the basic function that will be the subject of the study.

The FAST diagram is used in the identification and visualization of high-cost functions. By tying functional cost to a FAST diagram, attention can be focused on the high-cost function, or on the higher order function that makes that one necessary.

It is important during the Speculation Phase to concentrate on the function rather than the item itself. The use of the FAST diagram during this phase tends to draw attention away from the object and toward its function.

The preparation of a FAST diagram of, at least, the first choice alternate during the Development Phase, allows for a re-examination of the solution. Rethinking at this time can point up areas for additional savings that may have been overlooked. A comparison of the FAST diagram for the original design and that of the proposed alternate can be a valuable sales tool during the Presentation Phase. It has great value as a communication tool, because it is in functional terms that almost everyone can understand, no matter how technical or complex the item may be.

30.10 DETERMINATION OF FUNCTIONAL WORTH:

Worth is the most inexpensive way to perform a function. The establishment of the worth of a function, without considering where or how the function is used, commences after all functions have been identified, classified as basic or secondary, and all unnecessary functions have been discarded. The determination of functional worth is perhaps the most difficult step in VE, but the step is an indispensable. Determining the functional worth is a highly creative endeavor because worth is a subjective rather than absolute or objective measure. Skill, knowledge, and judgment play a major role in determining the quantitative aspect of worth, in terms of dollars.

The worth of a function is usually determined by comparing the relative costs of alternate methods of performing the function. An attempt is made to find the lowest cost to perform the function.

Worth is associated with the function under consideration and not with the use of the function in the present design. For example, consider a bolt supporting a steel beam in a bridge. The worth of the bolt is the lowest cost necessary to provide any reliable fastening to support a steel beam, and has nothing to do with the use of the beam in supporting a bridge.

30.11 DETERMINATION OF FUNCTIONAL COST:

Functional cost is the cost of the method chosen to perform the function under consideration. Where an item serves one function, the cost of the item is the cost of the function. However, where an item serves more than one function, the cost of the item should be pro-rated to each function.

For example, the cost of a noise barrier might be $2 per square foot. An appropriate breakdown of this cost on a functional basis might be:

ITEM	FUNCTION	TYPE	UNIT COST
Noise barrier	Absorb sound	B	1.25
	Beautify landscape	S	0.75

30.12 DETERMINATION OF FUNCTIONAL VALUE:

Value can be quantitatively expressed through the use of the cost to worth ratio, called the Value Opportunity Index. High ratios indicate poor value. Low ratios, approaching one, indicate good value. The Value Opportunity Index established for a project (or a function) provides a measurement of its true value, and suggests those items or functions susceptible to value studies.

Throughout the VE Job Plan, the team should keep in mind that value is maximum when performance is reliably achieved for minimum, total cost. Thus, satisfactory performance throughout the desired life cycle of the product is essential to good value. Value Engineers look beyond initial cost. The costs of operation, maintenance, and disposal or replacement must also be taken into consideration.

A complete Life Cycle Cost model should include an analysis of the following items calculated in terms of present value:

- Capital Cost - initial cost of construction, design, land, legal fees, etc.
- Maintenance - the cost of regular maintenance patrol, repair, salaries of maintenance personnel, and maintenance contracts
- Rehabilitation/Replacement - the cost of replacing materials, equipment or other elements during the life cycle of the entire facility
- Salvage - income derived from disposal of a facility or the value of unused service life
- Miscellaneous - other factors to be considered if appropriate include:
  - Finance Cost
  - Denial of Use
  - Lost Revenue

30.13 INVESTIGATION PHASE CHECKLIST:

- General
  - What is the item?
  - Are environmental commitments satisfied?
  - Are other commitments met?
  - How does it work?
  - What does it do or accomplish?
  - Why does it work?
  - What must it do or accomplish?
  - How does it relate to other systems?
  - Why is it needed?
  - Have all of the functions been identified?
  - Have redundant function been identified?
  - Have required functions been identified?
  - Are functional requirements understood?

- Specifications

  - Have specifications and requirements been reviewed?
  - Are specifications realistic?
  - Can a modification of the specifications simplify design and construction?
  - Are the specifications required, or are they just guidelines?
  - Are all performance and environmental requirements necessary and sufficient?
  - Have all of the specifications been interpreted correctly?
  - What are the desirable characteristics?
  - Have State and Federal polices, procedures and regulations been reviewed?

- Engineering and Design

  - Has the background information been collected?
  - Who designed it and when?
  - Who determined the requirements (this would be the members of the Concept Team)?
  - Who must review and approve a change (this would normally be the Project Manager or the manager of the Responsible Design Division)?
  - Who must approve implementation funding (the Deputy State Highway Engineer Development)?
  - Who must implement the change (this will probably be the Design Engineer)?
  - Does the design meet or exceed those set forth in the Concept Report?
  - What alternatives were considered during design?
  - Why were the alternatives rejected?
  - Are any changes to the design planned?
  - Do the drawings reflect state-of-the art?
  - What is the design life?
  - What are the Life Cycle Costs?

- Methods and Processes

  - Can functions be combined, simplified, or eliminated?
  - Are any nonfunctional or appearance-only items required (these should be identified in the Environmental Document)?
  - How is construction performed and why?
  - Are there any high direct labor costs?
  - Are high-cost areas or items identified?
  - What is the schedule (this is very important, because VE cannot be seen as a delaying process)?

- Materials
  - Are special, hard-to-get, or costly materials specified?
  - Were alternative materials considered, and if so why were they rejected?
  - Are the specified materials hazardous or difficult to handle?
  - Are there new materials that may perform the same function?
  - Is this a single source item?

- Maintenance
  - Has the Maintenance Division, District Engineer, and the District Maintenance Engineer been consulted?
  - What is normal maintenance?

- Function and Worth
  - Are costs assigned to each function?
  - Has a worth been established for each function?
  - Have target costs been determined for each function?
  - Are design requirements established that don't require any function to be performed?
  - Are functional requirements exceeded?
  - Are unnecessary features called for?
  - Can a function be eliminated, entirely or in part?
  - Does it cost more than it's worth?
  - Have all the high and unnecessary cost areas and high cost/worth ratio areas been identified?
  - Does the potential cost reduction (net savings) appear to be sufficient to make further VE investigations and potential worthwhile?

SECTION 40: SPECULATION PHASE

40.1 OBJECTIVE:

The objective of the Speculation Phase of the Value Engineering Job Plan is to "brainstorm" the functions of the design elements isolated by the investigation Phase, and to develop a number of alternatives to each.

40.2 SPECULATION PHASE OUTLINE:

- Understand and control the positive and negative factors in creative thinking.
- Plan for creative sessions.
- Select the creative techniques to be used.

40.3 PLAN FOR CREATIVE SESSIONS:

During this phase of the Job Plan, creative effort is directed toward the development of alternative means to accomplish the needed functions. Consideration of alternative solutions should not begin until the problem is thoroughly understood. All members of the VE task group should participate, because the greater the number of ideas conceived, the more likely that better quality, less costly alternatives will be among the ideas.

Challenge the present method of performing the function. Technology is changing so fast that the rules of a few years ago are probably obsolete. Create new ways (alternatives) for performing the necessary function(s) more efficiently and at a lower total life cycle cost. Take advantage of new products, processes, and materials.

Use Creative Techniques. Use as many creative techniques as necessary to get a fresh point of view. Adopt a positive mental approach to any problem. In developing ideas, <u>allow no negative thoughts</u>, no <u>judicial thinking</u>. Concentrate on creating as many ideas as possible on how the function <u>can</u> be performed. After writing down all of the ideas, consider all possible combinations to determine the best method of performing the function.

Every attempt should be made during this phase to depart from the ordinary patterns, typical solutions, and habitual methods. Experience indicates that it is often the new, fresh, and radically different approach that uncovers the best value solution(s).

The best solution may be complete elimination of the present functions or item. This possibility should not be overlooked. Only after determining that the function must remain should the study group look for alternative ways to perform the same function at the lowest conceivable cost. Free use of imagination is encouraged so that <u>all possible solutions are considered</u>.

40.4 CREATIVE THINKING TECHNIQUES:

Several techniques are available to the Team Leader for use during the Speculation Phase. They may be used singularly or in combination depending on the project under study and the preferences of the team leader. Some of the more widely known and used techniques are outlined below:

40.4.1 FREE ASSOCIATION TECHNIQUES: Free association of ideas is the fruit of both the conscious and subconscious mind. In fact, the subconscious mind is the most creative portion of the brain, but the conscious portion forms the input.

40.4.1.1 Brainstorming: This creative approach is an uninhibited, conference-type, group approach, based upon the stimulation of one person's mind by another's. A typical brainstorming session consists of a group of four to eight people spontaneously producing ideas designed to solve a specific problem. The objective is to produce the greatest possible number of alternative ideas for later evaluation and development.

- Rules observed during brainstorming
  - Judicial thinking must be withheld. This means controlling the natural tendency to instantaneously evaluate ideas.
  - No criticism by word of mouth, tone of voice, shrug of shoulders or other forms of body language, that indicates rejection, is permitted.
  - "Free-wheeling" is welcomed. The wilder the idea, the better; it is easier to tame down than to think up.
  - Apply the technique of "hitchhiking" or "piggybacking" to expand on the ideas of others by offering many variations (synergism).
  - Combination and improvement of ideas is suggested.
  - Set a goal in the number of ideas, or time, to force hard thinking.
- The general procedure for brainstorming is:
  - The group has a free discussion, with the group leader only questioning and guiding and occasionally supplying problem-related information.
  - All ideas are listed so that all members of the group can see as well as hear the ideas. The use of a flip chart and crayons, or felt tip pens, is preferable. The filled sheets can be taped to the walls so that they are constantly in view.

40.4.1.2 Gordon Technique: The Gordon Technique is a variation of brainstorming, having one basic difference. No one, except the group leader knows the exact nature of the problem under consideration.

40.4.2 ORGANIZED TECHNIQUES: These techniques are characterized by a logical step-by-step approach:

40.4.2.1 The Checklist Technique: is a system of getting idea-clues or "leads" by checking the items on a prepared list against the problem of subject under consideration. The objective is to obtain a number of general ideas for further follow-up and development into specific form.

40.4.2.2 The Catalog Technique: is simply the reference to various and sundry catalogs as a means of getting ideas that will, in turn, suggest other ideas. This technique can be used as a stimulant to a brainstorming session.

40.4.2.3 Morphological Analysis: is a comprehensive way to list and examine all of the possible combinations of ideas that might be useful in solving a problem. The procedure is as follows:

- State the problem as broadly and as generally as possible.
- Define the independent parameters that the solution must meet.
- List all alternative ways of fulfilling each parameter. These alternatives can be entered on a chart to aid in visualizing the possible combinations.

40.4.2.4 Attribute Listing is a technique used principally for improving a tangible thing. The procedure generally follows the four steps listed below:

- Choose the object to be improved.
- List the parts of the object.
- List the essential features or attributes of the object and its parts.
- Systematically change or modify these attributes.

40.5 SPECULATION PHASE CHECKLIST:

- Have creative thinking techniques been used?
- Has an atmosphere been provided that encourages and welcomes new ideas?
- Has there been cross-inspiration?

- Have all members of the team participated?
- Has an output goal been set?
- Have all of the ideas been recorded?
- Have negative responses been discouraged?
- Has the team reached for a large number of ideas?
- Have ideas been generated without all of the constraints of specifications and system requirements?
- Has a thorough search been conducted for other items that are similar in at least one significant characteristic to the study item?
- Have all basic functions of the project been defined?
- Has a speculation worksheet been filled out for each basic function?
- Have you dismissed from your thoughts the present way the basic function is accomplished?
- For group brainstorming, have techniques, method of approach, and "ground rules" been explained before proceeding?
- Have all of the basic functions of the project team been subjected to the complete speculation Phase?

SECTION 50: EVALUATION PHASE

50.1 OBJECTIVE:

The objective of the Evaluation Phase of the Value Engineering Job Plan is to analyze the results of the Speculation Phase and, through review of the various alternatives, select the best ideas for further expansion.

50.2 EVALUATION PHASE OUTLINE:

- Perform preliminary screening to separate the best ideas.
- Evaluate the alternatives to aid selection for development.
    - Determine criteria and objectives.
    - Weight the alternatives.
    - Weight the criteria and objectives of the project.
    - Compute numerical rating.
    - Rank alternatives.
    - Select the best alternates for development.

50.3 DISCUSSION:

During speculation, a conscious effort was made to prohibit any judicial thinking so as not to inhibit the creative process. Now the ideas thus produced must be critically evaluated. With all ideas recorded, evaluate the ideas for acceptance. The key questions listed below can be used as the basis for a set of evaluation criteria by which to judge the ideas:

KEY QUESTIONS

- How might the idea work?
- Can it be made to work?
- What is the cost?
- Will each idea perform the basic function?
- Which is the least expensive?
- Can it be modified or combined with another?
- What are the chances for implementation?
- Will it be relatively difficult or easy to make the change?
- Will the users' needs be satisfied?
- What is the savings potential, including life cycle costs?

50.4 WEIGHTING ALTERNATES:

50.4.1 ALTERNATE/CRITERIA METHOD: A method of graphically "weighting" alternates is useful when several are under consideration. Ideas are rated based on appropriate criteria, using a worksheet similar to that shown in Figure 50.4.1-1. In order to illustrate, let us assume we are studying an engine manufacturing plant that produces only a 6-cylinder in-line gasoline engine. They have discussed a large number of alternatives for the new line. These have been reviewed and the total reduced to four that are under serious consideration.

- V8 DIESEL
- V8 GASOLINE
- V6 GASOLINE
- IN-LINE 4-CYLINDER GASOLINE

In order to weight ideas, we need a set of standards or criteria. In arriving at a suitable set of criteria, the question is asked, "What will be affected by this idea if implemented?"

Criteria are then inserted in the spaces across the top of the form as shown. Alternates are rated against criteria by using 5 for superior to 1 for poor. It is recommended that rating be done from top-to-bottom rather than from left-to-right. Experience in problem-solving indicates that individuals tend to rate a preferred alternate high in all areas if the alternative is rated against each criteria rather than the criteria being rated against each alternate.

WEIGH ALTERNATIVES 5 SUPERIOR 4 GOOD 3 AVERAGE 2 FAIR 1 POOR		CUSTOMERS	PLANT EQUIPMENT	SKILLED LABOR	SPACE REQUIREMENTS	VEHICLE STYLE	PRODUCTIVITY	CORPORATE IMAGE	
ALTERNATIVES									TOTALS
V8 DIESEL		2	2	2	2	3	2	3	16
V8 GASOLINE		4	2	2	2	3	3	3	19
V6 GASOLINE		5	3	3	4	3	3	4	25
IN-LINE, 4 CYLINDER GASOLINE		3	3	5	5	4	5	2	27

Figure 5.4.1-1 - Rating Alternatives against Criteria

By adding numerical values from left-to-right, totals are obtained and inserted in the appropriate column at the right as shown in Figure 50.4.1-1. Figures in the "total" column can be used as an aid in decision-making.

50.4.2 ALTERNATE OBJECTIVE METHOD: As a variation of the Alternate criteria method, a set of criteria composed of "objectives" could be used. To develop our objectives, we ask, "What are the end results we would like to achieve?" We want specific, not general, goals. Objectives listed for our new engine line problem are entered across the top of the worksheet, as shown in Figure 50.5-1. You will note that this approach directs our thinking in such a way that a more meaningful set of standards may result.

50.5 WEIGHTING CRITERIA AND OBJECTIVES:

The method most commonly used for the final selection process is that of weighting each alternative against a set of chosen criteria or objectives.

It is seldom that "objectives" or "criteria" will be of equal importance and, therefore, some should have greater influence on the final decision than others. A weight factor can be introduced as shown in the blocks along the top of Figure 50.5-1. Weights from 1 to 10 can be used, with the highest number being given to the criteria with the most importance.

Again, using 5 for superior to 1 for poor, we proceed from top-to-bottom, inserting the appropriate rating in the upper left-hand portion of each divided block. Ratings are based on the degree of contribution made towards accomplishing each individual objective. If a particular alternative contributes substantially towards achieving an objective, it should be rated "5". A somewhat smaller contribution would be rated "4", and a poor contribution "1". No idea should be arbitrarily discarded; all should be given a preliminary evaluation, as objectively as possible, to determine whether or not there is some way the idea can be made to work.

A numerical rating is now computed by multiplying the weight factor times the rank. The result is inserted in the lower right-hand portion of each square as in Figure 50.5-1. Adding horizontally, totals are posted in the right-hand column, aiding selection.

OBJECTIVES/CRITERIA

WEIGH ALTERNATIVES 5 SUPERIOR 4 GOOD 3 AVERAGE 2 FAIR 1 POOR	FUEL CONSUMPTION	ACCELERATION (0-50)	MAINTENANCE COST	WEIGHT	ORIGINAL COST	LIFE OF ENGINE	ACCESSORY POWER	
ALTERNATIVES	7	4	3	2	10	9	5	TOTAL
V8 DIESEL	5/35	1/4	2/6	2/4	1/10	5/45	5/25	129
V8 GASOLINE	3/21	5/20	3/9	3/6	3/30	3/27	5/25	138
V6 GASOLINE	4/28	4/16	4/12	4/8	4/40	3/27	3/15	146
IN-LINE, 4 CYLINDER GASOLINE	5/35	2/8	5/15	5/10	5/50	2/18	1/5	141

Figure 50.5-1 – Ranking Analysis Complete

50.6 EVALUATION PHASE CHECKLIST:

- Have all ideas been reviewed?
- Has each idea been refined to see how it could be made to meet all needed functional and physical attributes?
- Have evaluation criteria been established?
- Has a cost estimate been made for each feasible idea?
- Has the time to implement each idea been considered and estimated?
- Has each idea been rated according to relative merits regarding cost and other advantages or disadvantages?
- Can alternates be simplified to attain further performance/cost optimization?
- Have all the functions been reevaluated as to their need?
- Have at least three ideas been selected as the best ideas?

SECTION 60: DEVELOPMENT PHASE

60.1 OBJECTIVE:

The objective of the Development Phase of the Value Engineering Job Plan is to collect additional data, to thoroughly analyze those best alternatives selected during the evaluation phase, and to prepare cost estimates and initial designs that will ensure acceptability and ultimate project implementation.

60.2 DEVELOPMENT PHASE OUTLINE:

- Determine sources for additional information.
- Ascertain technical feasibility of the selected alternatives.
- Determine economic feasibility of the selected alternatives.
- Present findings in detailed change proposals.
- Develop implementation plan.

60.3 DISCUSSION:

This phase is an objective appraisal of the lowest cost alternative methods of reliably performing the required functions. During this phase the most promising alternatives selected during the Evaluation Phase will be further developed into detailed alternative design ideas. The intent is to obtain and present adequate backup data regarding design changes and costs for presentation to management.

The best ideas are completely developed, with the assistance of experts and specialists, as required. Recommended design changes, materials, procedures, new forms, changes to standards and policy, all costs, and implementation requirements are to be documented. Select about three alternatives for performing each major function based on the best value potential(s). Develop each idea until enough data has been accumulated to prove the idea, and then choose the best, developing that one fully. Develop the next best idea deeply enough to prove its potential. The idea that was initially selected as the best could get rejected by management. It is handy to have a close-running number two idea to fall back on.

60.4 DEVELOPMENT PHASE TECHNIQUES:

- CONSIDER ALTERNATE PRODUCTS, AND MATERIALS. In developing ideas one should give consideration to all possible design solutions, including different products, and materials, as applicable.
- CONSULT SPECIALISTS. To obtain better value in design, one must obtain better answers to technical and construction problems through consultation with the most knowledgeable specialists available. If the

functions have been defined correctly, using precise verbs and measurable nouns, the area of knowledge needed for value can be identified. For example, "support weight" would indicate that a material specialist or structural designer could contribute.
While consultation can be done by telephone or mail, it is usually more desirable to have a personal meeting with the specialists. The Value Analyst must be able to: (a) Define the required functions and the cost problem; (b) Indicate the importance and priority of the problem; (c) Make the specialist a part of the project; (d) Direct the specialist's efforts; (e) Give credit for his contribution; and (f) Ask him/her to identify other specialists or sources of assistance. Effective use of specialists can remove many potential roadblocks.

- CONSULT SUPPLIERS. The highway industry employs a unique group of suppliers, particularly in the structural field, including personnel with the latest information on structural shapes, pipe culverts, cements, chemical additives, etc. Recent advances in traffic control techniques include electronic applications that the average highway engineer has no time to review. The Value Team's job is to find and use this knowledge.
Encourage your suppliers to suggest alternatives, other materials, design modifications, etc., to learn from their experience. In design, don't demand unnecessarily stringent requirements "just to be on the safe side." Over-specification may be safe and easy, but it is an expensive "shortcut." Solicit suggestions for improvement from the suppliers, and ask what there is about the design that causes high cost. In early planning, thoroughly describe the functional and technical requirements of the project, indicating those that are critical and those where some flexibility exists. Keep abreast of the services your suppliers have to offer, and maintain an up-to-date file of new services as a potential source of ideas leading to tangible dollar savings in future planning and design.

60.5 PROCEDURES:

- GENERAL. Each alternate must be subjected to: (a) careful analysis to insure that the user's needs are satisfied; (b) a determination of technical adequacy; (c) the preparation of estimates of construction and life-cycle costs; and (d) full consideration of the costs of implementation, including redesign and schedule changes.

- DEVELOP SPECIFIC ALTERNATES. Those alternates that stand up under close technical scrutiny should be followed through to the development of specific designs and recommendations. Prepare drawings or sketches of alternate solutions to facilitate identifying problem areas remaining in the design and to detail a cost analysis.

Perform a detailed cost analysis for proposed alternates to be included in the final proposal.

- TESTING. Tests required to demonstrate technical feasibility should be performed before the alternate is recommended for implementation. Often the desired tests have already been conducted by another agency. Ask for a report on those tests. If not already available, the VE team may arrange for the necessary testing and evaluation involved. Required testing should not delay approval of a proposal when: (a) Risk is low; (b) Consequences of less success would involve nothing more serious than less cost saving; (c) The element being tested involves an intangible or subjective factor; and (d) The test is normal confirmation procedure after an action is taken.

- DEVELOP IMPLEMENTATION PLANS. Anticipate problems relating to implementation and propose specific solutions to each. Particularly helpful in solving such problems are conferences with specialists in areas such as: inspection, environmental, legal, procurement, materials, and planning. Develop a specific recommended course of action for each proposal that details the steps required to implement the idea, who is to do it, and the time required.

60.6 LIFE CYCLE COSTING:

The life cycle cost of a bridge, highway, car, or any other item with a service life may be defined as "the total cost of ownership of the item over the service life of the item." Included in the Life Cycle Cost would be the original manufacturing or construction cost, maintenance and repair costs over the service life, operational costs, replacement cost, cost of money, and any salvage value the item may have.

The Value Analysis of an item uses Life Cycle Costing to evaluate the various alternatives considered in selecting the most cost effective item. The principles of Engineering Economy are readily applied to this selection process as a method of expressing all of the total ownership costs on an equal basis of comparison.

To make these comparisons all costs must be equated on an annual cost basis or on a present worth basis. Engineering Economics does this through mathematical equations that recognize the time value of money. Appendix B of this manual provides guidance and information on developing the Life Cycle Cost and analyzing the costs for the VE study alternatives.

SECTION 70: PRESENTATION PHASE

70.1 OBJECTIVE:

The objective of the Presentation Phase of the Value Engineering Job Plan is to put the recommended alternatives before the decision-makers in such convincing terms that they will accept them. Decision-makers are those individuals who will ultimately approve the VE Team's recommendations. Those projects requiring a VE Study per Section 20.2 of this manual will typically involve decision-makers that include the Deputy State Highway Engineer-Development and FHWA. These projects may also involve decision-makers from certain WVDOH divisions particularly affected by the recommendation.

70.2 PRESENTATION PHASE OUTLINE:

- Anticipate roadblocks to be overcome.
- Prepare written proposal.
    - Summarize study.
    - Identify expected benefits/disadvantages.
    - Make recommendation of specific action.
    - Suggest an implementation plan of action.
- Prepare oral presentation.
- Sell the ideas for change.

70.3 DISCUSSION:

The success of an individual VE Team Study is measured by the savings achieved from implemented proposals. Regardless of the merits of the proposal, the net benefit is zero if the proposals are not implemented. Presenting a proposal, and subsequently guiding it to implementation, often requires more effort than its actual generation.

The initial presentation of the recommendation must be concise, factual, and accurate with presentation in such a manner as to create a desire on the part of those responsible to implement the change. The selling of the recommendation depends to a large extent on the use of good human relations. The recommendation should be presented in such a way as to avoid any personal loss or embarrassment to those related to the study item. Proper credit should be given to those who contributed and to those responsible for implementation.

The information contained in the VEP will determine whether the VEP will be accepted or rejected. Although sufficient information may be available to the team, unless this information is documented in the proposal, undoubtedly, the change will be rejected.

Management must base its judgment on the documentation submitted with a proposal. The proposal and supporting documentation should provide all of the data the reviewer will need to reach a decision.

70.4 WRITTEN PROPOSAL:

A VEP should always be made in writing. Oral presentation of study results should supplement the written report. The systematic approach of the VE Job Plan includes the careful preparation of a written report, from which will evolve a more concise oral presentation.

70.5 GAINING VEP ACCEPTANCE:

Several hints that appear to be most successful in improving the probability of acceptance are discussed in the following paragraphs:

- CONSIDER THE REVIEWER'S NEEDS. Use terminology appropriate to the organization and position of the reviewer. Each proposal is usually directed toward two audiences. The first is technical, requiring sufficient detail to demonstrate the feasibility of the proposed change. The second is administrative, for whom the technical details can be summarized. Financial implications are emphasized. Long-range effects on policies are usually more significant to the manager than to the engineer.

- Early disclosure of potential changes can serve to warn the VE Team of any objections to the proposal. This "early warning" will give them an opportunity to incorporate modifications to overcome the objections. If management has been kept informed of progress, the VEP presentation may be only a concise summary of final estimates, pro and con discussion, and perhaps formal management approval.

- RELATE BENEFITS TO ORGANIZATION OBJECTIVES. The VEP that represents advancement toward some approved objective is most likely to receive favorable consideration from management. Therefore, the presentation should exploit all the advantages a VEP may offer toward fulfilling organizational objectives and goals. The objective may be not only savings but also the attainment of some other mission-related goal of the manager.

- SUPPORT THE DECISION-MAKER. The dollar yield of a VEP is likely to be improved if it is promptly implemented. Prompt implementation in turn, is dependent upon the expeditious approval by the individuals responsible for a decision in each organizational component affected by the proposal.

- ADEQUATE RETURN. If VE Proposals to management are to be given serious consideration, the proposal should include adequate evidence of satisfactory return on the investment. Often, current contract savings alone will assure an adequate return. In other cases, Life-Cycle or total program savings must be considered. Either way, evidence of substantial benefits will improve the acceptability of a proposal.

- SHOW COLLATERAL BENEFITS OF THE INVESTMENT. VE proposals often offer greater benefits than the immediate cost improvements specifically identified. Some of the benefits are collateral in nature, and difficult to equate in monetary terms. The likelihood of acceptance of the VEP is improved when all its collateral benefits are clearly identified and completely described. Some areas are maintenance, energy conservation, aesthetics, environmental quality, replacement cost, etc.

- OTHER FACTORS.

  - If the study has the approval of other authorities, cite this as an indication of broad organizational support.
  - The use of supplementary material depends on the nature of the report. If it is long and complex, simple charts, figures, and tables may be far more effective than pages of hard-to-read values, dates, and statistics. Illustrations and photos are always a welcome relief from pages of text.
  - Consider the procedures used by others in evaluating the proposal. View the proposal as others will view it.
  - Remember that those who read the proposal are busy; they want the facts quickly and concisely. The report must tell them all they want to know, about something with which they may not be familiar, in a clear and concise manner.

70.6 THE VE WORKBOOK:

A workbook is compiled throughout the life of a study, starting with the Investigation Phase. If properly maintained during the project, the workbook should require no additional preparation effort during this phase. The workbook should be a complete and ready document, facilitating preparation of the Summary Report and support the team's recommendations.

The following list indicates the type of information that should be recorded in the project workbook for each project:

- Identification of the project.

- A brief summary of the problem.

- An explanation of why this project was selected for study.

- A functional evaluation of the process or procedure under study.

- All information gathered by the group relative to the item under study.

- A complete list of all the alternates considered.
- An explanation of all logical alternates investigated, with reasons why they were not developed further.
- Technical data supporting the idea(s) selected, with other factual information to assure selection of the most favorable alternate(s).
- Original costs, cost of implementing the alternates being proposed, and cost data supporting all savings being claimed.
- Acknowledgment of contributions made by others to the study.
- Steps to be taken and the timetable for implementing the alternate(s) being proposed.
- Before-and-after sketches of the items under study.

The forms necessary to complete the VE Workbook are included in Appendix A of this manual.

70.7 REASONS FOR REJECTION OF VE RESULTS:

Failure to provide adequate proposal documentation is a major cause for proposal rejection, as indicated below:

- PROJECT ADVERSELY AFFECTED. It is safe to assume that any approval authority will want positive assurance that the integrity of the project is maintained.
- TECHNICAL SUPPORTING INFORMATION INCOMPLETE OR INACCURATE. For an approval authority to have confidence in accepting a VEP, all salient technical information must be provided. Proof of previous successful use or tests supporting the change proposal should accompany the VEP.
- COST ANALYSIS INCOMPLETE OR INACCURATE. Credibility of cost information is of major importance. Erring on the conservative side with cost estimates tends to gain more favorable consideration than presenting inflated claims of savings. Although approval authorities know that cost information must usually be estimated, the basis and sources of the estimates should be revealed.
- OTHER REASONS:

- There has been prior unsuccessful action to initiate or develop a similar VE proposal.
- There is inadequate time in which to implement the proposal.

70.8 PRESENTATION CHECKLIST:

- Is the need for a change clearly shown?
- Is the problem defined?
- Is the proposal concise?
- Are all the pertinent facts included?
- Are dollar savings included?
- Is your VE Proposal Summary Book complete and accurate?
- Have you double-checked your recommendations, costs, and savings?
- Is your information complete?
- Have you prepared back-up material for questions that may be asked?
- Has a plan of action been established that will assure implementation of a selected alternative?
- Is the change described?
- Are there pictures or sketches of before-and-after conditions?
- Has the best alternate been considered?
- Have all the constraints been considered?
- Has the implementation plan developed?
- Have the recommendations been extended to all areas of possible application?
- Has the improved Value design been considered for standard of preferred practice?
- Has credit been given to all participants?

- If you were a decision maker, is there enough information for you to make a decision?

The concluding paragraphs of this chapter provide some specific descriptions of how to improve your written and oral communications. These are essential elements in selling you new ideas of changes.

70.9 WRITTEN REPORTS:

- Clear communications should be the basic function of all writing. No matter what the purpose of the writing, the result should be the transfer of thought. The idea you have may be top-rate, but until you've explained it clearly to others, neither your organization nor you will gain from it.

- One of the ways to improve upon your written report is to observe these ten rules of clear writing:

    - Keep sentences short. Long sentences make reading difficult. Time and Readers Digest usually average 16 or 17 words per sentence. Business sentences often exceed 25 words.
    - Present simple thoughts and expressions.
    - Use familiar words.
    - Avoid using unnecessary words.
    - Put action in you verbs.
    - Write the way you talk. The written word sometimes gets "stuffy."
    - Use terms your reader's experience.
    - Write within your reader's experience.
    - Use variety in expressions.
    - Write to express; not impress.

70.10 ORAL PRESENTATION:

- The oral presentation is the keystone to selling a proposal. The presentation gives the VE team a chance to ensure that the written proposal is correctly understood, and that proper communication exists. Effectiveness of the presentation will be enhanced if:

    - The entire team is present and is introduced.
    - The presentation lasts no longer than 10 minutes, with added time for questions.
    - The presentation is illustrated through the use of mockups, models, slides, vu-graphs, opaque projector, or flip charts.

    - The team is prepared with sufficient backup material to answer all questions during the presentation.

- The oral presentation should include, but not necessarily be limited to, the following:

    - Identification of the project studied.
    - Brief summary of the problem.
    - Description of original design.
    - Cost of original design.
    - Results of the Function Analysis.
    - Technical data supporting selection of the alternative(s).
    - Cost data supporting the alternative(s).
    - Explanation of advantages and disadvantages and reasons for accepting the alternative(s).
    - Sketches of before-and-after design, clearly depicting proposed changes. (Drawings marked to show proposed changes are acceptable.)
    - Problems and costs of implementation.
    - Estimate net savings. Acknowledgment of contribution by others.
    - A summary statement.

70.11 VISUAL AIDS:

Good graphic illustrations can translate a large number of figures into a simple understandable "management language." But, the documentation on which a presentation is based, and the visuals that interpret that documentation, are measured by entirely different yardsticks.

Documentation is based on detailed findings. The facts, figures, and statistics that make up the documentation should be as complete, up-to-date, detailed, authentic, fully organized, and thoroughly indexed as possible.

The visuals summarize the situation at a glance. The charts, graphs or other visuals used in a presentation should be as few in number and as significant, simple, and free of detail as it is possible to make them, pinpointing the high spots that the briefing seeks to identify, clarify, and establish.

A good presentation chart should get the message across clearly in less than 30 seconds of study, requiring little explanation to enable the viewer to follow and understand the chart.

SECTION 80: IMPLEMENTATION PHASE

80.1 OBJECTIVE:

The objective of the Implementation Phase of the Value Engineering Job Plan is to assure that approved proposals are rapidly and properly translated into action, to achieve the savings or project improvements that were proposed.

80.2 IMPLEMENTATION PHASE OUTLINE:

- Develop an implementation plan.
- Execute the plan.
- Monitor the plan to completion.

80.3 DISCUSSION:

Even after formal presentation, the objectives of a VE study have not been fully attained. The recommendations must be converted into actions; hence, those who performed the study and the Project Manager who directed that the study be done, must all maintain an active interest until the proposal is fully incorporated into the design or plans. A poorly implemented proposal reflects discredit on all concerned. An approved VE proposal should not be permitted to die because of inaction in the implementation process.

80.4 IMPLEMENTATION INVESTMENT:

The need to invest time or funds in order to save money must be emphasized when submitting Value Change Proposals. Funds or personnel time for implementation must be provided.

Successful implementation depends on placement of the necessary actions into the normal routine of business. Progress should be reviewed periodically to ensure that any roadblocks that arise are overcome promptly.

80.5 EXPEDITING IMPLEMENTATION:

The fastest way to achieve implementation of an idea is to effectively utilize the knowledge gained by those who originated it. Whenever possible, the VE team should be required to prepare initial drafts of documents necessary to revise handbooks, specifications, change orders, drawings, and contract requirements. Such drafts will help to assure proper translation of the idea into action, and will serve as a baseline from which to monitor progress.

80.6 IMPLEMENTATION PHASE CHECKLIST:

- Are the expected results known?
- Has someone been designated as responsible for taking action to implement the approved alternatives?

- Has the contract been amended?
- Have the specifications or drawings been revised?
- Have completion dates for implementation been established?
- Have the resources needed to accomplish implementation been recommended and allocated?
- Have required test plans, allocations, and schedules been established?
- Have modifications to the VEP been documented?

SECTION 90: AUDIT PHASE

90.1 OBJECTIVE:

The objective of the Audit Phase of the Value Engineering Job Plan is to assure the desired results have been attained, properly documented, and reported.

90.2 AUDIT PHASE OUTLINE:

- Perform an audit.
- Evaluate results.
- Prepare final project report.
- Distribute information to interested parties.
- Compile results of all VE Studies in “Annual VE Report to FHWA”.

90.3 DISCUSSION:

Until audit of results are completed, the records on the project cannot be closed. Sometimes an audit is not accomplished because the audit requires additional effort (time-money-energy). Yet, the audit process is essential to the continuing success of the organization's VE program. There are two points of emphasis for completion of the Audit Phase of the VE program.

The first point of emphasis involves the VE coordinator establishing and maintaining a file on all completed VE Studies. These files should include all projects utilizing VE, including those projects requiring VE studies, VE change proposals by contractors, and VE studies performed by the WVDOH on other functions within the organization.

The second point of emphasis involves the compilation and submission of the “Annual VE Report to FHWA”. This report is a required step in the VE program. FHWA is required annually to report to Congress on the results of Value Engineering on a national basis. Therefore, the submission of WVDOH’s annual report to the West Virginia Division Office of FHWA is vital. The due date for this report is typically immediately following completion of the Federal Fiscal year (normally September 30). The VE coordinator shall utilize the file information from the VE studies noted above to prepare the report. However, coordination with the Responsible Division for the VE studies performed, particularly with the Consultant Review Section of Engineering Division and the Finalization Section of Contract Administration Division, may be required to obtain the information necessary to complete the report.

90.4 PROCEDURE

- The following steps will serve to foster and promote the success of future VE effort:
    - Obtain copies of all completed implementation actions.

- Compare actual results with original expectations to verify the accomplishment.
- Submit reports on cost savings or other improvements to management.
- Distribute information to all interested parties and other highway agencies.
- Review the project to identify any problems that arose, and recommend corrective action for the next project.
- Initiate recommendations for potential VE study ideas identified during the study just completed.
- Screen all contributors to the VE study for possible recognition, and initiate recommendations to management.
- Determine the effect on maintenance and other life cycle costs.

90.5 AUDIT RESPONSIBLILTY:

The VE coordinator is responsible for completing this phase of the Job Plan. Completed audit results will be included in the Annual VE Report to FHWA.

90.6 AUDIT PHASE CHECKLIST:

- Obtain and File A copy of the Final VE Study Report.
- Did the idea work?
- Was money saved?
- Was the design improved?
- Could it benefit others?
- Has it had proper publicity and distribution?
- Should any awards be made?
- Prepare Annual VE Report to FHWA.

SECTION 100: VALUE ENGINEERING CHANGE PROPOSAL

100.1 INTRODUCTION:

The West Virginia Division of Highways (WVDOH) has had a Value Engineering incentive clause in our Construction contracts for many years. The WVDOH encourages the use of Value Engineering Change Proposals (VECP) by the contracting industry as a means of increasing quality while saving construction dollars.

The Value Engineering specification that incorporates VECP's is included in all new construction projects, except on demonstration projects testing proprietary materials. This specification provides an incentive to the Contractor to initiate, develop, and present to WVDOH for consideration, any cost reduction proposals conceived by him. This could include changes in drawings, design, specifications, or other requirements of the contract. If accepted by the WVDOH, the net savings resulting from the VECP will be shared by the contractor and the WVDOH on a fifty-fifty basis.

100.2 PROCEDURES:

The internal process for the review and approval of VECP's is described in Contract Administration's Construction Manual.

SECTION 100: VALUE ENGINEERING CHANGE PROPOSAL

100.1 INTRODUCTION:

The West Virginia Division of Highways (WVDOH) has had a Value Engineering incentive clause in our Construction contracts for many years. The WVDOH encourages the use of Value Engineering Proposals (VEP) by the contracting industry as a means of increasing quality while saving construction dollars.

The Value Engineering specification that covers VEP's is included in all new construction projects. This provides an incentive to the Contractor to initiate, develop, and present to WVDOH for consideration, any cost reduction proposals conceived by him. This could include changes in drawings, design, specifications, or other requirements of the contract. If accepted by the WVDOH, the net savings resulting from the VEP will be shared by the contractor and the WVDOH on a fifty-fifty basis.

100.2 PROCEDURES:

- These are the basic steps required to administer a VEP (See Section 104.12 – “Value Engineering” of the West Virginia Division of Highways Standard Specifications Roads and Bridges, 2000).

- Contractor submits duplicate Formal or Preliminary VEP to the Project Supervisor.

- District Construction Engineer reviews proposal and contacts Design Project Manager to confirm submittal.

- The District Construction Engineer receives proposal in the format specified in Section 104.12.

- District Construction Engineer determines if proposal is Preliminary or Formal VEP.

  - Review for compliance to Section 104.
  - Evaluate math quantities, reasonable cost, accurate as compared to bid items and bid history etc.
  - Determine which specialty engineering groups are required.
  - Informally discuss with those units.
  - Informally discuss with Regional Construction Engineer.
  - Estimate effort required for review and compare it to the savings.

- District Construction Engineer determines the overall feasibility of the proposal.

- If not an acceptable cost to saving ratio and/or not feasible then the District Construction Engineer rejects proposal or requests a revision.

- If acceptable and the proposal is preliminary, advise contractor to proceed with Formal Proposal, following guidelines in Section 104.12. If the proposal is Formal the District Construction Engineer will select specialty Engineers to makeup the VE team (VET) to review proposal. This will include a representative from FHWA, if the job is Federally funded, or in an advisory role if not Federally funded. The design project manager will also be included in the VET.

- District Construction Engineer will head the team, distribute the VEP to them, and meet with them to determine if the proposal will work, if it is safe, will the service life be adequate, does it affect the appearance adversely, future maintenance concerns, and is the cost reasonable.

- Upon completion of the review the VET makes one of three recommendations, 1) Request revisions, 2) Reject Proposal, or 3) Approve the proposal.

- District Construction Engineer prepares a summary for the Regional Construction Engineer, including special condition, restriction, etc.

- The Deputy State Highway Engineer, Development uses the VET recommendation to make decision to accept or reject the VEP.

- If the VEP is approved, District Construction Engineer notifies the Contractor that the proposal will be approved pending construction change order. If there are federal funds involved the Regional Construction Engineer notifies FHWA.

- Calculate actual savings based on construction change order. Prepare follow-up summary of VEP and send copy to affected units.

- District Construction Engineer will send a copy of the completed VEP to the Value Engineering Coordinator for filing.

APPENDIX A

VALUE ENGINEERING STUDY - WORKBOOK

(BLANK)

NHI COURSE No. 13405
VALUE ENGINEERING
FOR HIGHWAYS

U.S. Department
of Transportation

Federal Highway Administration

VALUE
ENGINEERING
STUDY – WORKBOOK

Project Name: ______________________________

Location: ______________________________

Team No. ______________ Date: ______________

Publication No. FHWA-HI-88-051

VALUE ENGINEERING JOB PLAN PHASES

1. SELECTION

2. *INVESTIGATION*

3. *SPECULATION*

VE TEAM STUDY

4. *EVALUATION*

VE JOB PLAN

5. *DEVELOPMENT*

6. *PRESENTATION*

7. IMPLEMENTATION

8. AUDIT

VALUE ENGINEERING FOR HIGHWAYS

STUDY WORKBOOK

United States Department of Transportation
Federal Highway Administration
National Highway Institute

1980 Edition
Revised December 1992

General Instructions:

Complete each page clearly, legibly, and neatly with a dark pencil or black pen. In most cases this workbook will be reproduced as is and not retyped.

Instructions for Completing VE Study Identification

This is one of two pages used to identify the project and serve as an introduction to it. By reading this page, an interested party should be able to understand the general nature and scope of the project.

<u>VE TEAM MEMBERS</u>

This area is used to record the name, title, agency, and telephone number of each team member.

<u>PROJECT DESCRIPTION</u>

Length - In feet or miles

Cost - Estimated total project cost

Type of Funds - Are there Federal, State, and/or Local funds in the project? List their classification: construction, maintenance, local, etc.

Design Speed - Miles per hour

Projected Traffic - Average daily traffic (ADT) and design hourly volume (DHV)

Projected Award Date - Anticipated letting date

Major Project Elements - Describe what the project entails. What is involved? Give a verbal, non-technical description of what is included in this project. This description, followed by a listing of major components may be useful to individuals reviewing this workbook. For example: Grading, Drainage, Paving, Structures, Utility relocation, etc.

<u>ROUTE CONDITION / GEOMETRY</u>

It is often useful to know the condition of the adjacent segments, and the total route. For example: sufficiency rating, tangent section, rolling terrain, roadway cross-section, lack of shoulders, etc.

Value Engineering - Study Identification

Project: Team:
Location: Date:

VE TEAM MEMBERS

Name:	Title:	Organization:	Telephone:

PROJECT DESCRIPTION

Length: Cost:
Design Speed: Projected Traffic:
Projected Award Date: Type of Funds:
Major Project Elements:

ROUTE CONDITION / GEOMETRY

Adjacent Segments:	Overall Route:

Instructions for Completing Investigation Phase - Sources

AUTHORIZING PERSONS

List here the persons who will have to approve the VE recommendations. This information will be useful in ensuring that the recommendations are presented in a manner tailored to the unique habits and attitudes that may govern final acceptance.

PERSONAL CONTACTS

List here all the people from whom you seek advice and information regarding the study. Maintain and add to this list as the study progresses. Under "Notes," summarize the information obtained.

DOCUMENTS / ABSTRACTS

List all the reference material used in the study, i.e., standard specifications, AASHTO Guides, State standards, Means construction costs, AASHTO Green Book, etc. Briefly note the kind of information contained in them.

Investigation Phase - Sources

Project: Team:
Location: Date:

APPROVING / AUTHORIZING PERSONS

Name:	Position:	Telephone:

PERSONAL CONTACTS

Name:	Telephone:	Notes:

DOCUMENTS / ABSTRACTS

Reference:	Notes:

Instructions for Completing Investigation Phase - Cost Model

Prepare a COST MODEL for your project.

COST OF SIGNIFICANT BID ITEMS

It is often true that 20 percent of a project's elements constitute 80 percent of its cost.

Prepare a COST MODEL of all of the major items in you project. Using a Bar Chart format, show the cost of each item starting with the highest cost item first. Ten to twenty project cost elements are desired. Combine and/or breakdown cost elements to achieve this number of elements.

Draw a horizontal line to show the 80 percent cost split of the project items. This will indicate to the team those project elements deserving the most attention.

If some low cost project elements are used repeatedly throughout your organization, they may produce positive, organization-wide savings. List them on the cost graph, otherwise they will be ignored in the study.

Investigation Phase - Cost Model

Project: Team:

Date:

Instructions for Completing Information Phase - Function Analysis

This is where the conventional listing of project items and costs is transformed into a listing of project FUNCTIONS and their relative costs. Keep in mind that the objective of the investigation phase is to identify those functional areas that have the greatest opportunity for value improvement. The listing on this page is another step to ensure that the functions with the "best" potential for savings are examined first. In the title block, identify the FUNCTION of your total project using one verb and a noun.

Assign a LETTER to each project cost item. Next, enter a "Two-Word" definition (Action Verb & Descriptive Noun) that expresses the function of each item listed. Enter the item's cost as shown in the Cost Model. In making out this list, items satisfying the same function should be grouped together.

<u>OTHER ITEMS</u>

List any additional items that might have a potential for substantial savings if considered on a program-wide basis. Enter the "Two-Word" definition that expresses the function of each item listed. Enter the item's cost.

<u>WORTH</u>

Worth is the least cost that the VE team believes can accomplish the same function. Consider a functional comparative for each item listed. This should be a less costly way of performing the same function, irrespective of its project application. Use the "comment" column to identify the functional comparative or other means taken to achieve worth. This will show you if there is any substantial cost difference between the design cost and its worth. Some examples are:

	ITEM	FUNCTION	COST	WORTH	COMMENT
A.	Bridge	Cross Obstacle	$215,000	$115,000	Use Culvert
B.	Culvert Pipe	Convey Fluids	$100,000	$ 20,000	Use open ditch
C.	Slope widening	Enhance Safety	$125,000	$ 55,000	Guide Rail
D.	Traffic Light	Control Vehicles	$ 75,000	$ 10,000	Stop Signs

The size difference between the design cost and the worth of the functional comparative is an indication of value opportunity.

FHWA VE - 4 SHEET ___ OF ___

Investigation Phase - Function Analysis

Project: Team No:
Overall Project Function: Date:

Item		Basic Function:				
No.	Description:	Verb:	Noun:	Cost:	Worth:	Comments:

Instructions for Completing Investigation Phase - FAST Diagram

FAST DIAGRAM

The FAST diagram is a graphic representation of the functional logic applied to the original design. To develop a FAST diagram, one has to ask the questions, HOW is the basic function (verb) (noun) actually accomplished, or HOW is it proposed to be accomplished? The answer, expressed as a verb and a noun is written in the next block to the right of the scope line.

The process is continued to the right by asking HOW, for each new function on the diagram. The process is repeated until the answer falls outside the scope of the study. To check the answers to the HOW questions, ask the question WHY as you proceed backward through the FAST diagram, starting on the right side and proceeding to the left until you have exceeded the scope of the study (reached a function with a higher order than the basic function).

The line of functions you have developed is called the critical path. If one of the Required Secondary functions is taken away, the Basic Function of the system cannot be satisfied. If a function can be taken away without affecting the performance of the Basic Function, then the function removed is not critical, but may be a supporting function.

SUPPORTING FUNCTIONS

Functions that happen all the time, at the same time, or are caused by the critical functions are supporting functions. They result from the particular method chosen by the designer for accomplishing the Basic Function. All the time functions are shown above the critical path line and same time and caused by functions are shown below the line.

The FAST diagram can be used to identify and visualize high-cost functions by including the functional cost in each of the critical and supporting function blocks.

FHWA VE - 5 SHEET ___ OF ___

Investigation Phase - FAST Diagram

Project: Team:

Date:

Instructions for Completing Speculation - Brainstorming

This sheet is used for the SPECULATION / CREATIVE Phase of the VE Job Plan.

BRAINSTORM on each of the functions from the Function Analysis sheet. Put down as many ideas as possible. Use as many sheets as necessary. Do not limit your ideas. Write down all ideas. Remember the number one rule of brainstorming, DO NOT JUDGE!

Speculation Phase

Objective:

- Generate large numbers of ideas

Task:

- Speculate on functions
- Don't discuss

Key Questions:

- What else will perform the function?
- Where else may the function be done?
- How else may the function be done?

Techniques:

- List everything
- Be imaginative
- Use creative techniques
- Defer judgement
- Do not criticize
- Be courageous

FHWA VE - 6 SHEET ___ OF ___

SPECULATION PHASE - BRAINSTORMING

Project: Team:

Date:

Item: Function:	Item: Function:

Instructions for Completing Evaluation Phase

This sheet is used for the EVALUATION Phase of the VE Job Plan. Consider first those functions that have the greatest potential savings. Two Evaluation methods will be used.

FEASIBILITY EVALUATION

Review the creative ideas you have developed in your Brainstorming session and cross out those alternatives that the team believes are unrealistic and, therefore, unacceptable. CAUTION - Be absolutely sure everyone agrees the idea should be dropped.

SUITABILITY EVALUATION

Record all of the remaining ideas for each function that have not been crossed out and list their advantages and disadvantages. List the ideas for that item numbering consecutively (A-1, A-2, A-3; B-1, B-2, B-3; etc.)

Rate each idea from "poor" to "outstanding" (1 to 10). The rating is used to guide the team during the Development Phase ensuring the best ideas are developed first.

EVALUATION PHASE

Objective:

- Evaluate alternatives

Task:

- Speculate on evaluation criteria
- Evaluate alternatives
- Select the best alternatives

Key Questions:

- How might each idea work?
- What will be the cost?
- Will each idea satisfy the function?
- What is the better alternative?
- What are the chances of selling the idea?

Techniques:

- Weigh alternatives
- Choose evaluation criteria
- Refine ideas
- Place dollar value of each idea

FHWA VE - 7 SHEET ___ OF ___

Evaluation Phase

Project: Team No.
Date:

Item No.	Creative Idea Listing	Idea Evaluation: Advantage	Idea Evaluation: Disadvantage	Idea Rating

Instructions for Completing Evaluation Phase - Matrix Analysis

This is an optional worksheet for the EVALUATION Phase. It is a Matrix Analysis Form that you can use to assign numerical ratings to the subjective analysis you carried out on Form VE-7. It permits the team participants to weigh and rate various aspects of each alternative, while remaining free of any bias or predisposition about the alternative as a whole.

The Matrix Analysis is used to compare a variety of alternatives affecting a single project function. It is especially useful where there is no clear consensus among the VE team.

<u>OBJECTIVES OR CRITERIA</u>

List all the design objectives or performance criteria that apply to the project under study. Weigh them from 1 to 10 according to their relevance or importance (10 = high and 1 = low. Enter this weight in the horizontal line of boxes.

<u>ALTERNATIVES</u>

List the ORIGINAL item and all the alternatives from Form VE-7 that you want to compare. Rate how each of the alternatives satisfies each objective or criterion, i.e., 1 = poor and 5 = superior. Enter the rating for each alternative in the top part of the box.

TO ELIMINATE BIAS, it is essential to WORK DOWN each column, rating each alternative according to the same objective or criterion.

Multiply the rating by the weight for each combination. Enter the weighted rating in the lower part of the box.

Add the weighted ratings for each alternative together and enter its total score in the Totals column.

Rank the alternatives according to the total score (1 = highest, 2 = second highest, etc.). Now determine how the alternatives should be used and how they might be modified to improve the product.

Evaluation Phase - Matrix Analysis

Project: Team:
Creative Idea: Date:

EVALUATION CRITERIA

WEIGH ALTERNATIVES: 5 Superior 4 Good 3 Average 2 Fair 1 Poor							
ALTERNATIVES / WEIGHT							**TOTALS**

Instructions for Completing Development Phase - Recommendation

Once you identify the project elements and/or functional areas that can be modified, develop each area into a workable alternative solution. Complete Form VE-9 for each recommended alternative. Do not show any calculations or sketches on this sheet. Attach all backup calculation sheets used to develop the idea.

Keep in mind, the decision makers who will be reviewing these items are not familiar with the team's work this week. Develop your alternatives in a logical and complete fashion showing all calculations for documentation and listing all assumptions made.

The justification area is where you must state your reasons for making the change. Remember, you must "sell" your idea. Be complete. Use additional sheets of paper if necessary. Anticipate possible reasons to reject your idea and provide adequate responses to counter these objections.

Costs used on this sheet should include both initial and future costs. Detailed cost calculations should be shown on separate sheets. Future costs are the sum of lines 6 and 8 on the life cycle cost analysis worksheet (see Form VE-9D).

Development Phase - Recommendations

Creative Idea No. Team:

Recommendation: Date:

Original Design (Sketch attached Y N)

Proposed Change (Sketch attached Y N)

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design			
Proposed Change			
Savings			

Instructions for Completing Development Phase - Sketches

Having identified which functional areas can be changed, make a SIMPLE SKETCH of the project element as designed and as proposed. Be sure to include enough information to clearly identify the proposed changes.

HINT: A clear, easy to understand sketch is the best sales tool.

FHWA VE - 9A SHEET ___ OF ___

Development Phase - Sketches

Creative Idea No. Team:

Recommendation: Date:

Original Design

Recommended Design

Instructions for Completing Development Phase - Calculations

Show sufficient calculations to enable all reviewers to analyze your proposed change and determine that it is a workable and realistic alternative. Calculations should show technical data only. Reserve cost calculations for the cost worksheet. Be sure to identify and explain all assumptions you made if specific data is not available.

Include as many sheets as necessary.

FHWA VE - 9B SHEET ___ OF ___

Development Phase - Calculations

Creative Idea No. Team:
Recommendation: Date:

Instructions for Completing Development Phase - Cost Worksheet

A major element in "selling" your recommendations involves showing that they are not only viable engineering alternatives, but that they will result in a COST SAVINGS. This sheet allows for a comparison of the costs for the various proposed alternatives to their original costs.

Be as detailed in your costs as possible. Use the same unit costs for both the original and proposed estimate for each item of construction. List any assumptions made and indicate where your costs were obtained.

Item: This is the item of construction, such as; fill, concrete, 24" RCP, etc.

Unit: This is what units express the item, such as; CY, LF, SF, EA, etc.

FHWA VE - 9C SHEET ___ OF ___

Development Phase - Cost Worksheet

Creative Idea No. Team:

Recommendation: Date:

Construction Element		Orig. Cost			Prop. Cost		
		# of	Cost /	Total	# of	Cost /	Total
Item	Unit	Units	Unit	Cost	Units	Unit	Cost

Instructions for Completing Development Phase - Life Cycle Cost

This sheet is use to determent an item's LIFE CYCLE COST using the Present Worth method.

This worksheet is NOT required for each alternative, only those that evaluate costs other than initial construction costs.

Single payment factors and uniform series factors can be found in the Compound Interest Table at the end of this workbook.

1. Estimate the Economic Life for the Item (10, 15, 20, 35, 50, etc. - Years)
2. Determine the Discount Rate to be Used
3. List Initial Cost
4. List and Determine the Present Worth of all Future Single Costs
5. List and Determine the Present Worth of all Future Annual Costs
6. Sum the Costs to Determine the TOTAL Future Costs
   Include this Cost on Sheet VE-9

FHWA VE - 9D SHEET ___ OF ___

Life Cycle Cost Analysis - Present Worth Method

Creative Idea No. Team:
Recommendation: Date:
Discount Rate: Economic Life: ____ Years

	Original Design		Alt. No.1	
	Cost	PW	Cost	PW
1. Initial Cost:				

Single Expenditures: (i.e., stage Construction, Major Maintenance) a. Year ____ PWF ______				
b. Year ____ PWF ______				
c. Year ____ PWF ______				
d. Salvage / Unused Service Life Year ____ PWF ______				
2. Future Single Costs:				

Annual Costs:				
a. General Maintenance PWF ______				
b. Other Annual Costs PWF ______				
3. Future Annual Costs				

4. Total Future Costs: (2 + 3)				

5. Total Life Cycle Costs: (1 + 4)				

Instructions for Completing Development Phase - Summary of Cost Savings

This sheet provides a summary of all your recommended alternatives and their cost savings. List each of your proposed alternatives and its cost savings.

The TOTAL projected project savings should also be shown on this sheet to indicate the maximum potential savings. In determining the TOTAL savings, remember that some recommendations may overlap and therefore FULL credit cannot be taken for each. Use an asterisk in the last column to indicate which proposals are included in the TOTAL.

FHWA VE - 10 SHEET ___ OF ___

Development Phase - Summary of Cost Savings

Project: Team:
Location: Date:

Idea No.	Description	Original Design Cost	Proposed Change Cost	Initial Cost Savings	Future Cost Savings	Total Cost Savings

Instructions for Completing Development Phase - Executive Summary

The executive summary should include a concise, abstract of the VE study. It should be confined to one page if possible. This will serve as a summary document for the project and your recommendations. It is the executive action document from the team to the decision makers, highlighting the study and recommendations. As a minimum it should include:

General

- Project description including the total estimated construction cost
- Site and date of the VE study

Results Obtained

- Number of recommendations
- Total projected savings
- Savings as a percent of the project cost

Highlights

- Summarize significant recommendations (if many) or all recommendations (if few).

Constraints

- Identify any conditions (political, social, or site) that influenced the team's recommendations.

Development Phase - Executive Summary

Project: Team:

Date:

Instructions for Completing Presentation Phase

A good recommendation will require a good oral presentation. Team members should be ready to do this as succinctly as possible.

<u>OBJECTIVE:</u>

- Present alternatives

<u>TASKS:</u>

- Develop a written proposal
- Prepare adequate visual aids for your presentation
- Speculate on possible roadblocks to acceptance
- Present recommended alternatives

<u>KEY QUESTIONS:</u>

- Who must be convinced?
- How should the idea be presented?
- What was the problem?
- What is the new way?
- What are the benefits to be gained?
- What are the losses to be avoided?
- What are the savings?
- What is needed to implement the proposal?

<u>TECHNIQUES:</u>

- Make your recommendations
- Use selling techniques
- Be factual
- Be brief
- Give credit
- Provide an Implementation Plan

<u>VISUAL AIDS:</u>

Preparation of visual-aids for your oral presentation is very important. They must be simple to understand, clearly written, and easily read. Flip chart layouts are suggested.

PRINT USING 2-INCH LETTERS. Use multi-colored markers for interest. Be creative. This is where you are SELLING your team's recommendations.

Presentation Flip Chart

Sheet #1
Project Name:
Project Location / Number
Simple Location Sketch?
List Team Members

Sheet #2
Description of Project (as Designed)
List Major Project Elements
    Grading, Pavement, Structure, Etc.
List Major Project Data
    Length, Cost, Etc.

Sheet #3a
State First Recommendation
Simple Sketch of Recommendation
    Before Sketch
    After Sketch

Sheet #3b
List Each Recommendation's Advantages and Disadvantages (if any)
List Recommendation's Cost Savings

Sheet #4a & #4b
Report Above Items for Second Recommendation

CONTINUE TO REPORT ABOVE ITEMS FOR ALL RECOMMENDATIONS

Sheet #5
List Summary of all Savings
Total $ __________
% of Project _____

Sheet #6
Implementation Plan
Who Must Be Sold?
Time Constraints

PRINT USING 2-INCH LETTERS

VALUE ENGINEERING STUDY - WORKBOOK

(EXAMPLE)

Value Engineering - Study Identification

Project: Corridor Scherr to Forman Team: 1
Location: Grant County Date: 9/27/02

VE TEAM MEMBERS

Name:	Title:	Organization:	Telephone:
Joe Hall	Unit Leader - DDRR	WVDOH	3045582830
*Jason Foster	Proj. Mgr. - DDR	WVDOH	3045582830
Chad Lowther	Proj. Mgr. - DDR	WVDOH	3045582830
Bob Blosser	Bridge Mgr. - DDR	WVDOH	3045582830
Thom White	Bridge Des. - DDI	WVDOH	3045582885
Ted Whitmore	Sign Mgmt. - DT	WVDOH	3045583041
*Team Leader			

PROJECT DESCRIPTION

Length:2.3 Miles Cost:$62,000,000
Design Speed:65 mph Projected Traffic:16,100
Projected Award Date:2004 Type of Funds:80% Fed., 20% State

Major Project Elements:
Earthwork
Bridge 10360
Bridge 10361
Miscellaneous
Major Drainage

ROUTE CONDITION / GEOMETRY

Adjacent Segments:	Overall Route:
Mountainous, New alignment	Mountainous, New alignment

Investigation Phase - Sources

Project: Corr. H – Scherr to Forman Team: #1
Location: Grant County Date:9/27/02

APPROVING / AUTHORIZING PERSONS

Name:	Position:	Telephone:
John Morrison	Project Manager	3045582830
David Clevenger	Section Head - DDR	3045582830
Jim Sothen	Director of Engineering	3045582830
Randolph T. Epperly	Deputy State Highway Engineer	3045586266
	FHWA	

PERSONAL CONTACTS

Name:	Telephone:	Notes:
John Morrison	3045582830	Provided Background

DOCUMENTS / ABSTRACTS

Reference:	Notes:

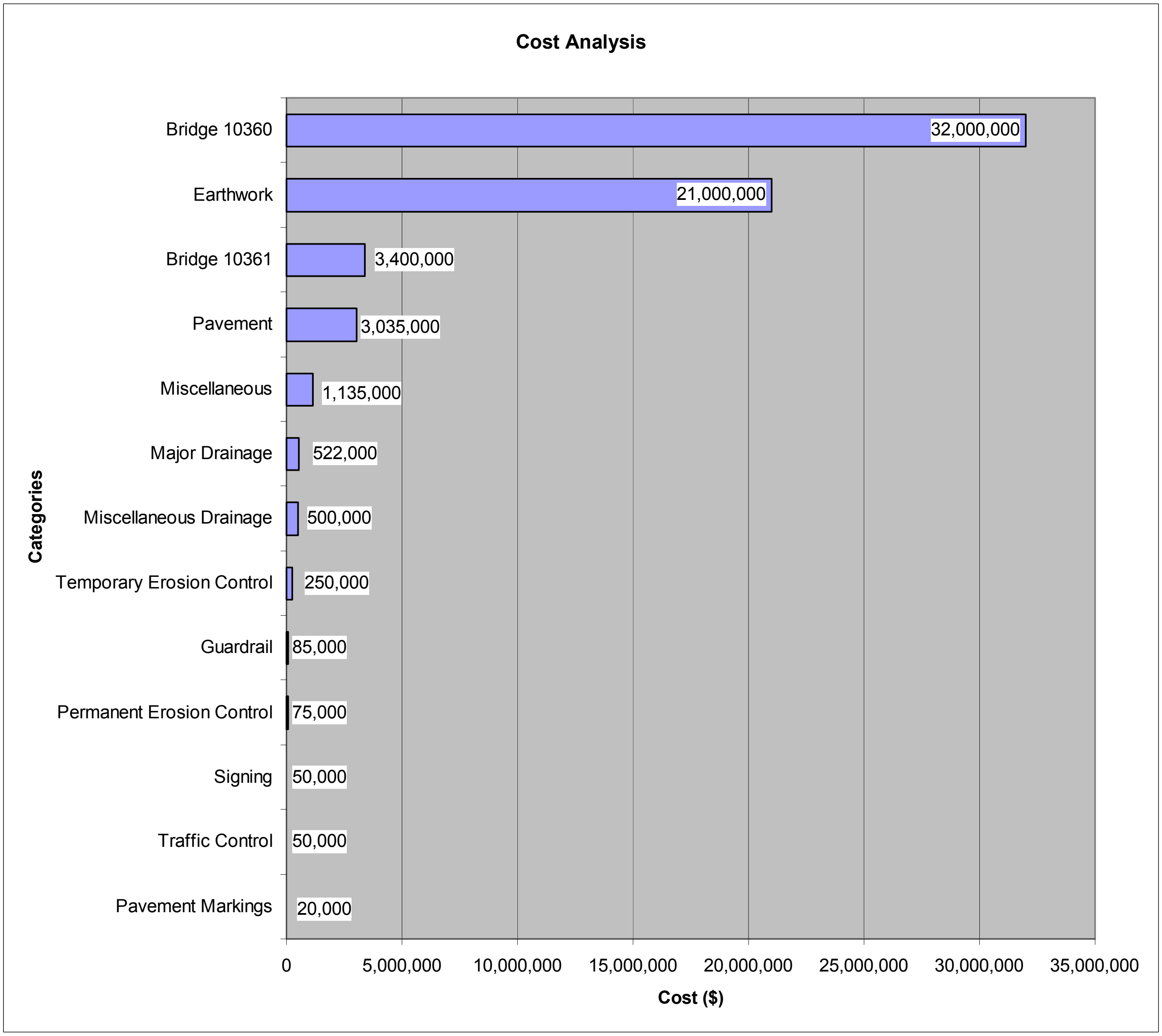
FHWA VE - 3 SHEET ___ OF ___

Investigation Phase - Cost Model

Project: Corridor H

Team: 1

Date: 9/27/02



Investigation Phase - Function Analysis

Project: Corridor H
Team No: 1
Overall Project Function: Decrease Restrictions
Date: 9/27/02

Item		Basic Function:				
No.	Description:	Verb:	Noun:	Cost:	Worth:	Comments:
1	Bridge 10360	Eliminate	Conflict	32,000,000	21,000,000	Shorten Length?
2	Earthwork	Support	Subgrade	21,000,000	15,000,000	Reduce Excavation
3	Bridge 10361	Eliminate	Conflict	3,400,000	250,000	Culvert/At-Grade 3
4	Pavement	Support	Vehicles	3,035,000	3,035,000	
5	Miscellaneous	Fulfill	Estimate	1,135,000	1,135,000	
6	Major Drainage	Transport	Fluid	522,000	522,000	
7	Misc. Drainage	Transport	Fluid	500,000	500,000	
8	Temp. E & S Control	Reduce	Sediment	250,000	250,000	
9	Guardrail	Redirect	Vehicles	85,000	85,000	
10	Perm. Erosion Control	Prevent	Erosion	75,000	75,000	
11	Traffic Control	Provide	Protection	50,000	50,000	
12	Signing	Provide	Information	50,000	5,000	Over Estimated
13	Pavement Markings	Provide	Delineation	20,000	10,000	Over Estimated

FHWA VE - 5 SHEET ___ OF ___

Investigation Phase - FAST Diagram

Project: Corridor H Team: 1

Date: 9/27/02

```
Decrease Restriction

---------------------------------------------------- How
                                                       |     Efficient Travel
Improve LOS                                            |     Improve Safety
                                                       \/    Economic Development
Provide Access                                               Attract Business/Provide Jobs

Move Vehicles

Decrease Time
                                                       /\
Improve Geometry --- Increase Speed                    |     Maintain Traffic
                                                       |     Transport Goods
---------------------------------------------------- Why

Build Road
```

FHWA VE - 6 SHEET ___ OF ___

SPECULATION PHASE - BRAINSTORMING

Project: Corridor H

Team: 1

Date: 9/27/02

Item: Function:	Function:

Item:

FHWA VE - 6 SHEET ___ OF ___

SPECULATION PHASE - BRAINSTORMING

Project: Corridor H
Team: 1
Date: 9/27/02

Item: Structure 10360 A
Function: Eliminate Conflict

Culvert 1
- Open Bottom
- Concrete
- Metal
- Arch

Fill Valley – Lake----
Shorten Bridge 2
- Realignment
- Lower Grade----

Narrower Bridge 3
Reduce # of Piers 4
Combine Bridges 5
Helicopters----
Trolley----
Tram----
Existing Roads----
Low Water Crossing----
One Lane Bridge----
Stack Decks 6

Function: Support Subgrade

Reduce Typical Width 1
- Median
- Shoulders
- # of Lanes

Steepen Slopes 2
Change Grade 3
Roll Grade----
RSS Slopes 4
MSE Walls-----
Retaining Walls----
New Alignment 5
Tunnel----
Flatten Fills (Waste on Site) 6
Berms 7
- Shoulder
- Median

Item: Earthwork B

SPECULATION PHASE - BRAINSTORMING

Project: Corridor H
Team: 1
Date: 9/27/02

Item: Bridge 10361 C
Function: Eliminate Conflict

Culvert 1
- Open Bottom
- Concrete
- Metal
- Arch

Fill Valley – Lake----
Shorten Bridge 2
- Realignment
- Lower Grade

Narrower Bridge 3
Reduce # of Piers 4
Combine Bridges 5
Helicopters----
Trolley----
Tram----
Existing Roads----
Low Water Crossing----
One Lane Bridge----
Stack Decks 6

Item: Pavement D
Function: Support Vehicles

Asphalt 1
Concrete 2
Tar & Chip----
Polymer Entrained 3
- Thinner

Narrower 4
Pre-Cast----
Eliminate Drainable Base/Trench----
Gravel----
Brick----
Chicken Bones----
Recycled Tires 5
Recycled Asphalt 6
Logs----

SPECULATION PHASE - BRAINSTORMING

Project: Corridor H

Team: 1

Date: 9/27/02

Item: Miscellaneous

Function: Fulfill Estimate

Function: Transport Fluid

Open Ditch / Channel 1
HDPE Pipe 2
Eliminate by Realignment 3
Wetlands 4
Lake----
French Drain----

Item: Major Drainage E

SPECULATION PHASE - BRAINSTORMING

Project: Corridor H

Team: 1

Date: 9/27/02

Item: Misc. Drainage F

Function: Transport Fluid

Open Ditch / Channel 1
HDPE Pipe 2
Eliminate by Realignment----
Wetlands 3
Lake----
French Drain----
Eliminate Ditch Lining----

Function: Reduce Sediment

Eliminate Earthwork----
Reduce Earthwork 1
On site Material 2
Ditch Lining----
Flatten Grades----
Eliminate Water----
Stop Rain----
No Build----

Item: Temp. E & S Control G

SPECULATION PHASE - BRAINSTORMING

Project: Corridor H

Team: 1
Date: 9/27/02

Item: Guardrail H
Function: Redirect Vehicles

Barrier 1
Eliminate Obstructions 2
Cable----
Flatten Slopes 3
Earthen Berms 4
- Shoulders
- Median

Lower Grade 5

J
Function: Prevent Erosion

No Build----
No Earthwork----
Reduce Earthwork 1
Kudzu----
Eliminate Water Sources----
Shot Crete----
Crown Vetch----
Multi Floral Rose----
Rock Veins 2
Matting/Lining 3
Tunnel----

Item: Perm. Erosion Control

SPECULATION PHASE - BRAINSTORMING

Project: Corridor H

Team: 1

Date: 9/27/02

Item: Traffic Control

Function: Provide Protection

Close Road----
No Build----
Re Route ----
Reduce Speed----
Flyers----

Function: Provide Information

Eliminate----
Combine 1
Reduce Size 2
Smaller Supports----
Not Break – Away 3
Median Barrier 4
No Letters----
Less Retro Reflectivity----

Item: Signing K

SPECULATION PHASE - BRAINSTORMING

Project: Corridor H
Team: 1
Date: 9/27/02

Item: Pavement Markings
Function: Provide Delineation

Cheaper Paint 1
Eliminate Thermoplastics 2
Less Frequent Markers----
Narrower Lines----
Use Lights----
Eliminate----
Use 'Rumble Strips' 3
Reduce Lanes----
Tubular Markers----
C-8's----
C-6's----

Function:

Item:

Evaluation Phase

Project: Corridor H

Team No. 1
Date: 9/27/02

Item No.	Creative Idea Listing	Idea Evaluation: Advantage	Idea Evaluation: Disadvantage	Idea Rating
A	Bridge 10360			
A-1	Culvert – Open Bottom, Concrete, Metal, Arch	Lower structure cost, increase embankment (4.7 million yds. waste)	Environmental Concerns	9
A-2	Shorten Bridge – Realign, Lower Grade	Lowers Structure Cost	Realignment/lower grade increases excavation, Grade Cannot exceed 5%	5
A-3	Narrower Bridge	Lowers Structure Cost	Possible Functional Concerns including disabled vehicles and bicyclists	5
A-4	Reduce # of Piers	Lowers Structure Cost	Increase Superstructure cost, possible material delivery problems	5
A-5	Combine Bridges – Twin to Single Deck	Lower Substructure Cost, Fewer barriers	Major Rehab/repair MOT issues	10
A-6	Stack Decks	Substantial Substructure and potential superstructure savings, tourism	Major Rehab/repair MOT issues, Potential perception issues, Grade	6

Evaluation Phase

Project: Corridor H

Team No. 1
Date: 9/27/02

Item No.	Creative Idea Listing	Idea Evaluation: Advantage	Idea Evaluation: Disadvantage	Idea Rating
B	Earthwork			
B-1	Reduce Typical Width - Median, Shldrs., # Lanes	Lessens Excavation	Med- Barrier req'd, Shldrs – Bicyclists, # of Lanes – Capacity/Uniformity	10 -Med 2 - Other
B-2	Steepen Slopes	Lessens Excavation	Create unstable slopes, Currently inadequate geotechnical information	5
B-3	Change Grade	Potentially lessen excavation and increase embankment	Grade cannot exceed 5% and lowering the VPI increases excavation	2
B-4	Reinforced Soil Slopes at Bridges	Steeper fill slopes, shorter bridges	Potentially effect abutment design, Maintenance	9
B-5a	New Alignment (Mainline)	Potentially Lower cost and less impacts	No reasonable alignments within mapping limits	2
B-5b	New Alignment (County Route 3)	Reduces waste, Eliminates need for Bridge 10361	Increases right of way, Requires all traffic to cross Mainline	10
B-6	Flatten Fills – Waste on Site	Reduces waste	Increases right of way (Deep Fillls), Lengthens Culverts	5
B-7	Add Berms on Outside Shoulders and in Median	Reduces waste, Guardrail requirement, and median barrier (fill sections only)	May increase typical width, right of way width, and reduce scenic visibility	10

Evaluation Phase

Project: Corridor H

Team No. 1
Date: 9/27/02

Item No.	Creative Idea Listing	Idea Evaluation Advantage	Disadvantage	Idea Rating
C	Bridge 10361			
C-1	Culvert – Open Bottom, Concrete, Metal, Arch	Lower structure cost, increase embankment (4.7 million yds. waste)	Environmental Concerns	10
C-2	Shorten Bridge – Realign, Lower Grade	Lowers Structure Cost	Realignment/lower grade increases excavation, Grade Cannot exceed 5%	5
C-3	Narrower Bridge	Lowers Structure Cost	Possible Functional Concerns including disabled vehicles and bicyclists	5
C-4	Reduce # of Piers	Lowers Structure Cost	Increase Superstructure cost, possible material delivery problems	5
C-5	Combine Bridges – Twin to Single Deck	Lower Substructure Cost, Fewer barriers	Major Rehab/repair MOT issues Proximate to intersection	8
C-6	Stack Decks	Substantial Substructure and potential superstructure savings, tourism	Major Rehab/repair MOT issues, Potential perception issues, Grade	5

Evaluation Phase

Project: Corridor H

Team No. 1
Date: 9/27/02

Item No.	Creative Idea Listing	Idea Evaluation: Advantage	Idea Evaluation: Disadvantage	Idea Rating
D	Pavement			
D-1	Asphalt	Readily available, quick placement, ease of rehab, cost less	Will go 'stale' if traffic is not on road when complete	10
D-2	Concrete	Perceived life cycle improvement	Availability, slower construction, more difficult rehab	5
D-3	Polymer Entrained	Longer lasting, more durable asphalt	Greater initial cost, no absolute proof that life cycle cost is lower	6
D-4	Narrower	Lower Overall Cost	Impedes Function	2
D-5	Recycled Tires	Lessens current environmental concern	Increased cost	5
D-6	Recycled Asphalt	Adaptive reuse of existing material	Limited source, potential increase to cost	5

Evaluation Phase

Project: Corridor H

Team No. 1
Date: 9/27/02

Item No.	Creative Idea Listing	Idea Evaluation Advantage	Disadvantage	Idea Rating
E	Major Drainage			
E-1	Eliminate Pipes by using Open Ditch/Channel	Lower Cost, easier to maintain	Relocates outfall	5
E-2	Use HDPE Pipe	Virtually no deterioration, easier to handle	May crush if not properly installed	8
E-3	Eliminate Crossings by Realigning the road	Reduces pipe and impacts	No practical alternate	0
E-4	Create Wetlands by Under sizing Pipes	Resource agencies, lower cost	Increase R/W, Flooding, limits maintainability and future expansion	5
F	Miscellaneous Drainage			
F-1	Open Ditch/Channel	Lower Cost, easier to maintain	Relocates outfall	5
F-2	HDPE Pipe	Virtually no deterioration, easier to handle	May crush if not properly installed	8
F-3	Create Wetlands by Under Sizing Pipes	Resource agencies, lower cost	Increase R/W, Flooding, limits maintainability and future expansion	5

Evaluation Phase

Project: Corridor H

Team No. 1
Date: 9/27/02

Item No.	Creative Idea Listing	Idea Evaluation: Advantage	Idea Evaluation: Disadvantage	Idea Rating
G	Temporary E & S Control			
G-1	Reduce Earthwork	Lessens acreage,	May not meet grade requirements	2
G-2	Use Available On Site Material (Logs, ets)	Lowers material cost	Increases labor cost, may not be a tangible estimate	2
H	Guardrail			
H-1	Rigid Barrier	Zero deflection, typically less deterioration	More costly, more difficult to repair	4
H-2	Eliminate Obstructions –i.e. Need for guardrail	Allows motorist to recover without impact	May increase overall project cost	6
H-3	Flatten Slopes	May eliminate the need for guardrail	Increase R/W, Deep fills make this less practical	2
H-4	Earthen Berms – Shoulders, Median	Eliminates the need for guardrail (fill sections only)	Eliminates scenic visibility, perception of being ‘boxed in’, drainage issues	10
H-5	Lower Grade of Road	May eliminate the need for guardrail	No practical solution available	0

Evaluation Phase

Project: Corridor H

Team No. 1
Date: 9/27/02

Item No.	Creative Idea Listing	Idea Evaluation: Advantage	Idea Evaluation: Disadvantage	Idea Rating
J	Permanent Erosion Control			
J-1	Reduce Earthwork	Lessens acreage,	May not meet grade requirements	2
J-2	Rock Veins Through Fill to 'wick' water	Water is controlled and released without structures	May clog, no good way to design, requires expert construction methods	5
J-3	Use Matting/Lining in channels/ditches	Reduces rip rap, easy to handle, traversable	Costly	9
K	Signing			
K-1	Combine Signs to a Single Support/Location	Reduces # of supports	Structures may get large, may get information overload	7
K-2	Reduce Overall Size	Lowers cost, easier to handle/install	May not function well for a variety of drivers and weather conditions	2
K-3	Eliminate the Need for Breakaway Posts	Reduces foundation requirements	May not be able to get outside the clear zone and remain within visible area	8
K-4	Place signs on the Median Barrier	Signs can serve both directions, easily visible	Limited to a single post, smaller signs, possibly more costly	9

Evaluation Phase

Project: Corridor H

Team No. 1
Date: 9/27/02

Item No.	Creative Idea Listing	Idea Evaluation: Advantage	Idea Evaluation: Disadvantage	Idea Rating
L	Pavement Markings			
L-1	Use Cheaper Paint	Lower initial Cost	Increase maintenance frequency, less visibility	6
L-2	Eliminate Thermoplastics	Lowers cost	Increase maintenance frequency, less visibility	2
L-3	Use miniature rumble strips	May lower paint frequency, provide audible/physical delineation	Not recognized nationally, may cause undesirable reaction	6

FHWA VE - 8 SHEET ___ OF ___

Evaluation Phase - Matrix Analysis

Project: Corridor H Team: 1
Creative Idea: Date: 9/27/02

EVALUATION CRITERIA

WEIGH ALTERNATIVES: 5 Superior 4 Good 3 Average 2 Fair 1 Poor								
ALTERNATIVES / WEIGHT								**TOTALS**

Development Phase - Recommendations

Creative Idea No. A-1 Team: 1
Recommendation: Culvert Date: 9/27/02

Original Design (Sketch attached Y N)

1800' Span Bridge

Proposed Change (Sketch attached Y N)

Replace Bridge with a culvert of appropriate size and fill the valley.
For estimation; 16X8 twin culvert, 1000' length

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

Bridge appears unnecessary to pass the required flow of water , and due to height, the bridge is extremely long. Maintenance costs for a culvert are traditionally much less than for a bridge.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design	32,000,000	More	32,000,000
Proposed Change	1,700,000	Less	1,700,000
Savings	30,300,000		Huge!!!

Development Phase - Recommendations

Creative Idea No. A-5 Team: 1
Recommendation: Combine the twin structures Date: 9/27/02

Original Design (Sketch attached Y N)

Twin, Adjacent structures

Proposed Change (Sketch attached Y N)

Combine the substructures and join the decks to have a single structure.

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

Substructure cost should lower and the proposed typical change should facilitate this recommendation.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design	32,000,000		32,000,000
Proposed Change	30,400,000		30,400,000
Savings	1,600,000		1,600,000

Development Phase - Recommendations

Creative Idea No. B-1 Team: 1
Recommendation: Reduce median width by adding PCMB Date: 9/28/02

Original Design (Sketch attached Y N)
Full width grass median

Proposed Change (Sketch attached Y N)
Eliminate grass median and add concrete median barrier between EB and WB directions along cut sections.

Possibly combine with B-7 (Berms) and use embankment through fill sections and PCMB in cut sections only.

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

The addition of the median barrier will reduce the amount of excavation, which is significant on this project. Although it will accomplish the function of separating traffic, possible disadvantages include the use of a rigid barrier for separation instead of a traversable median/recovery area and increased glare on oncoming drivers.

The use of a median berm in fill sections reduces waste, provides separation and eliminates glare. This will increase typical width (vs. barrier) but the current VE proposal is to maintain the original fill width, so this is not an issue.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design	$2,100,000*	Cost of maintenance (mowing, trash pickup)	
Proposed Change	$480,000	minimal	
Savings	$1,620,000		

*Estimated installation of full width median accounts for approximately 10% of excavation costs

Development Phase - Recommendations

Creative Idea No. B-4 Team: 1

Recommendation: Reinforced bridge soil slopes for bridges Date: 9/28/02

Original Design (Sketch attached Y N)

Typical 2:1 abutment slopes.

Proposed Change (Sketch attached Y N)

Through the use of reinforced soil methods, increase the slope of the banks to 1:1 or possibly greater.

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

The main advantage of this option is the potential to shorten the overall lengths of the bridges. This will also use more of the waste material, thus reducing off site wasting.

Disadvantages include the cost associated with reinforcing the soil and the possibility of future problems that may require expensive maintenance.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design	9,000,000		9,000,000
Proposed Change	7,500,000		7,500,000
Savings	1,500,000		1,500,000

Development Phase - Recommendations

Creative Idea No. B-5b Team: 1
Recommendation: Re-align County Route 3 Date: 9/27/02

Original Design (Sketch attached Y N)

Bridge over CR 3, New access road onto/from mainline in cut section

Proposed Change (Sketch attached Y N)

Install at-grade intersection on fill

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

At-grade intersection uses excess excavation, the current intersection requires 150,000 yds. of excavation that will not have to be wasted.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design	450,000		450,000
Proposed Change	0		0
Savings	450,000		450,000

Development Phase - Recommendations

Creative Idea No. B-7 Team: 1
Recommendation: Add berms to fill section Date: 9/27/02

Original Design (Sketch attached Y N)

The standard 46' median with guardrail

Proposed Change (Sketch attached Y N)

Use berms on the outside shoulder in place of guardrail station 5560+00 to 5579+00

Use a berm in the median station 5560+00 to 5579+00

Use berms on the outside shoulder in place of guardrail approaching/departing from bridge 10360.

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

The project is currently wasting 4.7 million yards of material. This recommendation is valid only to the point of balanced earthwork.

The median barrier is required in the cut sections to reduce the 46' median to 10'. This can be functionally replaced in the fill sections with a berm.

It was deemed not practical due to drainage and concrete median barrier usage.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design	$10/'GR - 50/'B		
Proposed Change	N/A		
Savings	GR/B Cost		

Development Phase - Recommendations

Creative Idea No. C-1 Team: 1
Recommendation: Culvert in place of Bridge 10361 Date: 9/27/02

Original Design (Sketch attached Y N)

A 500' Bridge spanning CR 3 and a designated wetland area.

Proposed Change (Sketch attached Y N)

Replace Bridge with a culvert of appropriate size and fill the valley.
For estimation; single 16X8 culvert, length 325 feet.
Also, reroute County Route 3 southbound and northbound to junction with the Corridor west of the originally planned location of the bridge in order to reroute CR-3 on a fill section rather than a section that would require excavation. County Route 3 will then junction with the Corridor in lieu of running underneath it.

As an alternate proposal in the event that the proposed culvert is not acceptable, it is proposed that County Route 3 be rerouted, as described above, the length of the bridge be shortened, and that the east and west bridge structures be combined into one structure. The combining of the bridge structures is also proposed under Creative Idea Number C-5.

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

By eliminating the bridge, the wetland area can still be adequately preserved by using the proposed culvert. This proposal will also utilize approximately 1,500,000 Cubic Yards of waste material. The initial cost and future maintenance costs associated with filling the valley and installing the culvert will be less than the originally planned bridges.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design	$3,400,000		$3,400,000
Proposed Change	$325,000		$325,000
Savings	$3,075,000		$3,075,000

Development Phase - Recommendations

Creative Idea No. C-5 Team: 1
Recommendation: Combine the twin structures Date:9/28/02

Original Design (Sketch attached Y N)

Twin, Adjacent structures

Proposed Change (Sketch attached Y N)

Combine the substructures and join the decks to have a single structure.

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

Reduce total deck width and reduce substructure costs.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design	$3,200,000		$3,200,000
Proposed Change	$3,040,000		$3,040,000
Savings	$160,000		$160,000

Development Phase - Recommendations

Creative Idea No. E-2 Team: 1
Recommendation: Use HDPE pipe in lieu of CMP pipe Date: 9/28/02

Original Design (Sketch attached Y N)

The original design provides for the use of 54" CMP pipe for drainage.

Proposed Change (Sketch attached Y N)
Use HDPE pipe in lieu of CMP.

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

The team originally felt that there was a potential cost savings due to the easier handling characteristics of the HDPE pipe. Also, it was also felt that a smaller size pipe could be used due to the lower friction losses associated with HDPE pipe.

After further evaluation, it was determined that replacing the CMP with HDPE pipe would not be cost effective. No further investigation was performed on this item.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design	78,000		78,000
Proposed Change	89,000		89,000
Savings	(11,000)		(11,000)

Development Phase - Recommendations

Creative Idea No. F-2 Team: 1
Recommendation: Use HDPE pipe in lieu of CMP pipe Date: 9/28/02

Original Design (Sketch attached Y N)

The original design provides for the use of 54" CMP pipe for drainage.

Proposed Change (Sketch attached Y N)
Use HDPE pipe in lieu of CMP.

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

The team originally felt that there was a potential cost savings due to the easier handling characteristics of the HDPE pipe. Also, it was also felt that a smaller size pipe could be used due to the lower friction losses associated with HDPE pipe.

After further evaluation, it was determined that replacing the CMP with HDPE pipe would not be cost effective. No further investigation was performed on this item.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design			
Proposed Change			
Savings			

Development Phase - Recommendations

Creative Idea No. H-4 Team: 1

Recommendation: Install earth berms in median and on shoulders Date: 9/28/02

Original Design (Sketch attached Y N)

46 foot medians with 6:1 side slopes and 15 ft. shoulder recovery areas with 6:1 slope on cut sections.

Proposed Change (Sketch attached Y N)

Install earthen berms in median and on shoulders approximately 5 feet high and 20 feet wide.

Justification (Describe advantages/disadvantages, reasoning, and compliance with standards and requirements)

After further investigation, it was determined that for the medians, concrete median barrier was a more acceptable option. It was also determined that on the medians and shoulders, there is too much of a potential for drainage problems using the earthen berms.

No further investigation was performed.

Life Cycle Cost Summary (Present Worth Method)	Initial Cost	Future Cost	Total Cost
Original Design			
Proposed Change			
Savings			

FHWA VE - 9A SHEET ___ OF ___

Development Phase - Sketches

Creative Idea No. Team:
Recommendation: Date:

Original Design

Recommended Design

FHWA VE - 9B SHEET ____ OF ____

Development Phase - Calculations

Creative Idea No. Team:

Recommendation: Date:

Development Phase - Cost Worksheet

Creative Idea No. Team:
Recommendation: Date:

Construction Element		Orig. Cost			Prop. Cost		
Item	Unit	# of Units	Cost / Unit	Total Cost	# of Units	Cost / Unit	Total Cost
A-1 Bridge vs. Culvert				32 mil.			1.5 mil.

Life Cycle Cost Analysis - Present Worth Method

Creative Idea No. Team:
Recommendation: Date:
Discount Rate: Economic Life: ___ Years

	Original Design		Alt. No.1	
	Cost	PW	Cost	PW
1. Initial Cost:				

Single Expenditures: (i.e., stage Construction, Major Maintenance) a. Year ____ PWF ______				
b. Year ____ PWF ______				
c. Year ____ PWF ______				
d. Salvage / Unused Service Life Year ____ PWF ______				
2. Future Single Costs:				

Annual Costs:				
a. General Maintenance PWF ______				
b. Other Annual Costs PWF ______				
3. Future Annual Costs				

4. Total Future Costs: (2 + 3)				

5. Total Life Cycle Costs: (1 + 4)				

FHWA VE - 10 SHEET ____ OF ____

Development Phase - Summary of Cost Savings

Project: Team:
Location: Date:

Idea No.	Description	Original Design Cost	Proposed Change Cost	Initial Cost Savings	Future Cost Savings	Total Cost Savings
A-1	Replace Bridge w/Culvert	32,000,000	5,000,000	27,000,000		27,000,000
A-5	Combine Twin Structures	32,000,000	30,400,000	1,600,000		1,600,000
B-1	Replace grass median with concrete barrier	2,100,000	480,000	1,620,000		1,620,000
B-4	Use Reinforced Soil Slope at abutments	9,000,000	7,500,000	1,500,000		1,500,000
B-5b	CR 3 Realignment	450,000	0	450,000		450,000
C-1	Replace Bridge 10361 w/culvert	3,400,000	325,000	3,075,000		3,075,000
C-5	Combine twin structures	3,200,000	3,040,000	160,000		160,000
Total	**A-5, B-1, B-4, B-5b, C-1**					**$8.2 M**
Total	**A-1, B-1, B-5b, C-1**					**$32.1 M**

Development Phase - Executive Summary

Project: CORRIDOR H(SCHERR TO FORMAN) Team: #1
Date: 9/27/02

INTRODUCTION: This project begins approximately 1 mile west of Grant Co. Rte. 42/3 to Grant Co. Rte. 3. The work involves a new alignment, which includes 2 structures, major drainage pipes and an intersection realignment. The length of the project is approximately 2.34 miles and the proposed cost is $62.1 million.

STUDY RESULTS: The Value Engineering Team identified 6 specific recommendations. Acceptance of all the recommendations would result in a savings of between approximately $32 M and $8 M, or between 52 % and 13 % percent of the original project cost depending on combinations used.

CONSTRAINTS: The project must bridge over Middle Fork of Patterson Creek, a native trout steam. An archeological site has been identified parallel to the alignment. The vertical alignment has been set at 5% throughout the length of the project and could not be compromised.

HIGHLIGHTS: Three major areas of the project were examined by the Value Engineering team. These areas included 2 bridges and overall earthwork of the project.

A summary of all the recommendations is attached

APPENDIX B

LIFE CYCLE COST ANALYSIS

B10.1 INTRODUCTION:

In deciding between alternative fixed assets, economically sound decisions with respect to proposed expenditures require detailed analysis in order to make the proper choice. A cost effective choice over the life of the asset becomes the key issue. Low initial cost advantages may be offset by a short life and therefore high future costs. So which proposal do you chose?

The time value of money and well-recognized procedures are important considerations in the decision making process. A formal analysis using engineering economics provides the answer. Design engineers may be doing this and not even know they used an economic process. Estimating the costs of alternative designs and then comparing them is engineering economics. This is done to find the design that best meets the needs of the user given specific traffic volume and loads at the lowest construction and maintenance costs over time.[1]

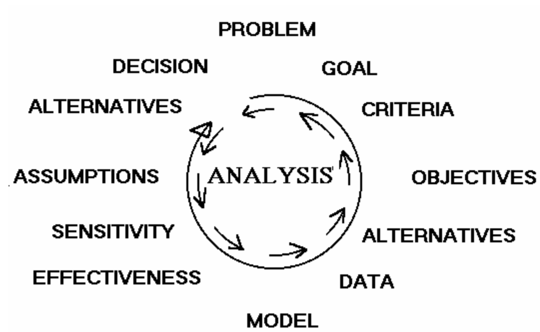
Engineering economics provides a way to choose between alternatives when the expenditure of capital funds comes in to play. Three basic steps are involved in conducting the economic analysis.[2]

(1) Identify and define the different alternatives among which a selection is to be made.

(2) Identify and define the various elements or factors that may result in differences in the cost of the alternatives and remove from further consideration all events that have happened or may happen regardless of which alternative is selected.

(3) Reduce all of the alternatives to a comparable basis by translating all of the applicable factors to a common dollar base and then make a cost comparison among the alternatives over time, considering the time value of money through the use of compound interest.

With increasing costs, decreasing budgets, and environmental impacts, effective decision-making provides the best choice. Getting to that point can be a problem. A systems approach provides the direction. Before getting started consider the following:



An economic study must first answer the question: "Why do it at all?" In other words, does the proposed improvement represent an attractive investment when compared with other possible uses of available resources? Where there is only one plan for a particular improvement, a favorable answer clearly indicates that the project is desirable. However, where there are alternative methods for improvement, a second question is in order. It is "Why do it this way?" or "Which of the proposals is the best?" This is answered by finding whether the *increment* of investment between cheaper and more expensive plans also appears attractive. By successively eliminating those proposals that fail either the first or the second of these tests, the best of the lot may be found.[3]

In accomplishing the study, proper framework plays a leading role. No matter how good the data, incorrect procedures gives erroneous results. The following guidelines provide the proper direction.[4]

(1) Economy studies are concerned with forecasting the future consequences of possible investments of resources. Past happenings, unless they affect the future, are not considered.

(2) Each alternative among which choices are to be made must be fully and clearly spelled out.

(3) The viewpoint taken in the analysis must be defined and observed.

Life cycle cost (LCC) analysis is the most appropriate economic evaluation process in deciding between alternatives. This analysis considers the cost of construction, rehabilitation, maintenance of a facility, and associated user impacts over a specific period, usually encompassing the service life of all alternatives. Two important definitions follow: Life cycle costing - "Economic assessment of an item, area, system, or facility and competing design alternatives considering all significant costs of ownership over the economic life, expressed in terms of equivalent dollars"[5] and Life cycle design - "Analysis which considers the construction, operation, and maintenance of a facility during its entire design life."[6]

In general, life cycle costs include all costs anticipated over the life of the facility. As part of the analysis, trade-offs can be made among factors that may affect the life cycle cost of a pavement, such as the relationship between the initial costs of construction and the future cost of maintenance. The analysis requires identifying and evaluating the economic consequences of various alternatives over time or the life cycle of the alternative.[7]

Again, organization equals the key to success. This begins by selecting the study area followed by generation of alternatives. Follow any established procedures and checklists, eliminating cost items common to all alternatives. Brainstorming is a good method to come up with different alternatives. Evaluating each alternative, making a selection decision with appropriate presentation and implementation concludes the process.[5]

The process includes models based on the concepts associated with discounted cash flow analysis, wherein all the costs expected to occur throughout the life of the highway or bridge for example are estimated and converted to an equivalent uniform annual cost for purposes of comparison. Costs likely to occur during the life of the project should be considered in LCC analysis.[8] The costs are summarized over time by discounting all costs that occur at different times using the present worth method to account for the time value of money and can be shown as either total present worth or an annualized cost.

Costs normally associated with pavement reconstruction include:

- Initial Construction Costs,
- Maintenance Costs,
- Rehabilitation Costs,
- User Costs,
- Energy Costs.

Costs normally associated with bridges include:[8]

- Initial design, construction, and construction inspection.
- Periodic inspection and preventive maintenance.
- Scheduled maintenance and repair.
- Breakdown maintenance.
- Rehabilitation, such as deck replacement and repair or replacement of superstructure.
- Upgrades, to improve the level of service.
- Traffic delay costs attributable to maintenance, repair, rehabilitation, or total replacement.
- Demolition, restoration of the site, and, if appropriate, replacement, net of any salvage value, of the existing bridge at the end of its useful life.

No matter what the project, many costs would be the same for any specific project, therefore only differential costs require consideration for all project specific alternatives. In the case of highway bridges, life cycle cost analysis is inappropriate at this time because information on differential costs does not exist. As reliable data becomes available, consider using LCC analysis for bridges. Also, traffic delay and increased inspection costs are considered part of the true cost of a bridge by few, if any, bridge owners.

LCC analysis, the availability of funds, project specific and environmental conditions or constraints, project constructability, and the ability of each alternative to serve the anticipated volumes should all be used in the decision process for selecting the most appropriate alternative.

B10.2 ENGINEERING ECONOMICS

There are four concepts that form the basis of life cycle analysis methodology.

(1) Time value of money.

(2) Opportunity cost of capital.

(3) Discount rate.

(4) Analysis period.

B10.2.1 TIME VALUE OF MONEY

Two factors attribute to the time value of money, rate of return and inflation.

*** Rate of Return**

The rate of return is the amount of money earned from the use of capital. Interest on a savings account illustrates the rate of return. The rate is calculated for a specific investment. The complexity of the determination varies depending on the length of time considered for the investment.

*** Inflation**

Inflation is a general increase in the level of prices throughout the economy. A present dollar's purchasing power or worth is greater than a future dollar. Rates are not easily obtainable in that neither accurate nor universally acceptable predicting procedures for points far in the future exist. Because analysis considers projects with lives up to 50 years, the use of unreliable inflation rates could lead to inaccurate results.

Inflation affects different segments of the economy in varying ways. For example, inflation in the construction industry may be different from general consumer goods. This makes it difficult to select an appropriate rate for the alternatives being considered.

A diversity of opinions exists on the handling of inflation in LCC analysis. The manner significantly effects the outcome of the analysis. Two types of price changes exist, inflation and differential price trends. During an inflationary period, general increases in prices occur throughout the economy. The difference between the price change for each item being evaluated and the overall economic price trend is differential pricing.[7]

A choice between "constant" and "current" dollars must be made during economic analysis. Uninflated constant dollars represent price levels prevailing during the base year. Inflated current dollars represent possible future price levels projected for the costs at a future date. Highway agencies do not normally include inflation when analyzing alternatives because of the uncertainty in predicting future inflation rates. Because only differential inflation on future costs requires identification, the constant dollar method is usually chosen.[7]

B10.2.2 OPPORTUNITY COST OF CAPITAL

Opportunity cost, the foregone opportunity for an expected rate of return on capital when that capital serves another purpose. In other words, if a funded highway project was postponed to invest the funds, the lost potential return represents the opportunity cost.

B10.2.3 DISCOUNT RATE

Use the discount rate as a means to compare alternative uses of funds by reducing the future expected costs or benefits to present day terms. Discount rates reduce costs or benefits to their present worth or annualized costs. The economics of the alternatives can then be compared. The term *interest rate,* associated with borrowing money, is often called the *market interest rate*. The later includes an allowance for expected inflation and a return that represents the real cost of capital.[7]

Why use a discount rate? Because, the value of money is worth more today than a later date; greater purchasing power.

Interest and inflation tend to reduce the future value of a fixed amount of money. For example, rehabilitating a pavement in several years will cost more because of inflation. Proper evaluation first requires the determination of the future cost based on the inflation rate. Using the interest rate, the present worth can be determined. One recommendation, a good approximation, shows the discount rate equal to the interest rate minus the inflation rate. Others suggest that the market interest rate minus inflation in terms of constant dollars be used to estimate the discount rate. Several scholars have suggested a discount rate of 4 percent based on evaluation of historical data.[7]

On a national basis, no consistent agreement exists on a single discount factor for use on public works projects. A survey[7] in 1984 of DOT's in 45 states, the District of Columbia, and three Canadian provinces indicated a rate of four to ten percent for use in LCC analysis. The U.S. Department of Energy, Corps of Engineers, and the Office of Management and Budget use rates of seven, eight, and ten percent, respectively. Respondees using rates at the lower end to the range appear to represent a minority. Using low discount rates is inconsistent with the concepts of opportunity costs and reasonable social discount rates, that rate used for public works projects.

Some even argue that because a high-way agency does not invest funds, an appropriate rate should be zero percent. Two major flaws exist in this thinking. The option disregards the opportunity cost of capital. In addition, it is inconsistent with the concept of the time value of money.

AASHTO's Red Book states "if future benefits and costs are in constant dollars, only the real cost of capital should be represented in the discount rate used. The real cost of capital has been estimated at about 4 percent in recent years for low risk investments." The Portland Cement Association suggests typical values are in the range of 1 and 2.5 percent based on three or four decades of data.[7]

Selection of a low discount rate tends to place greater emphasis on cash flows occurring later in a project's life. The discount rate can significantly effect the outcome of the analysis. The lower the discount rate the greater the effect future dollars have on the present. Therefore, the selection of a low discount rate gives greater emphasis to capital outlays in future years. Erroneous conclusions can result based on an analysis using an inappropriate discount rate.

An equation (follows)[9] to determine the "true interest rate" or real discount rate taking into consideration interest rate, inflation rate, and the rate of increase in highway funding.

$$i^* = \{[(1 + i)(1 + q)]/(1 + f)\} - 1$$

where i^* = True interest rate (discount rate) taking into account the effects of inflation.
i = Interest rate (market).
q = Annual compound rate of increase in highway funding.
f = Annual compound rate of increase in cost of highway construction or maintenance (inflation rate).

Another possibility for a discount rate comes from Eugene Grant and Grant Ireson.[10] They recommend a discount rate of seven percent for highway economy studies. Their rate represents a reasonable opportunity cost and social discount rate.

Given the volatility of the issue and the possibility that a single discount rate may change over the years, it is recommended that a sensitivity analysis be done on all analyses using discount rates between four and ten percent, inclusive.

"The discount rate can affect the outcome of a life cycle cost analysis in that certain alternatives may be favored by higher or lower discount rates. High discount rates favor alternatives that stretch out costs over a period of time, since the future costs are discounted in relation to the initial cost. A low discount rate favors *high initial cost alternatives* since future costs are added in at almost face value. In the case of a discount rate equal to 0, all costs are treated equally regardless of when they occur. Where alternative strategies have similar maintenance, rehabilitation, and operating costs, the discount rate will have a minor effect on the analysis and initial costs will have a larger effect."[11]

B10.2.4 ANALYSIS PERIOD[7]

The final component that should be established before performing an LCC analysis is to select an appropriate time period for comparing design alternatives. The analysis period is the total length of time the facility is expected to serve its intended function or the time frame before the component in question requires replacement or upgrade. This period may contain several maintenance and rehabilitation activities. Figure B10.2.4-1 illustrates an example of these activities for pavement performance.

Determination of the analysis period for highway facilities may be subjective and may not equal the actual physical life. The recommended analysis period for new pavements is 25 to 40 years and 5 to 15 years for rehabilitation alternatives. However, factors such as geometrics, traffic capacity, etc. may dictate a shorter period.

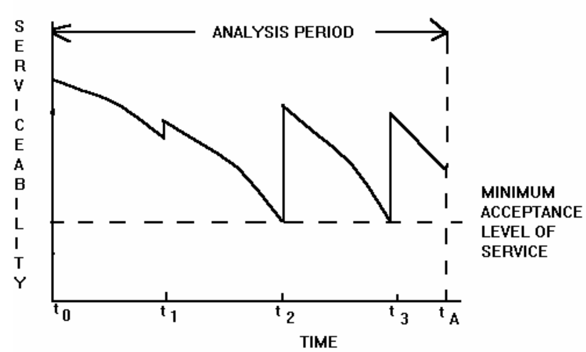


Figure B10.2.4-1

With these four key areas defined, discussion of Engineering Economics concludes with Discounted Cash Flow Analysis including formulas, and Sensitivity Analysis. Procedures are then outlined.

B10.2.5 DISCOUNTED CASH FLOW ANALYSIS

Three analysis options exist, present worth, annualized, and rate of return. The first two are the primary economic methods. Because the rate of return method requires more effort and calculations, this method does not have general support. The primary methods are discussed below.

B10.2.5.1-Present Worth Method

The present worth method is an economic method that involves the conversion of all of the present and future expenses to a base of today's costs. The present worth of some planned future expenditure is equivalent to the amount of money that would need to be invested now at a given compound interest rate for the original investment plus interest to equal the expected cost at the time it is needed.[7]

This allows the comparison of alternatives having outlays at different points in their lives on an equal basis. A disadvantage in the use of the present worth method is that the method can only be used to compare alternatives with equal analysis periods. The present worth method cannot be used, for example, to compare alternatives with lives of 20 and 50 years.

The following formulas are presented to facilitate understanding of the derivation of the various factors used in life cycle analyses. In most cases actual manual calculations are not necessary because these factors have been calculated and tabulated for various interest rates. Tables of these factors, found in Standard Economic Tables, are included in Section B10.6 of this manual. Examples illustrating the use of these tables are shown in Section B10.7 of this manual. Table B10.2.5-1 lists the discount factors used in these tables.[12]

The general form of the present worth equation for a single present worth of a future sum follows:

$$P = F[1/(1 + i)^n]$$

where P = Present worth
F = The future sum of money at the end of n years
n = Number of years
i = Discount rate

The factor $1/(1 + i)^n$ is also known as the Single Payment Present Worth (SPW).

or

(P/F,i%,n)

A simplified calculation for P involves multiplying F by the SPW or factor, found in Section B10.7.

Use the following equation for present worth of a series of end-of-year payments.

$$P = A\{[(1 + i)^n - 1]/[i(1 + i)^n]\}$$

where A = End-of-year payments in a uniform series for n years that is equivalent to P at discount rate i.

Factor Name	Converts	Symbol	Formula
Single payment compound interest	P to F	(F/P,i%,n)	$(1 + i)^n$
Present Worth	F to P	(P/F,i%,n)	$1/(1 + i)^n$
Uniform series Sinking Fund	F to A	(A/F,i%,n)	$i/[(1 + i)^n - 1]$
Capital Recovery	P to A	(A/P,i%,n)	$[i(1 + i)^n]/[(1 + i)^n - 1]$
Compound amount	A to F	(F/A,i%,n)	$[(1 + i)^n - 1]/i$
Equal series present worth	A to P	P/A,i%,n)	$[(1 + i)^n - 1]/[i(1 + i)^n]$
Uniform gradient	G to P	(P/G,i%,n)	$[(1+i)^n-1]/[i^2(1+i)^n] - n/[i(1+i)^n$

Table B10.2.5-1

The factor $[(1 + i)^n - 1]/[i(1 + i)^n]$ is also known as the Uniform Present Worth Factor (UPW).

or

(P/A,i%,n)

A simplified calculation for P involves multiplying A by the UPW or factor, found B10.6.

B10.2.5.2-Annualized Method

One of the most valuable tools of economic analysis, this method converts present and future expenditures to a uniform annual cost, resulting in a common base of a uniform annual cost. Quality equates to accuracy. Divide expected costs, positive or negative, over the life of the system into uniform annual costs using the appropriate discount rate. This method converts initial, recurring, and nonrecurring costs into annual payments. Estimated uniform annual maintenance expenditures are recurring costs already in terms of annual cost. Future expenditures must be converted to present worth using the above equation before using the following equation to determine annualized cost.[7]

$$A = P\{[i(1 + i)^n]/[(1 + i)^n - 1]\}$$

where	P	=	Present worth
	A	=	Annualized cost or annual cost
	n	=	Number of years
	i	=	Discount rate

The factor $[i(1 + i)^n]/[(1 + i)^n - 1]$ is also know as the Uniform Capital Recovery Factor (UCR).

or

(A/P,i%,n)

A simplified calculation for A involves multiplying P by the UCR, found in B10.6.

The advantage of the latter method is that it can be utilized to calculate the annual cost of alternatives with different lives.

As mentioned previously, the various cash flow factors have been calculated and tabulated. The factors are available in most engineering economics texts. For ease of reference the tables are included in Section B10.6 of this manual. Examples illustrating this method are included in Section B10.7 of this manual.

B10.2.6 SENSITIVITY ANALYSIS[7]

Cost and benefit variables, including discount rates, analysis period, and the costs of various factors including maintenance and user costs related to specific projects have varying effects. Sensitivity is the relative effect that each variable may have on the choice of alternatives. Sensitivity analysis tests the effects of variations in these variables. Testing identifies the most influential variables and the extent of influence. The analysis may identify design options requiring further consideration in greater detail and variables requiring additional information. Project risk may also be identified. Sensitivity analysis takes place as part of an economic analysis, in the formative stages of a project.

Inadequate input data, initial assumptions, accuracy of estimates, or any combination effects the outcome. The following critical questions must be answered.

"(1) How sensitive are the results of the analysis to variations in these uncertain parameters?

(2) Will these variations tend to justify the selection of an alternative not currently being considered?

(3) How much variation in a given parameter is required to shift the decision to select alternation B rather than alternative A?"[5]

Sensitivity analysis has two purposes, to determine how sensitive the outputs from the life cycle cost analysis are to variations in certain inputs and to evaluate the risk and uncertainty related to a selected alternative. The designer can then determine the probability of making the wrong choice or selecting the wrong alternative. The analysis provides the greatest benefit when the difference between alternatives may not be very great. Accomplish the analysis when performing a more detailed life cycle cost analysis.

While this process is not difficult or time consuming, the entire LCC analysis process contains a great deal of uncertainty. The means to determine the effect of this uncertainty on numerous factors is found in sensitivity analysis. Results of analyses related to other agencies show that:

- "Results of solutions by the annual cost method are markedly affected by interest rate. Low interest rates favor those alternatives that combine large capital investments with low maintenance or user costs, whereas high interest rates favor reverse combinations."[3]
- "As the interest rates increase and the time period grows longer, then the assumption that a system will be used for an indefinite period of time becomes less significant. Forecasts into the future are less significant when interest rates are higher and the periods of time are longer than are short range forecasts using lower interest rates."[13]
- "It was found that if the resurfacing costs and/or reconstruction costs increased slightly, then with a 10% discount rate, the road would be resurfaced one more time before reconstruction. Similarly, if these costs decreased slightly and a 5% discount rate is used, the pavement would be resurfaced one fewer times before reconstruction."[14]

B10.3 COST FACTORS[7]

B10.3.1 INITIAL COSTS

Design and construction costs are the two types of costs included in this category. Design costs are included only if the cost of designing one alternative is different from the costs of another alternative. When design costs are identical for all alternatives note that fact and exclude them from the analysis. Source information for design costs would be bid design hours. Construction cost is probably the most important of the cost components and is used by more agencies than any other component. The source of information for construction costs would be previous bids, previous projects, historical cost data, etc. Use the most current and accurate data available. When previous bids or contracts are not available for new materials or techniques being used as part of the alternatives then care should be taken in generating the estimated costs for those items. Accomplish a sensitivity analysis to determine the effect of cost variations on the end result when a range of possible costs for the new items exists.

Reflect all unique costs associated with each alternative for construction costs. For example, account for different roadway sections and material quantities for each alternative. Because of repetition, common items such as bridge and embankment widening, guard rail replacement, etc., should not be included in the analysis. Each overlay option requires some grade adjustment of adjacent ramps, guard rails, barriers, etc. Added costs, unique to each alternative should be included in the analysis.

B10.3.2 MAINTENANCE COSTS

These costs are those associated with maintaining the pavement surface, etc., at some acceptable level and are one of the most difficult areas to deal with in LCC analysis. Inherent problems exist in obtaining accurate and reliable maintenance costs. The type and extent of maintenance work performed at various time intervals into the future directly influences the cost of pavement maintenance. Predicting the type of maintenance required and the time frame very far in advance is the main problem. Maintenance needs are influenced by pavement performance. This area needs further work in order to improve prediction capability.

To help alleviate some of the prediction problem and to possibly provide the precision needed in LCC analysis the following is provided. National Cooperative Highway Research Program (NCHRP) Synthesis 46 provides some direction on how to improve the reliability of maintenance cost data.[15] NCHRP Synthesis 110[16] and 77[17] provide help to agencies in improving their capability for predicting future maintenance needs and costs. Studies have been accomplished comparing performance characteristics and maintenance costs. The differential in maintenance requirements for the various alternatives being considered is the most important item. If maintenance costs are identical for all alternatives, then there would be no need to include maintenance in the analysis.

Maintenance costs can also be adversely affected if a maintenance activity is delayed. For example, as pavement condition decreases, the cost of maintenance significantly increases. NCHRP Synthesis 58[18] provides extensive details on delayed activity.

B10.3.3 REHABILITATION COSTS

These costs are those associated with pavement rehabilitation or restoration activities.

Compute costs consistent with and in the same manner as initial construction costs. With respect to pavement rehabilitation, projects are normally bid and constructed under the same criteria as new pavement construction. When considering rehabilitation costs relative to LCC analysis, two time frames come into play. The first time frame applicable to many projects begins at "time zero." This constitutes the beginning of an LCC analysis and applies where the pavement existed for years, requiring long-term improvements. In this case, treat rehabilitation similar to initial construction. The second time frame applies to future needs for a new pavement or a newly rehabilitated pavement. Accurate prediction of the future time when rehabilitation might be required is a major problem. When required, make the best estimate possible of the future time period using good historical performance data. Sensitivity analysis varying the time to rehabilitation helps determine to what extent time alters the final design selection.

The long time frames involved almost guarantee the occurrence of new materials and techniques applicable to the rehabilitation of pavements. Study these new materials as soon as possible using laboratory evaluations and project experimentation before the materials general use. Consider only those projects demonstrating a high success rate for widespread use.

B10.3.4 USER COSTS

These costs are those associated with vehicle operating costs such as fuel consumption, parts, tires, etc. and user delay costs such as denial-of-use, delays due to speed changes, speed reductions, and idling time.

Considering different surface types at the same general performance level, usually data are not precise enough to detect vehicle operating cost differences between two pavements. When considering paved versus unpaved roads and smooth versus rough pavements, significant user cost differences exist. For example, vehicle operating costs including fuel consumption increase as the pavement roughness increases. Deteriorating pavement caused cost increases result in higher rates for freight and bus transportation services. Higher costs directly affect minimum allowable pavement performance levels and maintenance policies.

High user delay costs result from slow downs caused by construction and maintenance activities and denial-of-use costs stemming from the closure of a section of highway during major repairs. Increased vehicle operating costs result when longer alternative routes and traffic stoppage and slow down caused by construction, rehabilitation, and maintenance occur.

The American Associations of State Highway and Transportation Official's (AASHTO) "A Manual on User Benefit Analysis of Highway and Bus Transit Improvements" or "Red Book" provides a reference for user costs in addition to the ones mentioned previously.

Assess the relative effect of user costs for different alternatives using sensitivity analysis if sufficient applicable data can be identified for the project being studied.

If used, one method for determining user costs follows a 1986 California

Department of Transportation study. The study found the average value of time to be \$6.25 per vehicle-hour of delay. Based on a four percent inflation rate, \$8.22 would be used in 1993 calculations. Modify this for 1993 and future years based on the inflation rate.

Use the following equation to determine user costs.

UC=(AVT)[(L/RS) - (L/IS)](ADT)(PT)(CP)

where

UC	=	User Cost
AVT	=	Average Value of Time (\$8.22 or as determined)
L	=	Project Length
RS	=	Reduced speed through construction zone
IS	=	Initial speed prior to construction zone
ADT	=	Average daily traffic in current year (only portion of ADT affected by the project
PT	=	Percent of the traffic affected by the construction project. Perform traffic study to determine percent of traffic using facility during the period.
CP	=	Construction period

Consider the inclusion of User Costs very carefully given their lack of supporting data:

B10.3.5 SALVAGE VALUE

These costs are those remaining at the end of a life cycle analysis. Because this value can be either positive or negative, salvage value may be more appropriately call residual value. Due to the nature of pavements, some remaining life or value may by left for an alternative after completing the analysis period. Of the study group mentioned earlier, only 12 agencies indicated the consideration of salvage value as part of their LCC analysis in the selection of pavement alternatives. Base the determination of value on such factors as percent of pavement life remaining, experience, and historical data.

While a positive value for useful salvageable materials or remaining life may exist, a negative value exists if it costs more to remove and dispose of the material than it is worth. Include a salvage or residual value, positive or negative, in the LCC analysis if one can be assigned to a given pavement alternative at the end of the analysis period. Bring the value back to its present worth (PW) using the PW equation discussed previously. Use the proper discount rate and analysis period. If the alternative comparison is based on present worth use the PW cost for the appropriate alternative. Use average yearly cost or benefit if the comparison is annualized. The equation to convert present worth to annual costs follows the PW equation discussion.

One method of calculating salvage valve follows the following equation:

$$SV = (CC)[(ERL)/(TEL)]$$

where SV = Salvage Value
CC = Last construction or rehabilitation cost
ERL = Expected remaining life
TEL = Total expected life

B10.3.6 ENERGY COSTS

Costs associated with energy are normally part of construction, maintenance, and rehabilitation costs. These costs are not included separately in LCC analysis. Analysis as a separate factor would be extremely difficult. Therefore, consider energy factors as one of the other factors after the LCC analysis is complete. In that energy costs are part of other costs they are not independent or overriding factors.

B10.3.7 EXAMPLES

See Section B10.7 of this manual for examples illustrating the complete Life Cycle Cost analysis process as it applies to the West Virginia Division of Highways. These examples illustrate life cycle cost techniques used in comparison of alternatives for transportation projects. Sensitivity Analysis is shown for each example, with a graphical depiction of the resultant findings.

B10.4 SUMMARY[7]

The majority of this LCC procedure is based on the "Life Cycle Cost Analysis of Pavements" compiled by Dale E. Peterson for the National Cooperative Highway Research Program Synthesis of Highway Practice for the Highway Research Board, National Research Council. Most of the references used in this procedure were taken from Peterson's report.

***CONCLUSIONS**

(1) The use of LCC procedures to analyze new design alternatives is a proven and acceptable procedure.
(2) The process may also apply in selecting pavement rehabilitation alternatives.

B10.5 GLOSSARY[7]

Alternatives

Different courses of action or systems that will satisfy objectives and goals.

Analysis period

The time period used for comparing design alternatives. An analysis period may contain several maintenance and rehabilitation activities during the life cycle of the pavement being evaluated. It is sometimes referred to as the economic life, that period over which an investment is considered for satisfying a particular need. The length of time for the analysis period would be established by the agency.

Annualized method

Economic method that requires conversion of all present and future expenditures to a uniform annual cost.

Benefit/cost analysis

Technique intended to relate the economic benefits of a solution to the costs incurred in providing the solution.

Brainstorming

A widely used creativity technique for generating a large quantity and wide variety of ideas for alternative ways of solving a problem or making a decision. All judgment and evaluation are suspended during the free-wheeling generation of ideas.

Cash-flow diagram

Schematic diagram of dollar costs and benefits with respect to time.

Constant dollars

Dollars that have not been adjusted for the effects of expected future inflation or deflation; sometimes referred to as dollars as of a specific date (for example, "1980 dollars").

Corrective maintenance

Type of maintenance used to take care of day-to-day emergencies and repair deficiencies as they develop. May include both temporary and permanent repairs; sometimes referred to as remedial maintenance.

Current dollars

An expression of costs stated at price levels prevailing at the time costs are incurred. Current dollars are inflated and represent price levels that may exist at some future date when the costs are incurred.

Denial-of-use costs

Extra costs occurring during the life cycle because occupancy or income (production) is delayed as a result of a process decision.

Depreciation

The allocation of the cost of a fixed asset over the estimated years of productive use. It is a process of allocation, not valuation. (Straight line; Declining balance; Sum of years-digits).

Design life

The length of time (in years) for which a pavement facility is being designed, including programmed rehabilitation. At the end of this period, the physical life of the facility is considered to be ended, i.e., the pavement structure has deteriorated to a point where total reconstruction would be necessary.

Discount rate

A value in percent used as the means for comparing the alternative used for funds by reducing the future expected costs or benefits to present day terms. Discount rates are used to reduce various costs or benefits to their present worth or to uniform annual costs so that the economics of the different alternatives can be compared.

Engineering economics

Technique that allows the assessment of proposed engineering alternatives on the basis of considering their economic consequences over time.

Equivalent dollars

Dollars, both present and future, expressed in a common baseline reflecting the time value of money and inflation.

Escalation (differential) rate

That rate of inflation above the general devaluation of the purchasing power of the dollar.

Failure

Unsatisfactory performance of a pavement or portion such that it can no longer serve its intended purpose.

Flexible pavement

A pavement structure that maintains intimate contact with and distributes loads to the subgrade and depends on aggregate interlock, particle friction, and cohesion for stability.

Inflation

A continuing rise in the general price levels, caused usually by an increase in the volume of money and credit relative to available goods.

Initial costs

Costs associated with initial development of a facility, including project costs (fees, real estate, site, etc.) as well as construction cost.

Interest

A ratio of the amount paid for using resources for a given period of time to the total investment. A term generally associated with borrowing money and is often referred to as market interest rates. The market interest rate includes both an allowance for expected inflation as well as a return that represents the real cost of capital.

Life cycle costing

An economic assessment of an item, area, system, or facility and competing design alternatives considering all significant costs of ownership over the economic life, expressed in terms of equivalent dollars.

Maintenance

Anything done to pavement after original construction until complete reconstruction, excluding shoulders and bridges. It includes pavement rehabilitation and restoration.

Minimum attractive rate of return

Reflects the cost of using resources and the risk that the project may fail to produce the expected results. The risk portion of the minimum attractive rate of return varies with different cost centers and even with projects within cost centers.

Non-recurring cost

Cost that occurs, or is expected to occur, only once.

Opportunity rate

That rate of return that the organization could make by investing its resources in the most beneficial (profitable) projects to the limit of the resources available.

Pavement condition

The present status or performance of a pavement.

Pavement management system

A set of tools or methods that assist decision makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time.

Pavement performance

Measure of accumulated service provided by a facility; i.e., the adequacy that it fills its purpose based on all indicators or measurement types.

Present worth method

Economic method that requires conversion of all present and future expenditures to a baseline of today's cost.

Preventive maintenance

The type of maintenance intended to deep the pavement above some minimum acceptable level at all times. It is used as a means of preventing further pavement deterioration that would require corrective maintenance. It may include either structural or nonstructural improvements to a pavement surface.

Rate of return

The interest rate that, over a period of time, equates the benefits derived from an opportunity to the investment cost of the project.

Recurring costs

Costs that recur on a periodic basis throughout the life of the project.

Rehabilitation

The act of restoring the pavement to a former condition so that so that it can fulfill its function.

Replacement costs

Those one-time costs to be incurred in the future to maintain the original function of the facility or item.

Rigid pavement

A pavement structure that distributes loads to the subgrade having as one course a Portland Cement Concrete slab of relatively high bending resistance.

Risk

Exists when each alternative will lead to one of a set of possible outcomes and there is a known probability of each outcome.

Salvage value

The value (positive if it has residual economic value and negative if requiring demolition) of competing alternatives at the end of the life cycle or the analysis period. Sometimes referred to as residual value.

Sensitivity analysis

A technique to assess the relative effect a change in input variable(s) has (have) on the resulting output.

Time value of money

Recognition that all organizations have limited resources (finances, people, facilities, equipment) and that the commitment of these to a project precludes their use for any other investment. Whether internal resources are used, or borrowed, the interest that these resources could produce is a cost to the project.

Trade-offs

Giving up one thing to obtain something else.

Uncertainty

Exists when the probabilities of the outcomes are completely or partially unknown.

Useful life

The period of time over which a building element may be expected to give service. It may represent physical, technological, or economic life.

User costs

Those costs that are accumulated by the user of a facility. In a life cycle cost analysis these could be in the form of delay costs or change in vehicle operating costs.

Value engineering (VE)

An analysis of materials, processes, and products where functions are related to cost and from which a selection may be made for the purpose of achieving the required function at the lowest overall cost consistent with the requirements for performance, reliability, and maintainability; sometimes called value analysis.

B10.6 ENGINEERING ECONOMIC TABLES

Engineering Economic Tables for interest rates of two through ten, twelve, and fifteen percent follow on pages B-20 to B-30:

INTEREST RATE = 2.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.9804	0.9804	0.0000	1.0200	1.0000	1.0200	1.0000	1
2	0.9612	1.9416	0.9612	1.0404	2.0200	0.5150	0.4950	2
3	0.9423	2.8839	2.8458	1.0612	3.0604	0.3468	0.3268	3
4	0.9238	3.8077	5.6173	1.0824	4.1216	0.2626	0.2426	4
5	0.9057	4.7135	9.2403	1.1041	5.2040	0.2122	0.1922	5
6	0.8880	5.6014	13.6801	1.1262	6.3081	0.1785	0.1585	6
7	0.8706	6.4720	18.9035	1.1487	7.4343	0.1545	0.1345	7
8	0.8535	7.3255	24.8779	1.1717	8.5830	0.1365	0.1165	8
9	0.8368	8.1622	31.5720	1.1951	9.7546	0.1225	0.1025	9
10	0.8203	8.9826	38.9551	1.2190	10.9497	0.1113	0.0913	10
11	0.8043	9.7868	46.9977	1.2434	12.1687	0.1022	0.0822	11
12	0.7885	10.5753	55.6712	1.2682	13.4121	0.0946	0.0746	12
13	0.7730	11.3484	64.9475	1.2936	14.6803	0.0881	0.0681	13
14	0.7579	12.1062	74.7999	1.3195	15.9739	0.0826	0.0626	14
15	0.7430	12.8493	85.2021	1.3459	17.2934	0.0778	0.0578	15
16	0.7284	13.5777	96.1288	1.3728	18.6393	0.0737	0.0537	16
17	0.7142	14.2919	107.5554	1.4002	20.0121	0.0700	0.0500	17
18	0.7002	14.9920	119.4581	1.4282	21.4123	0.0667	0.0467	18
19	0.6864	15.6785	131.8139	1.4568	22.8406	0.0638	0.0438	19
20	0.6730	16.3514	144.6003	1.4859	24.2974	0.0612	0.0412	20
21	0.6598	17.0112	157.7959	1.5157	25.7833	0.0588	0.0388	21
22	0.6468	17.6580	171.3795	1.5460	27.2990	0.0566	0.0366	22
23	0.6342	18.2922	185.3309	1.5769	28.8450	0.0547	0.0347	23
24	0.6217	18.9139	199.6305	1.6084	30.4219	0.0529	0.0329	24
25	0.6095	19.5235	214.2592	1.6406	32.0303	0.0512	0.0312	25
26	0.5976	20.1210	229.1987	1.6734	33.6709	0.0497	0.0297	26
27	0.5859	20.7069	244.4311	1.7069	35.3443	0.0483	0.0283	27
28	0.5744	21.2813	259.9392	1.7410	37.0512	0.0470	0.0270	28
29	0.5631	21.8444	275.7064	1.7758	38.7922	0.0458	0.0258	29
30	0.5521	22.3965	291.7164	1.8114	40.5681	0.0446	0.0246	30
31	0.5412	22.9377	307.9538	1.8476	42.3794	0.0436	0.0236	31
32	0.5306	23.4683	324.4035	1.8845	44.2270	0.0426	0.0226	32
33	0.5202	23.9886	341.0508	1.9222	46.1116	0.0417	0.0217	33
34	0.5100	24.4986	357.8817	1.9607	48.0338	0.0408	0.0208	34
35	0.5000	24.9986	374.8826	1.9999	49.9945	0.0400	0.0200	35
36	0.4902	25.4888	392.0405	2.0399	51.9944	0.0392	0.0192	36
37	0.4806	25.9695	409.3424	2.0807	54.0343	0.0385	0.0185	37
38	0.4712	26.4406	426.7764	2.1223	56.1149	0.0378	0.0178	38
39	0.4619	26.9026	444.3304	2.1647	58.2372	0.0372	0.0172	39
40	0.4529	27.3555	461.9931	2.2080	60.4020	0.0366	0.0166	40
41	0.4440	27.7995	479.7535	2.2522	62.6100	0.0360	0.0160	41
42	0.4353	28.2348	497.6010	2.2972	64.8622	0.0354	0.0154	42
43	0.4268	28.6616	515.5253	2.3432	67.1595	0.0349	0.0149	43
44	0.4184	29.0800	533.5165	2.3901	69.5027	0.0344	0.0144	44
45	0.4102	29.4902	551.5652	2.4379	71.8927	0.0339	0.0139	45
46	0.4022	29.8923	569.6621	2.4866	74.3306	0.0335	0.0135	46
47	0.3943	30.2866	587.7985	2.5363	76.8172	0.0330	0.0130	47
48	0.3865	30.6731	605.9657	2.5871	79.3535	0.0326	0.0126	48
49	0.3790	31.0521	624.1557	2.6388	81.9406	0.0322	0.0122	49
50	0.3715	31.4236	642.3606	2.6916	84.5794	0.0318	0.0118	50
51	0.3642	31.7878	660.5727	2.7454	87.2710	0.0315	0.0115	51
52	0.3571	32.1449	678.7849	2.8003	90.0164	0.0311	0.0111	52
53	0.3501	32.4950	696.9900	2.8563	92.8167	0.0308	0.0108	53
54	0.3432	32.8383	715.1815	2.9135	95.6731	0.0305	0.0105	54
55	0.3365	33.1748	733.3527	2.9717	98.5865	0.0301	0.0101	55
56	0.3299	33.5047	751.4975	3.0312	101.5583	0.0298	0.0098	56
57	0.3234	33.8281	769.6100	3.0918	104.5894	0.0296	0.0096	57
58	0.3171	34.1452	787.6845	3.1536	107.6812	0.0293	0.0093	58
59	0.3109	34.4561	805.7154	3.2167	110.8348	0.0290	0.0090	59
60	0.3048	34.7609	823.6975	3.2810	114.0515	0.0288	0.0088	60
65	0.2761	36.1975	912.7085	3.6225	131.1262	0.0276	0.0076	65
70	0.2500	37.4986	999.8343	3.9996	149.9779	0.0267	0.0067	70
75	0.2265	38.6771	1084.6393	4.4158	170.7918	0.0259	0.0059	75
80	0.2051	39.7445	1166.7868	4.8754	193.7720	0.0252	0.0052	80
85	0.1858	40.7113	1246.0241	5.3829	219.1439	0.0246	0.0046	85
90	0.1683	41.5869	1322.1701	5.9431	247.1567	0.0240	0.0040	90
95	0.1524	42.3800	1395.1033	6.5617	278.0850	0.0236	0.0036	95
100	0.1380	43.0984	1464.7527	7.2446	312.2323	0.0232	0.0032	100

INTEREST RATE = 3.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.9709	0.9709	0.0000	1.0300	1.0000	1.0300	1.0000	1
2	0.9426	1.9135	0.9426	1.0609	2.0300	0.5226	0.4926	2
3	0.9151	2.8286	2.7729	1.0927	3.0909	0.3535	0.3235	3
4	0.8885	3.7171	5.4383	1.1255	4.1836	0.2690	0.2390	4
5	0.8626	4.5797	8.8888	1.1593	5.3091	0.2184	0.1884	5
6	0.8375	5.4172	13.0762	1.1941	6.4684	0.1846	0.1546	6
7	0.8131	6.2303	17.9547	1.2299	7.6625	0.1605	0.1305	7
8	0.7894	7.0197	23.4806	1.2668	8.8923	0.1425	0.1125	8
9	0.7664	7.7861	29.6119	1.3048	10.1591	0.1284	0.0984	9
10	0.7441	8.5302	36.3088	1.3439	11.4639	0.1172	0.0872	10
11	0.7224	9.2526	43.5330	1.3842	12.8078	0.1081	0.0781	11
12	0.7014	9.9540	51.2482	1.4258	14.1920	0.1005	0.0705	12
13	0.6810	10.6350	59.4196	1.4685	15.6178	0.0940	0.0640	13
14	0.6611	11.2961	68.0141	1.5126	17.0863	0.0885	0.0585	14
15	0.6419	11.9379	77.0002	1.5580	18.5989	0.0838	0.0538	15
16	0.6232	12.5611	86.3477	1.6047	20.1569	0.0796	0.0496	16
17	0.6050	13.1661	96.0280	1.6528	21.7616	0.0760	0.0460	17
18	0.5874	13.7535	106.0137	1.7024	23.4144	0.0727	0.0427	18
19	0.5703	14.3238	116.2788	1.7535	25.1169	0.0698	0.0398	19
20	0.5537	14.8775	126.7987	1.8061	26.8704	0.0672	0.0372	20
21	0.5375	15.4150	137.5496	1.8603	28.6765	0.0649	0.0349	21
22	0.5219	15.9369	148.5094	1.9161	30.5368	0.0627	0.0327	22
23	0.5067	16.4436	159.6566	1.9736	32.4529	0.0608	0.0308	23
24	0.4919	16.9355	170.9711	2.0328	34.4265	0.0590	0.0290	24
25	0.4776	17.4131	182.4336	2.0938	36.4593	0.0574	0.0274	25
26	0.4637	17.8768	194.0260	2.1566	38.5530	0.0559	0.0259	26
27	0.4502	18.3270	205.7309	2.2213	40.7096	0.0546	0.0246	27
28	0.4371	18.7641	217.5320	2.2879	42.9309	0.0533	0.0233	28
29	0.4243	19.1885	229.4137	2.3566	45.2189	0.0521	0.0221	29
30	0.4120	19.6004	241.3613	2.4273	47.5754	0.0510	0.0210	30
31	0.4000	20.0004	253.3609	2.5001	50.0027	0.0500	0.0200	31
32	0.3883	20.3888	265.3993	2.5751	52.5028	0.0490	0.0190	32
33	0.3770	20.7658	277.4642	2.6523	55.0778	0.0482	0.0182	33
34	0.3660	21.1318	289.5437	2.7319	57.7302	0.0473	0.0173	34
35	0.3554	21.4872	301.6267	2.8139	60.4621	0.0465	0.0165	35
36	0.3450	21.8323	313.7028	2.8983	63.2759	0.0458	0.0158	36
37	0.3350	22.1672	325.7622	2.9852	66.1742	0.0451	0.0151	37
38	0.3252	22.4925	337.7956	3.0748	69.1594	0.0445	0.0145	38
39	0.3158	22.8082	349.7942	3.1670	72.2342	0.0438	0.0138	39
40	0.3066	23.1148	361.7499	3.2620	75.4013	0.0433	0.0133	40
41	0.2976	23.4124	373.6551	3.3599	78.6633	0.0427	0.0127	41
42	0.2890	23.7014	385.5024	3.4607	82.0232	0.0422	0.0122	42
43	0.2805	23.9819	397.2852	3.5645	85.4839	0.0417	0.0117	43
44	0.2724	24.2543	408.9972	3.6715	89.0484	0.0412	0.0112	44
45	0.2644	24.5187	420.6325	3.7816	92.7199	0.0408	0.0108	45
46	0.2567	24.7754	432.1856	3.8950	96.5015	0.0404	0.0104	46
47	0.2493	25.0247	443.6515	4.0119	100.3965	0.0400	0.0100	47
48	0.2420	25.2667	455.0255	4.1323	104.4084	0.0396	0.0096	48
49	0.2350	25.5017	466.3031	4.2562	108.5406	0.0392	0.0092	49
50	0.2281	25.7298	477.4803	4.3839	112.7969	0.0389	0.0089	50
51	0.2215	25.9512	488.5535	4.5154	117.1808	0.0385	0.0085	51
52	0.2150	26.1662	499.5191	4.6509	121.6962	0.0382	0.0082	52
53	0.2088	26.3750	510.3742	4.7904	126.3471	0.0379	0.0079	53
54	0.2027	26.5777	521.1157	4.9341	131.1375	0.0376	0.0076	54
55	0.1968	26.7744	531.7411	5.0821	136.0716	0.0373	0.0073	55
56	0.1910	26.9655	542.2481	5.2346	141.1538	0.0371	0.0071	56
57	0.1855	27.1509	552.6345	5.3917	146.3884	0.0368	0.0068	57
58	0.1801	27.3310	562.8985	5.5534	151.7800	0.0366	0.0066	58
59	0.1748	27.5058	573.0384	5.7200	157.3334	0.0364	0.0064	59
60	0.1697	27.6756	583.0526	5.8916	163.0534	0.0361	0.0061	60
65	0.1464	28.4529	631.2010	6.8300	194.3328	0.0351	0.0051	65
70	0.1263	29.1234	676.0869	7.9178	230.5941	0.0343	0.0043	70
75	0.1089	29.7018	717.6978	9.1789	272.6309	0.0337	0.0037	75
80	0.0940	30.2008	756.0865	10.6409	321.3630	0.0331	0.0031	80
85	0.0811	30.6312	791.3529	12.3357	377.8570	0.0326	0.0026	85
90	0.0699	31.0024	823.6302	14.3005	443.3489	0.0323	0.0023	90
95	0.0603	31.3227	853.0742	16.5782	519.2720	0.0319	0.0019	95
100	0.0520	31.5989	879.8540	19.2186	607.2877	0.0316	0.0016	100

INTEREST RATE = 4.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.9615	0.9615	0.0000	1.0400	1.0000	1.0400	1.0000	1
2	0.9246	1.8861	0.9246	1.0816	2.0400	0.5302	0.4902	2
3	0.8890	2.7751	2.7025	1.1249	3.1216	0.3603	0.3203	3
4	0.8548	3.6299	5.2670	1.1699	4.2465	0.2755	0.2355	4
5	0.8219	4.4518	8.5547	1.2167	5.4163	0.2246	0.1846	5
6	0.7903	5.2421	12.5062	1.2653	6.6330	0.1908	0.1508	6
7	0.7599	6.0021	17.0657	1.3159	7.8983	0.1666	0.1266	7
8	0.7307	6.7327	22.1806	1.3686	9.2142	0.1485	0.1085	8
9	0.7026	7.4353	27.8013	1.4233	10.5828	0.1345	0.0945	9
10	0.6756	8.1109	33.8814	1.4802	12.0061	0.1233	0.0833	10
11	0.6496	8.7605	40.3772	1.5395	13.4864	0.1141	0.0741	11
12	0.6246	9.3851	47.2477	1.6010	15.0258	0.1066	0.0666	12
13	0.6006	9.9856	54.4546	1.6651	16.6268	0.1001	0.0601	13
14	0.5775	10.5631	61.9618	1.7317	18.2919	0.0947	0.0547	14
15	0.5553	11.1184	69.7355	1.8009	20.0236	0.0899	0.0499	15
16	0.5339	11.6523	77.7441	1.8730	21.8245	0.0858	0.0458	16
17	0.5134	12.1657	85.9581	1.9479	23.6975	0.0822	0.0422	17
18	0.4936	12.6593	94.3498	2.0258	25.6454	0.0790	0.0390	18
19	0.4746	13.1339	102.8933	2.1068	27.6712	0.0761	0.0361	19
20	0.4564	13.5903	111.5647	2.1911	29.7781	0.0736	0.0336	20
21	0.4388	14.0292	120.3414	2.2788	31.9692	0.0713	0.0313	21
22	0.4220	14.4511	129.2024	2.3699	34.2480	0.0692	0.0292	22
23	0.4057	14.8568	138.1284	2.4647	36.6179	0.0673	0.0273	23
24	0.3901	15.2470	147.1012	2.5633	39.0826	0.0656	0.0256	24
25	0.3751	15.6221	156.1040	2.6658	41.6459	0.0640	0.0240	25
26	0.3607	15.9828	165.1212	2.7725	44.3117	0.0626	0.0226	26
27	0.3468	16.3296	174.1385	2.8834	47.0842	0.0612	0.0212	27
28	0.3335	16.6631	183.1424	2.9987	49.9676	0.0600	0.0200	28
29	0.3207	16.9837	192.1206	3.1187	52.9663	0.0589	0.0189	29
30	0.3083	17.2920	201.0618	3.2434	56.0849	0.0578	0.0178	30
31	0.2965	17.5885	209.9556	3.3731	59.3283	0.0569	0.0169	31
32	0.2851	17.8736	218.7924	3.5081	62.7015	0.0559	0.0159	32
33	0.2741	18.1476	227.5634	3.6484	66.2095	0.0551	0.0151	33
34	0.2636	18.4112	236.2607	3.7943	69.8579	0.0543	0.0143	34
35	0.2534	18.6646	244.8768	3.9461	73.6522	0.0536	0.0136	35
36	0.2437	18.9083	253.4052	4.1039	77.5983	0.0529	0.0129	36
37	0.2343	19.1426	261.8399	4.2681	81.7022	0.0522	0.0122	37
38	0.2253	19.3679	270.1754	4.4388	85.9703	0.0516	0.0116	38
39	0.2166	19.5845	278.4070	4.6164	90.4091	0.0511	0.0111	39
40	0.2083	19.7928	286.5303	4.8010	95.0255	0.0505	0.0105	40
41	0.2003	19.9931	294.5414	4.9931	99.8265	0.0500	0.0100	41
42	0.1926	20.1856	302.4370	5.1928	104.8196	0.0495	0.0095	42
43	0.1852	20.3708	310.2141	5.4005	110.0124	0.0491	0.0091	43
44	0.1780	20.5488	317.8700	5.6165	115.4129	0.0487	0.0087	44
45	0.1712	20.7200	325.4028	5.8412	121.0294	0.0483	0.0083	45
46	0.1646	20.8847	332.8104	6.0748	126.8706	0.0479	0.0079	46
47	0.1583	21.0429	340.0914	6.3178	132.9454	0.0475	0.0075	47
48	0.1522	21.1951	347.2446	6.5705	139.2632	0.0472	0.0072	48
49	0.1463	21.3415	354.2689	6.8333	145.8337	0.0469	0.0069	49
50	0.1407	21.4822	361.1638	7.1067	152.6671	0.0466	0.0066	50
51	0.1353	21.6175	367.9289	7.3910	159.7738	0.0463	0.0063	51
52	0.1301	21.7476	374.5638	7.6866	167.1647	0.0460	0.0060	52
53	0.1251	21.8727	381.0686	7.9941	174.8513	0.0457	0.0057	53
54	0.1203	21.9930	387.4436	8.3138	182.8454	0.0455	0.0055	54
55	0.1157	22.1086	393.6890	8.6464	191.1592	0.0452	0.0052	55
56	0.1112	22.2198	399.8054	8.9922	199.8055	0.0450	0.0050	56
57	0.1069	22.3267	405.7935	9.3519	208.7978	0.0448	0.0048	57
58	0.1028	22.4296	411.6540	9.7260	218.1497	0.0446	0.0046	58
59	0.0989	22.5284	417.3881	10.1150	227.8757	0.0444	0.0044	59
60	0.0951	22.6235	422.9966	10.5196	237.9907	0.0442	0.0042	60
65	0.0781	23.0467	449.2014	12.7987	294.9684	0.0434	0.0034	65
70	0.0642	23.3945	472.4789	15.5716	364.2905	0.0427	0.0027	70
75	0.0528	23.6804	493.0408	18.9453	448.6314	0.0422	0.0022	75
80	0.0434	23.9154	511.1161	23.0498	551.2450	0.0418	0.0018	80
85	0.0357	24.1085	526.9384	28.0436	676.0901	0.0415	0.0015	85
90	0.0293	24.2673	540.7369	34.1193	827.9833	0.0412	0.0012	90
95	0.0241	24.3978	552.7307	41.5114	1012.7846	0.0410	0.0010	95
100	0.0198	24.5050	563.1249	50.5049	1237.6237	0.0408	0.0008	100

INTEREST RATE = 5.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.9524	0.9524	0.0000	1.0500	1.0000	1.0500	1.0000	1
2	0.9070	1.8594	0.9070	1.1025	2.0500	0.5378	0.4878	2
3	0.8638	2.7232	2.6347	1.1576	3.1525	0.3672	0.3172	3
4	0.8227	3.5460	5.1028	1.2155	4.3101	0.2820	0.2320	4
5	0.7835	4.3295	8.2369	1.2763	5.5256	0.2310	0.1810	5
6	0.7462	5.0757	11.9680	1.3401	6.8019	0.1970	0.1470	6
7	0.7107	5.7864	16.2321	1.4071	8.1420	0.1728	0.1228	7
8	0.6768	6.4632	20.9700	1.4775	9.5491	0.1547	0.1047	8
9	0.6446	7.1078	26.1268	1.5513	11.0266	0.1407	0.0907	9
10	0.6139	7.7217	31.6520	1.6289	12.5779	0.1295	0.0795	10
11	0.5847	8.3064	37.4988	1.7103	14.2068	0.1204	0.0704	11
12	0.5568	8.8633	43.6241	1.7959	15.9171	0.1128	0.0628	12
13	0.5303	9.3936	49.9879	1.8856	17.7130	0.1065	0.0565	13
14	0.5051	9.8986	56.5538	1.9799	19.5986	0.1010	0.0510	14
15	0.4810	10.3797	63.2880	2.0789	21.5786	0.0963	0.0463	15
16	0.4581	10.8378	70.1597	2.1829	23.6575	0.0923	0.0423	16
17	0.4363	11.2741	77.1405	2.2920	25.8404	0.0887	0.0387	17
18	0.4155	11.6896	84.2043	2.4066	28.1324	0.0855	0.0355	18
19	0.3957	12.0853	91.3275	2.5270	30.5390	0.0827	0.0327	19
20	0.3769	12.4622	98.4884	2.6533	33.0660	0.0802	0.0302	20
21	0.3589	12.8212	105.6673	2.7860	35.7193	0.0780	0.0280	21
22	0.3418	13.1630	112.8461	2.9253	38.5052	0.0760	0.0260	22
23	0.3256	13.4886	120.0087	3.0715	41.4305	0.0741	0.0241	23
24	0.3101	13.7986	127.1402	3.2251	44.5020	0.0725	0.0225	24
25	0.2953	14.0939	134.2275	3.3864	47.7271	0.0710	0.0210	25
26	0.2812	14.3752	141.2585	3.5557	51.1135	0.0696	0.0196	26
27	0.2678	14.6430	148.2226	3.7335	54.6691	0.0683	0.0183	27
28	0.2551	14.8981	155.1101	3.9201	58.4026	0.0671	0.0171	28
29	0.2429	15.1411	161.9126	4.1161	62.3227	0.0660	0.0160	29
30	0.2314	15.3725	168.6226	4.3219	66.4388	0.0651	0.0151	30
31	0.2204	15.5928	175.2333	4.5380	70.7608	0.0641	0.0141	31
32	0.2099	15.8027	181.7392	4.7649	75.2988	0.0633	0.0133	32
33	0.1999	16.0025	188.1351	5.0032	80.0638	0.0625	0.0125	33
34	0.1904	16.1929	194.4168	5.2533	85.0670	0.0618	0.0118	34
35	0.1813	16.3742	200.5807	5.5160	90.3203	0.0611	0.0111	35
36	0.1727	16.5469	206.6237	5.7918	95.8363	0.0604	0.0104	36
37	0.1644	16.7113	212.5434	6.0814	101.6281	0.0598	0.0098	37
38	0.1566	16.8679	218.3378	6.3855	107.7095	0.0593	0.0093	38
39	0.1491	17.0170	224.0054	6.7048	114.0950	0.0588	0.0088	39
40	0.1420	17.1591	229.5452	7.0400	120.7998	0.0583	0.0083	40
41	0.1353	17.2944	234.9564	7.3920	127.8398	0.0578	0.0078	41
42	0.1288	17.4232	240.2389	7.7616	135.2318	0.0574	0.0074	42
43	0.1227	17.5459	245.3925	8.1497	142.9933	0.0570	0.0070	43
44	0.1169	17.6628	250.4175	8.5572	151.1430	0.0566	0.0066	44
45	0.1113	17.7741	255.3145	8.9850	159.7002	0.0563	0.0063	45
46	0.1060	17.8801	260.0844	9.4343	168.6852	0.0559	0.0059	46
47	0.1009	17.9810	264.7281	9.9060	178.1194	0.0556	0.0056	47
48	0.0961	18.0772	269.2467	10.4013	188.0254	0.0553	0.0053	48
49	0.0916	18.1687	273.6418	10.9213	198.4267	0.0550	0.0050	49
50	0.0872	18.2559	277.9148	11.4674	209.3480	0.0548	0.0048	50
51	0.0831	18.3390	282.0673	12.0408	220.8154	0.0545	0.0045	51
52	0.0791	18.4181	286.1013	12.6428	232.8562	0.0543	0.0043	52
53	0.0753	18.4934	290.0184	13.2749	245.4990	0.0541	0.0041	53
54	0.0717	18.5651	293.8208	13.9387	258.7739	0.0539	0.0039	54
55	0.0683	18.6335	297.5104	14.6356	272.7126	0.0537	0.0037	55
56	0.0651	18.6985	301.0894	15.3674	287.3482	0.0535	0.0035	56
57	0.0620	18.7605	304.5599	16.1358	302.7157	0.0533	0.0033	57
58	0.0590	18.8195	307.9243	16.9426	318.8514	0.0531	0.0031	58
59	0.0562	18.8758	311.1846	17.7897	335.7940	0.0530	0.0030	59
60	0.0535	18.9293	314.3432	18.6792	353.5837	0.0528	0.0028	60
65	0.0419	19.1611	328.6910	23.8399	456.7980	0.0522	0.0022	65
70	0.0329	19.3427	340.8409	30.4264	588.5285	0.0517	0.0017	70
75	0.0258	19.4850	351.0721	38.8327	756.6537	0.0513	0.0013	75
80	0.0202	19.5965	359.6460	49.5614	971.2288	0.0510	0.0010	80
85	0.0158	19.6838	366.8007	63.2544	1245.0871	0.0508	0.0008	85
90	0.0124	19.7523	372.7488	80.7304	1594.6073	0.0506	0.0006	90
95	0.0097	19.8059	377.6774	103.0347	2040.6935	0.0505	0.0005	95
100	0.0076	19.8479	381.7492	131.5013	2610.0252	0.0504	0.0004	100

INTEREST RATE = 6.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.9434	0.9434	0.0000	1.0600	1.0000	1.0600	1.0000	1
2	0.8900	1.8334	0.8900	1.1236	2.0600	0.5454	0.4854	2
3	0.8396	2.6730	2.5692	1.1910	3.1836	0.3741	0.3141	3
4	0.7921	3.4651	4.9455	1.2625	4.3746	0.2886	0.2286	4
5	0.7473	4.2124	7.9345	1.3382	5.6371	0.2374	0.1774	5
6	0.7050	4.9173	11.4594	1.4185	6.9753	0.2034	0.1434	6
7	0.6651	5.5824	15.4497	1.5036	8.3938	0.1791	0.1191	7
8	0.6274	6.2098	19.8416	1.5938	9.8975	0.1610	0.1010	8
9	0.5919	6.8017	24.5768	1.6895	11.4913	0.1470	0.0870	9
10	0.5584	7.3601	29.6023	1.7908	13.1808	0.1359	0.0759	10
11	0.5268	7.8869	34.8702	1.8983	14.9716	0.1268	0.0668	11
12	0.4970	8.3838	40.3369	2.0122	16.8699	0.1193	0.0593	12
13	0.4688	8.8527	45.9629	2.1329	18.8821	0.1130	0.0530	13
14	0.4423	9.2950	51.7128	2.2609	21.0151	0.1076	0.0476	14
15	0.4173	9.7122	57.5546	2.3966	23.2760	0.1030	0.0430	15
16	0.3936	10.1059	63.4592	2.5404	25.6725	0.0990	0.0390	16
17	0.3714	10.4773	69.4011	2.6928	28.2129	0.0954	0.0354	17
18	0.3503	10.8276	75.3569	2.8543	30.9057	0.0924	0.0324	18
19	0.3305	11.1581	81.3062	3.0256	33.7600	0.0896	0.0296	19
20	0.3118	11.4699	87.2304	3.2071	36.7856	0.0872	0.0272	20
21	0.2942	11.7641	93.1136	3.3996	39.9927	0.0850	0.0250	21
22	0.2775	12.0416	98.9412	3.6035	43.3923	0.0830	0.0230	22
23	0.2618	12.3034	104.7007	3.8197	46.9958	0.0813	0.0213	23
24	0.2470	12.5504	110.3812	4.0489	50.8156	0.0797	0.0197	24
25	0.2330	12.7834	115.9732	4.2919	54.8645	0.0782	0.0182	25
26	0.2198	13.0032	121.4684	4.5494	59.1564	0.0769	0.0169	26
27	0.2074	13.2105	126.8600	4.8223	63.7058	0.0757	0.0157	27
28	0.1956	13.4062	132.1420	5.1117	68.5281	0.0746	0.0146	28
29	0.1846	13.5907	137.3096	5.4184	73.6398	0.0736	0.0136	29
30	0.1741	13.7648	142.3588	5.7435	79.0582	0.0726	0.0126	30
31	0.1643	13.9291	147.2864	6.0881	84.8017	0.0718	0.0118	31
32	0.1550	14.0840	152.0901	6.4534	90.8898	0.0710	0.0110	32
33	0.1462	14.2302	156.7681	6.8406	97.3432	0.0703	0.0103	33
34	0.1379	14.3681	161.3192	7.2510	104.1838	0.0696	0.0096	34
35	0.1301	14.4982	165.7427	7.6861	111.4348	0.0690	0.0090	35
36	0.1227	14.6210	170.0387	8.1473	119.1209	0.0684	0.0084	36
37	0.1158	14.7368	174.2072	8.6361	127.2681	0.0679	0.0079	37
38	0.1092	14.8460	178.2490	9.1543	135.9042	0.0674	0.0074	38
39	0.1031	14.9491	182.1652	9.7035	145.0585	0.0669	0.0069	39
40	0.0972	15.0463	185.9568	10.2857	154.7620	0.0665	0.0065	40
41	0.0917	15.1380	189.6256	10.9029	165.0477	0.0661	0.0061	41
42	0.0865	15.2245	193.1732	11.5570	175.9505	0.0657	0.0057	42
43	0.0816	15.3062	196.6017	12.2505	187.5076	0.0653	0.0053	43
44	0.0770	15.3832	199.9130	12.9855	199.7580	0.0650	0.0050	44
45	0.0727	15.4558	203.1096	13.7646	212.7435	0.0647	0.0047	45
46	0.0685	15.5244	206.1938	14.5905	226.5081	0.0644	0.0044	46
47	0.0647	15.5890	209.1681	15.4659	241.0986	0.0641	0.0041	47
48	0.0610	15.6500	212.0351	16.3939	256.5645	0.0639	0.0039	48
49	0.0575	15.7076	214.7972	17.3775	272.9584	0.0637	0.0037	49
50	0.0543	15.7619	217.4574	18.4202	290.3359	0.0634	0.0034	50
51	0.0512	15.8131	220.0181	19.5254	308.7561	0.0632	0.0032	51
52	0.0483	15.8614	222.4823	20.6969	328.2814	0.0630	0.0030	52
53	0.0456	15.9070	224.8525	21.9387	348.9783	0.0629	0.0029	53
54	0.0430	15.9500	227.1316	23.2550	370.9170	0.0627	0.0027	54
55	0.0406	15.9905	229.3222	24.6503	394.1720	0.0625	0.0025	55
56	0.0383	16.0288	231.4272	26.1293	418.8223	0.0624	0.0024	56
57	0.0361	16.0649	233.4490	27.6971	444.9517	0.0622	0.0022	57
58	0.0341	16.0990	235.3905	29.3589	472.6488	0.0621	0.0021	58
59	0.0321	16.1311	237.2542	31.1205	502.0077	0.0620	0.0020	59
60	0.0303	16.1614	239.0428	32.9877	533.1282	0.0619	0.0019	60
65	0.0227	16.2891	246.9450	44.1450	719.0829	0.0614	0.0014	65
70	0.0169	16.3845	253.3271	59.0759	967.9322	0.0610	0.0010	70
75	0.0126	16.4558	258.4527	79.0569	1300.9487	0.0608	0.0008	75
80	0.0095	16.5091	262.5493	105.7960	1746.5999	0.0606	0.0006	80
85	0.0071	16.5489	265.8096	141.5789	2342.9817	0.0604	0.0004	85
90	0.0053	16.5787	268.3946	189.4645	3141.0752	0.0603	0.0003	90
95	0.0039	16.6009	270.4375	253.5463	4209.1042	0.0602	0.0002	95
100	0.0029	16.6175	272.0471	339.3021	5638.3681	0.0602	0.0002	100

INTEREST RATE = 7.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.9346	0.9346	0.0000	1.0700	1.0000	1.0700	1.0000	1
2	0.8734	1.8080	0.8734	1.1449	2.0700	0.5531	0.4831	2
3	0.8163	2.6243	2.5060	1.2250	3.2149	0.3811	0.3111	3
4	0.7629	3.3872	4.7947	1.3108	4.4399	0.2952	0.2252	4
5	0.7130	4.1002	7.6467	1.4026	5.7507	0.2439	0.1739	5
6	0.6663	4.7665	10.9784	1.5007	7.1533	0.2098	0.1398	6
7	0.6227	5.3893	14.7149	1.6058	8.6540	0.1856	0.1156	7
8	0.5820	5.9713	18.7889	1.7182	10.2598	0.1675	0.0975	8
9	0.5439	6.5152	23.1404	1.8385	11.9780	0.1535	0.0835	9
10	0.5083	7.0236	27.7156	1.9672	13.8164	0.1424	0.0724	10
11	0.4751	7.4987	32.4665	2.1049	15.7836	0.1334	0.0634	11
12	0.4440	7.9427	37.3506	2.2522	17.8885	0.1259	0.0559	12
13	0.4150	8.3577	42.3302	2.4098	20.1406	0.1197	0.0497	13
14	0.3878	8.7455	47.3718	2.5785	22.5505	0.1143	0.0443	14
15	0.3624	9.1079	52.4461	2.7590	25.1290	0.1098	0.0398	15
16	0.3387	9.4466	57.5271	2.9522	27.8881	0.1059	0.0359	16
17	0.3166	9.7632	62.5923	3.1588	30.8402	0.1024	0.0324	17
18	0.2959	10.0591	67.6219	3.3799	33.9990	0.0994	0.0294	18
19	0.2765	10.3356	72.5991	3.6165	37.3790	0.0968	0.0268	19
20	0.2584	10.5940	77.5091	3.8697	40.9955	0.0944	0.0244	20
21	0.2415	10.8355	82.3393	4.1406	44.8652	0.0923	0.0223	21
22	0.2257	11.0612	87.0793	4.4304	49.0057	0.0904	0.0204	22
23	0.2109	11.2722	91.7201	4.7405	53.4361	0.0887	0.0187	23
24	0.1971	11.4693	96.2545	5.0724	58.1767	0.0872	0.0172	24
25	0.1842	11.6536	100.6765	5.4274	63.2490	0.0858	0.0158	25
26	0.1722	11.8258	104.9814	5.8074	68.6765	0.0846	0.0146	26
27	0.1609	11.9867	109.1656	6.2139	74.4838	0.0834	0.0134	27
28	0.1504	12.1371	113.2264	6.6488	80.6977	0.0824	0.0124	28
29	0.1406	12.2777	117.1622	7.1143	87.3465	0.0814	0.0114	29
30	0.1314	12.4090	120.9718	7.6123	94.4608	0.0806	0.0106	30
31	0.1228	12.5318	124.6550	8.1451	102.0730	0.0798	0.0098	31
32	0.1147	12.6466	128.2120	8.7153	110.2182	0.0791	0.0091	32
33	0.1072	12.7538	131.6435	9.3253	118.9334	0.0784	0.0084	33
34	0.1002	12.8540	134.9507	9.9781	128.2588	0.0778	0.0078	34
35	0.0937	12.9477	138.1353	10.6766	138.2369	0.0772	0.0072	35
36	0.0875	13.0352	141.1990	11.4239	148.9135	0.0767	0.0067	36
37	0.0818	13.1170	144.1441	12.2236	160.3374	0.0762	0.0062	37
38	0.0765	13.1935	146.9730	13.0793	172.5610	0.0758	0.0058	38
39	0.0715	13.2649	149.6883	13.9948	185.6403	0.0754	0.0054	39
40	0.0668	13.3317	152.2928	14.9745	199.6351	0.0750	0.0050	40
41	0.0624	13.3941	154.7892	16.0227	214.6096	0.0747	0.0047	41
42	0.0583	13.4524	157.1807	17.1443	230.6322	0.0743	0.0043	42
43	0.0545	13.5070	159.4702	18.3444	247.7765	0.0740	0.0040	43
44	0.0509	13.5579	161.6609	19.6285	266.1209	0.0738	0.0038	44
45	0.0476	13.6055	163.7559	21.0025	285.7493	0.0735	0.0035	45
46	0.0445	13.6500	165.7584	22.4726	306.7518	0.0733	0.0033	46
47	0.0416	13.6916	167.6714	24.0457	329.2244	0.0730	0.0030	47
48	0.0389	13.7305	169.4981	25.7289	353.2701	0.0728	0.0028	48
49	0.0363	13.7668	171.2417	27.5299	378.9990	0.0726	0.0026	49
50	0.0339	13.8007	172.9051	29.4570	406.5289	0.0725	0.0025	50
51	0.0317	13.8325	174.4915	31.5190	435.9860	0.0723	0.0023	51
52	0.0297	13.8621	176.0037	33.7253	467.5050	0.0721	0.0021	52
53	0.0277	13.8898	177.4447	36.0861	501.2303	0.0720	0.0020	53
54	0.0259	13.9157	178.8173	38.6122	537.3164	0.0719	0.0019	54
55	0.0242	13.9399	180.1243	41.3150	575.9286	0.0717	0.0017	55
56	0.0226	13.9626	181.3685	44.2071	617.2436	0.0716	0.0016	56
57	0.0211	13.9837	182.5524	47.3015	661.4506	0.0715	0.0015	57
58	0.0198	14.0035	183.6786	50.6127	708.7522	0.0714	0.0014	58
59	0.0185	14.0219	184.7496	54.1555	759.3648	0.0713	0.0013	59
60	0.0173	14.0392	185.7677	57.9464	813.5204	0.0712	0.0012	60
65	0.0123	14.1099	190.1452	81.2729	1146.7552	0.0709	0.0009	65
70	0.0088	14.1604	193.5185	113.9894	1614.1342	0.0706	0.0006	70
75	0.0063	14.1964	196.1035	159.8760	2269.6574	0.0704	0.0004	75
80	0.0045	14.2220	198.0748	224.2344	3189.0627	0.0703	0.0003	80
85	0.0032	14.2403	199.5717	314.5003	4478.5761	0.0702	0.0002	85
90	0.0023	14.2533	200.7042	441.1030	6287.1854	0.0702	0.0002	90
95	0.0016	14.2626	201.5581	618.6697	8823.8535	0.0701	0.0001	95
100	0.0012	14.2693	202.2001	867.7163	12381.6618	0.0701	0.0001	100

INTEREST RATE = 8.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.9259	0.9259	0.0000	1.0800	1.0000	1.0800	1.0000	1
2	0.8573	1.7833	0.8573	1.1664	2.0800	0.5608	0.4808	2
3	0.7938	2.5771	2.4450	1.2597	3.2464	0.3880	0.3080	3
4	0.7350	3.3121	4.6501	1.3605	4.5061	0.3019	0.2219	4
5	0.6806	3.9927	7.3724	1.4693	5.8666	0.2505	0.1705	5
6	0.6302	4.6229	10.5233	1.5869	7.3359	0.2163	0.1363	6
7	0.5835	5.2064	14.0242	1.7138	8.9228	0.1921	0.1121	7
8	0.5403	5.7466	17.8061	1.8509	10.6366	0.1740	0.0940	8
9	0.5002	6.2469	21.8081	1.9990	12.4876	0.1601	0.0801	9
10	0.4632	6.7101	25.9768	2.1589	14.4866	0.1490	0.0690	10
11	0.4289	7.1390	30.2657	2.3316	16.6455	0.1401	0.0601	11
12	0.3971	7.5361	34.6339	2.5182	18.9771	0.1327	0.0527	12
13	0.3677	7.9038	39.0463	2.7196	21.4953	0.1265	0.0465	13
14	0.3405	8.2442	43.4723	2.9372	24.2149	0.1213	0.0413	14
15	0.3152	8.5595	47.8857	3.1722	27.1521	0.1168	0.0368	15
16	0.2919	8.8514	52.2640	3.4259	30.3243	0.1130	0.0330	16
17	0.2703	9.1216	56.5883	3.7000	33.7502	0.1096	0.0296	17
18	0.2502	9.3719	60.8426	3.9960	37.4502	0.1067	0.0267	18
19	0.2317	9.6036	65.0134	4.3157	41.4463	0.1041	0.0241	19
20	0.2145	9.8181	69.0898	4.6610	45.7620	0.1019	0.0219	20
21	0.1987	10.0168	73.0629	5.0338	50.4229	0.0998	0.0198	21
22	0.1839	10.2007	76.9257	5.4365	55.4568	0.0980	0.0180	22
23	0.1703	10.3711	80.6726	5.8715	60.8933	0.0964	0.0164	23
24	0.1577	10.5288	84.2997	6.3412	66.7648	0.0950	0.0150	24
25	0.1460	10.6748	87.8041	6.8485	73.1059	0.0937	0.0137	25
26	0.1352	10.8100	91.1842	7.3964	79.9544	0.0925	0.0125	26
27	0.1252	10.9352	94.4390	7.9881	87.3508	0.0914	0.0114	27
28	0.1159	11.0511	97.5687	8.6271	95.3388	0.0905	0.0105	28
29	0.1073	11.1584	100.5738	9.3173	103.9659	0.0896	0.0096	29
30	0.0994	11.2578	103.4558	10.0627	113.2832	0.0888	0.0088	30
31	0.0920	11.3498	106.2163	10.8677	123.3459	0.0881	0.0081	31
32	0.0852	11.4350	108.8575	11.7371	134.2135	0.0875	0.0075	32
33	0.0789	11.5139	111.3819	12.6760	145.9506	0.0869	0.0069	33
34	0.0730	11.5869	113.7924	13.6901	158.6267	0.0863	0.0063	34
35	0.0676	11.6546	116.0920	14.7853	172.3168	0.0858	0.0058	35
36	0.0626	11.7172	118.2839	15.9682	187.1021	0.0853	0.0053	36
37	0.0580	11.7752	120.3713	17.2456	203.0703	0.0849	0.0049	37
38	0.0537	11.8289	122.3579	18.6253	220.3159	0.0845	0.0045	38
39	0.0497	11.8786	124.2470	20.1153	238.9412	0.0842	0.0042	39
40	0.0460	11.9246	126.0422	21.7245	259.0565	0.0839	0.0039	40
41	0.0426	11.9672	127.7470	23.4625	280.7810	0.0836	0.0036	41
42	0.0395	12.0067	129.3651	25.3395	304.2435	0.0833	0.0033	42
43	0.0365	12.0432	130.8998	27.3666	329.5830	0.0830	0.0030	43
44	0.0338	12.0771	132.3547	29.5560	356.9496	0.0828	0.0028	44
45	0.0313	12.1084	133.7331	31.9204	386.5056	0.0826	0.0026	45
46	0.0290	12.1374	135.0384	34.4741	418.4261	0.0824	0.0024	46
47	0.0269	12.1643	136.2739	37.2320	452.9002	0.0822	0.0022	47
48	0.0249	12.1891	137.4428	40.2106	490.1322	0.0820	0.0020	48
49	0.0230	12.2122	138.5480	43.4274	530.3427	0.0819	0.0019	49
50	0.0213	12.2335	139.5928	46.9016	573.7702	0.0817	0.0017	50
51	0.0197	12.2532	140.5799	50.6537	620.6718	0.0816	0.0016	51
52	0.0183	12.2715	141.5121	54.7060	671.3255	0.0815	0.0015	52
53	0.0169	12.2884	142.3923	59.0825	726.0316	0.0814	0.0014	53
54	0.0157	12.3041	143.2229	63.8091	785.1141	0.0813	0.0013	54
55	0.0145	12.3186	144.0065	68.9139	848.9232	0.0812	0.0012	55
56	0.0134	12.3321	144.7454	74.4270	917.8371	0.0811	0.0011	56
57	0.0124	12.3445	145.4421	80.3811	992.2640	0.0810	0.0010	57
58	0.0115	12.3560	146.0987	86.8116	1072.6451	0.0809	0.0009	58
59	0.0107	12.3667	146.7173	93.7565	1159.4568	0.0809	0.0009	59
60	0.0099	12.3766	147.3000	101.2571	1253.2133	0.0808	0.0008	60
65	0.0067	12.4160	149.7387	148.7798	1847.2481	0.0805	0.0005	65
70	0.0046	12.4428	151.5326	218.6064	2720.0801	0.0804	0.0004	70
75	0.0031	12.4611	152.8448	321.2045	4002.5566	0.0802	0.0002	75
80	0.0021	12.4735	153.8001	471.9548	5886.9354	0.0802	0.0002	80
85	0.0014	12.4820	154.4925	693.4565	8655.7061	0.0801	0.0001	85
90	0.0010	12.4877	154.9925	1018.9151	12723.9386	0.0801	0.0001	90
95	0.0007	12.4917	155.3524	1497.1205	18701.5069	0.0801	0.0001	95
100	0.0005	12.4943	155.6107	2199.7613	27484.5157	0.0800	0.0000	100

INTEREST RATE = 9.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.9174	0.9174	0.0000	1.0900	1.0000	1.0900	1.0000	1
2	0.8417	1.7591	0.8417	1.1881	2.0900	0.5685	0.4785	2
3	0.7722	2.5313	2.3860	1.2950	3.2781	0.3951	0.3051	3
4	0.7084	3.2397	4.5113	1.4116	4.5731	0.3087	0.2187	4
5	0.6499	3.8897	7.1110	1.5386	5.9847	0.2571	0.1671	5
6	0.5963	4.4859	10.0924	1.6771	7.5233	0.2229	0.1329	6
7	0.5470	5.0330	13.3746	1.8280	9.2004	0.1987	0.1087	7
8	0.5019	5.5348	16.8877	1.9926	11.0285	0.1807	0.0907	8
9	0.4604	5.9952	20.5711	2.1719	13.0210	0.1668	0.0768	9
10	0.4224	6.4177	24.3728	2.3674	15.1929	0.1558	0.0658	10
11	0.3875	6.8052	28.2481	2.5804	17.5603	0.1469	0.0569	11
12	0.3555	7.1607	32.1590	2.8127	20.1407	0.1397	0.0497	12
13	0.3262	7.4869	36.0731	3.0658	22.9534	0.1336	0.0436	13
14	0.2992	7.7862	39.9633	3.3417	26.0192	0.1284	0.0384	14
15	0.2745	8.0607	43.8069	3.6425	29.3609	0.1241	0.0341	15
16	0.2519	8.3126	47.5849	3.9703	33.0034	0.1203	0.0303	16
17	0.2311	8.5436	51.2821	4.3276	36.9737	0.1170	0.0270	17
18	0.2120	8.7556	54.8860	4.7171	41.3013	0.1142	0.0242	18
19	0.1945	8.9501	58.3868	5.1417	46.0185	0.1117	0.0217	19
20	0.1784	9.1285	61.7770	5.6044	51.1601	0.1095	0.0195	20
21	0.1637	9.2922	65.0509	6.1088	56.7645	0.1076	0.0176	21
22	0.1502	9.4424	68.2048	6.6586	62.8733	0.1059	0.0159	22
23	0.1378	9.5802	71.2359	7.2579	69.5319	0.1044	0.0144	23
24	0.1264	9.7066	74.1433	7.9111	76.7898	0.1030	0.0130	24
25	0.1160	9.8226	76.9265	8.6231	84.7009	0.1018	0.0118	25
26	0.1064	9.9290	79.5863	9.3992	93.3240	0.1007	0.0107	26
27	0.0976	10.0266	82.1241	10.2451	102.7231	0.0997	0.0097	27
28	0.0895	10.1161	84.5419	11.1671	112.9682	0.0989	0.0089	28
29	0.0822	10.1983	86.8422	12.1722	124.1354	0.0981	0.0081	29
30	0.0754	10.2737	89.0280	13.2677	136.3075	0.0973	0.0073	30
31	0.0691	10.3428	91.1024	14.4618	149.5752	0.0967	0.0067	31
32	0.0634	10.4062	93.0690	15.7633	164.0370	0.0961	0.0061	32
33	0.0582	10.4644	94.9314	17.1820	179.8003	0.0956	0.0056	33
34	0.0534	10.5178	96.6935	18.7284	196.9823	0.0951	0.0051	34
35	0.0490	10.5668	98.3590	20.4140	215.7108	0.0946	0.0046	35
36	0.0449	10.6118	99.9319	22.2512	236.1247	0.0942	0.0042	36
37	0.0412	10.6530	101.4162	24.2538	258.3759	0.0939	0.0039	37
38	0.0378	10.6908	102.8158	26.4367	282.6298	0.0935	0.0035	38
39	0.0347	10.7255	104.1345	28.8160	309.0665	0.0932	0.0032	39
40	0.0318	10.7574	105.3762	31.4094	337.8824	0.0930	0.0030	40
41	0.0292	10.7866	106.5445	34.2363	369.2919	0.0927	0.0027	41
42	0.0268	10.8134	107.6432	37.3175	403.5281	0.0925	0.0025	42
43	0.0246	10.8380	108.6758	40.6761	440.8457	0.0923	0.0023	43
44	0.0226	10.8605	109.6456	44.3370	481.5218	0.0921	0.0021	44
45	0.0207	10.8812	110.5561	48.3273	525.8587	0.0919	0.0019	45
46	0.0190	10.9002	111.4103	52.6767	574.1860	0.0917	0.0017	46
47	0.0174	10.9176	112.2115	57.4176	626.8628	0.0916	0.0016	47
48	0.0160	10.9336	112.9625	62.5852	684.2804	0.0915	0.0015	48
49	0.0147	10.9482	113.6661	68.2179	746.8656	0.0913	0.0013	49
50	0.0134	10.9617	114.3251	74.3575	815.0836	0.0912	0.0012	50
51	0.0123	10.9740	114.9420	81.0497	889.4411	0.0911	0.0011	51
52	0.0113	10.9853	115.5193	88.3442	970.4908	0.0910	0.0010	52
53	0.0104	10.9957	116.0593	96.2951	1058.8349	0.0909	0.0009	53
54	0.0095	11.0053	116.5642	104.9617	1155.1301	0.0909	0.0009	54
55	0.0087	11.0140	117.0362	114.4083	1260.0918	0.0908	0.0008	55
56	0.0080	11.0220	117.4772	124.7050	1374.5001	0.0907	0.0007	56
57	0.0074	11.0294	117.8892	135.9285	1499.2051	0.0907	0.0007	57
58	0.0067	11.0361	118.2739	148.1620	1635.1335	0.0906	0.0006	58
59	0.0062	11.0423	118.6331	161.4966	1783.2955	0.0906	0.0006	59
60	0.0057	11.0480	118.9683	176.0313	1944.7921	0.0905	0.0005	60
65	0.0037	11.0701	120.3344	270.8460	2998.2885	0.0903	0.0003	65
70	0.0024	11.0844	121.2942	416.7301	4619.2232	0.0902	0.0002	70
75	0.0016	11.0938	121.9646	641.1909	7113.2321	0.0901	0.0001	75
80	0.0010	11.0998	122.4306	986.5517	10950.5741	0.0901	0.0001	80
85	0.0007	11.1038	122.7533	1517.9320	16854.8003	0.0901	0.0001	85
90	0.0004	11.1064	122.9758	2335.5266	25939.1842	0.0900	0.0000	90
95	0.0003	11.1080	123.1287	3593.4971	39916.6350	0.0900	0.0000	95
100	0.0002	11.1091	123.2335	5529.0408	61422.6755	0.0900	0.0000	100

INTEREST RATE = 10.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.9091	0.9091	0.0000	1.1000	1.0000	1.1000	1.0000	1
2	0.8264	1.7355	0.8264	1.2100	2.1000	0.5762	0.4762	2
3	0.7513	2.4869	2.3291	1.3310	3.3100	0.4021	0.3021	3
4	0.6830	3.1699	4.3781	1.4641	4.6410	0.3155	0.2155	4
5	0.6209	3.7908	6.8618	1.6105	6.1051	0.2638	0.1638	5
6	0.5645	4.3553	9.6842	1.7716	7.7156	0.2296	0.1296	6
7	0.5132	4.8684	12.7631	1.9487	9.4872	0.2054	0.1054	7
8	0.4665	5.3349	16.0287	2.1436	11.4359	0.1874	0.0874	8
9	0.4241	5.7590	19.4215	2.3579	13.5795	0.1736	0.0736	9
10	0.3855	6.1446	22.8913	2.5937	15.9374	0.1627	0.0627	10
11	0.3505	6.4951	26.3963	2.8531	18.5312	0.1540	0.0540	11
12	0.3186	6.8137	29.9012	3.1384	21.3843	0.1468	0.0468	12
13	0.2897	7.1034	33.3772	3.4523	24.5227	0.1408	0.0408	13
14	0.2633	7.3667	36.8005	3.7975	27.9750	0.1357	0.0357	14
15	0.2394	7.6061	40.1520	4.1772	31.7725	0.1315	0.0315	15
16	0.2176	7.8237	43.4164	4.5950	35.9497	0.1278	0.0278	16
17	0.1978	8.0216	46.5819	5.0545	40.5447	0.1247	0.0247	17
18	0.1799	8.2014	49.6395	5.5599	45.5992	0.1219	0.0219	18
19	0.1635	8.3649	52.5827	6.1159	51.1591	0.1195	0.0195	19
20	0.1486	8.5136	55.4069	6.7275	57.2750	0.1175	0.0175	20
21	0.1351	8.6487	58.1095	7.4002	64.0025	0.1156	0.0156	21
22	0.1228	8.7715	60.6893	8.1403	71.4027	0.1140	0.0140	22
23	0.1117	8.8832	63.1462	8.9543	79.5430	0.1126	0.0126	23
24	0.1015	8.9847	65.4813	9.8497	88.4973	0.1113	0.0113	24
25	0.0923	9.0770	67.6964	10.8347	98.3471	0.1102	0.0102	25
26	0.0839	9.1609	69.7940	11.9182	109.1818	0.1092	0.0092	26
27	0.0763	9.2372	71.7773	13.1100	121.0999	0.1083	0.0083	27
28	0.0693	9.3066	73.6495	14.4210	134.2099	0.1075	0.0075	28
29	0.0630	9.3696	75.4146	15.8631	148.6309	0.1067	0.0067	29
30	0.0573	9.4269	77.0766	17.4494	164.4940	0.1061	0.0061	30
31	0.0521	9.4790	78.6395	19.1943	181.9434	0.1055	0.0055	31
32	0.0474	9.5264	80.1078	21.1138	201.1378	0.1050	0.0050	32
33	0.0431	9.5694	81.4856	23.2252	222.2515	0.1045	0.0045	33
34	0.0391	9.6086	82.7773	25.5477	245.4767	0.1041	0.0041	34
35	0.0356	9.6442	83.9872	28.1024	271.0244	0.1037	0.0037	35
36	0.0323	9.6765	85.1194	30.9127	299.1268	0.1033	0.0033	36
37	0.0294	9.7059	86.1781	34.0039	330.0395	0.1030	0.0030	37
38	0.0267	9.7327	87.1673	37.4043	364.0434	0.1027	0.0027	38
39	0.0243	9.7570	88.0908	41.1448	401.4478	0.1025	0.0025	39
40	0.0221	9.7791	88.9525	45.2593	442.5926	0.1023	0.0023	40
41	0.0201	9.7991	89.7560	49.7852	487.8518	0.1020	0.0020	41
42	0.0183	9.8174	90.5047	54.7637	537.6370	0.1019	0.0019	42
43	0.0166	9.8340	91.2019	60.2401	592.4007	0.1017	0.0017	43
44	0.0151	9.8491	91.8508	66.2641	652.6408	0.1015	0.0015	44
45	0.0137	9.8628	92.4544	72.8905	718.9048	0.1014	0.0014	45
46	0.0125	9.8753	93.0157	80.1795	791.7953	0.1013	0.0013	46
47	0.0113	9.8866	93.5372	88.1975	871.9749	0.1011	0.0011	47
48	0.0103	9.8969	94.0217	97.0172	960.1723	0.1010	0.0010	48
49	0.0094	9.9063	94.4715	106.7190	1057.1896	0.1009	0.0009	49
50	0.0085	9.9148	94.8889	117.3909	1163.9085	0.1009	0.0009	50
51	0.0077	9.9226	95.2761	129.1299	1281.2994	0.1008	0.0008	51
52	0.0070	9.9296	95.6351	142.0429	1410.4293	0.1007	0.0007	52
53	0.0064	9.9360	95.9679	156.2472	1552.4723	0.1006	0.0006	53
54	0.0058	9.9418	96.2763	171.8719	1708.7195	0.1006	0.0006	54
55	0.0053	9.9471	96.5619	189.0591	1880.5914	0.1005	0.0005	55
56	0.0048	9.9519	96.8264	207.9651	2069.6506	0.1005	0.0005	56
57	0.0044	9.9563	97.0712	228.7616	2277.6156	0.1004	0.0004	57
58	0.0040	9.9603	97.2977	251.6377	2506.3772	0.1004	0.0004	58
59	0.0036	9.9639	97.5072	276.8015	2758.0149	0.1004	0.0004	59
60	0.0033	9.9672	97.7010	304.4816	3034.8164	0.1003	0.0003	60
65	0.0020	9.9796	98.4705	490.3707	4893.7073	0.1002	0.0002	65
70	0.0013	9.9873	98.9870	789.7470	7887.4696	0.1001	0.0001	70
75	0.0008	9.9921	99.3317	1271.8954	12708.9537	0.1001	0.0001	75
80	0.0005	9.9951	99.5606	2048.4002	20474.0021	0.1000	0.0000	80
85	0.0003	9.9970	99.7120	3298.9690	32979.6903	0.1000	0.0000	85
90	0.0002	9.9981	99.8118	5313.0226	53120.2261	0.1000	0.0000	90
95	0.0001	9.9988	99.8773	8556.6760	85556.7605	0.1000	0.0000	95
100	0.0001	9.9993	99.9202	13780.6123	137796.1234	0.1000	0.0000	100

INTEREST RATE = 12.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.8929	0.8929	0.0000	1.1200	1.0000	1.1200	1.0000	1
2	0.7972	1.6901	0.7972	1.2544	2.1200	0.5917	0.4717	2
3	0.7118	2.4018	2.2208	1.4049	3.3744	0.4163	0.2963	3
4	0.6355	3.0373	4.1273	1.5735	4.7793	0.3292	0.2092	4
5	0.5674	3.6048	6.3970	1.7623	6.3528	0.2774	0.1574	5
6	0.5066	4.1114	8.9302	1.9738	8.1152	0.2432	0.1232	6
7	0.4523	4.5638	11.6443	2.2107	10.0890	0.2191	0.0991	7
8	0.4039	4.9676	14.4714	2.4760	12.2997	0.2013	0.0813	8
9	0.3606	5.3282	17.3563	2.7731	14.7757	0.1877	0.0677	9
10	0.3220	5.6502	20.2541	3.1058	17.5487	0.1770	0.0570	10
11	0.2875	5.9377	23.1288	3.4785	20.6546	0.1684	0.0484	11
12	0.2567	6.1944	25.9523	3.8960	24.1331	0.1614	0.0414	12
13	0.2292	6.4235	28.7024	4.3635	28.0291	0.1557	0.0357	13
14	0.2046	6.6282	31.3624	4.8871	32.3926	0.1509	0.0309	14
15	0.1827	6.8109	33.9202	5.4736	37.2797	0.1468	0.0268	15
16	0.1631	6.9740	36.3670	6.1304	42.7533	0.1434	0.0234	16
17	0.1456	7.1196	38.6973	6.8660	48.8837	0.1405	0.0205	17
18	0.1300	7.2497	40.9080	7.6900	55.7497	0.1379	0.0179	18
19	0.1161	7.3658	42.9979	8.6128	63.4397	0.1358	0.0158	19
20	0.1037	7.4694	44.9676	9.6463	72.0524	0.1339	0.0139	20
21	0.0926	7.5620	46.8188	10.8038	81.6987	0.1322	0.0122	21
22	0.0826	7.6446	48.5543	12.1003	92.5026	0.1308	0.0108	22
23	0.0738	7.7184	50.1776	13.5523	104.6029	0.1296	0.0096	23
24	0.0659	7.7843	51.6929	15.1786	118.1552	0.1285	0.0085	24
25	0.0588	7.8431	53.1046	17.0001	133.3339	0.1275	0.0075	25
26	0.0525	7.8957	54.4177	19.0401	150.3339	0.1267	0.0067	26
27	0.0469	7.9426	55.6369	21.3249	169.3740	0.1259	0.0059	27
28	0.0419	7.9844	56.7674	23.8839	190.6989	0.1252	0.0052	28
29	0.0374	8.0218	57.8141	26.7499	214.5828	0.1247	0.0047	29
30	0.0334	8.0552	58.7821	29.9599	241.3327	0.1241	0.0041	30
31	0.0298	8.0850	59.6761	33.5551	271.2926	0.1237	0.0037	31
32	0.0266	8.1116	60.5010	37.5817	304.8477	0.1233	0.0033	32
33	0.0238	8.1354	61.2612	42.0915	342.4294	0.1229	0.0029	33
34	0.0212	8.1566	61.9612	47.1425	384.5210	0.1226	0.0026	34
35	0.0189	8.1755	62.6052	52.7996	431.6635	0.1223	0.0023	35
36	0.0169	8.1924	63.1970	59.1356	484.4631	0.1221	0.0021	36
37	0.0151	8.2075	63.7406	66.2318	543.5987	0.1218	0.0018	37
38	0.0135	8.2210	64.2394	74.1797	609.8305	0.1216	0.0016	38
39	0.0120	8.2330	64.6967	83.0812	684.0102	0.1215	0.0015	39
40	0.0107	8.2438	65.1159	93.0510	767.0914	0.1213	0.0013	40
41	0.0096	8.2534	65.4997	104.2171	860.1424	0.1212	0.0012	41
42	0.0086	8.2619	65.8509	116.7231	964.3595	0.1210	0.0010	42
43	0.0076	8.2696	66.1722	130.7299	1081.0826	0.1209	0.0009	43
44	0.0068	8.2764	66.4659	146.4175	1211.8125	0.1208	0.0008	44
45	0.0061	8.2825	66.7342	163.9876	1358.2300	0.1207	0.0007	45
46	0.0054	8.2880	66.9792	183.6661	1522.2176	0.1207	0.0007	46
47	0.0049	8.2928	67.2028	205.7061	1705.8838	0.1206	0.0006	47
48	0.0043	8.2972	67.4068	230.3908	1911.5898	0.1205	0.0005	48
49	0.0039	8.3010	67.5929	258.0377	2141.9806	0.1205	0.0005	49
50	0.0035	8.3045	67.7624	289.0022	2400.0182	0.1204	0.0004	50
51	0.0031	8.3076	67.9169	323.6825	2689.0204	0.1204	0.0004	51
52	0.0028	8.3103	68.0576	362.5243	3012.7029	0.1203	0.0003	52
53	0.0025	8.3128	68.1856	406.0273	3375.2272	0.1203	0.0003	53
54	0.0022	8.3150	68.3022	454.7505	3781.2545	0.1203	0.0003	54
55	0.0020	8.3170	68.4082	509.3206	4236.0050	0.1202	0.0002	55
56	0.0018	8.3187	68.5046	570.4391	4745.3257	0.1202	0.0002	56
57	0.0016	8.3203	68.5923	638.8918	5315.7647	0.1202	0.0002	57
58	0.0014	8.3217	68.6719	715.5588	5954.6565	0.1202	0.0002	58
59	0.0012	8.3229	68.7443	801.4258	6670.2153	0.1201	0.0001	59
60	0.0011	8.3240	68.8100	897.5969	7471.6411	0.1201	0.0001	60
65	0.0006	8.3281	69.0581	1581.8725	13173.9374	0.1201	0.0001	65
70	0.0004	8.3303	69.2103	2787.7998	23223.3319	0.1200	0.0000	70
75	0.0002	8.3316	69.3031	4913.0558	40933.7987	0.1200	0.0000	75
80	0.0001	8.3324	69.3594	8658.4831	72145.6925	0.1200	0.0000	80
85	0.0001	8.3328	69.3935	15259.2057	127151.7140	0.1200	0.0000	85
90	0.0000	8.3330	69.4140	26891.9342	224091.1185	0.1200	0.0000	90
95	0.0000	8.3332	69.4263	47392.7766	394931.4719	0.1200	0.0000	95
100	0.0000	8.3332	69.4336	83522.2657	696010.5477	0.1200	0.0000	100

INTEREST RATE = 15.00%

N	(P/F)	(P/A)	(P/G)	(F/P)	(F/A)	(A/P)	(A/F)	N
1	0.8696	0.8696	0.0000	1.1500	1.0000	1.1500	1.0000	1
2	0.7561	1.6257	0.7561	1.3225	2.1500	0.6151	0.4651	2
3	0.6575	2.2832	2.0712	1.5209	3.4725	0.4380	0.2880	3
4	0.5718	2.8550	3.7864	1.7490	4.9934	0.3503	0.2003	4
5	0.4972	3.3522	5.7751	2.0114	6.7424	0.2983	0.1483	5
6	0.4323	3.7845	7.9368	2.3131	8.7537	0.2642	0.1142	6
7	0.3759	4.1604	10.1924	2.6600	11.0668	0.2404	0.0904	7
8	0.3269	4.4873	12.4807	3.0590	13.7268	0.2229	0.0729	8
9	0.2843	4.7716	14.7548	3.5179	16.7858	0.2096	0.0596	9
10	0.2472	5.0188	16.9795	4.0456	20.3037	0.1993	0.0493	10
11	0.2149	5.2337	19.1289	4.6524	24.3493	0.1911	0.0411	11
12	0.1869	5.4206	21.1849	5.3503	29.0017	0.1845	0.0345	12
13	0.1625	5.5831	23.1352	6.1528	34.3519	0.1791	0.0291	13
14	0.1413	5.7245	24.9725	7.0757	40.5047	0.1747	0.0247	14
15	0.1229	5.8474	26.6930	8.1371	47.5804	0.1710	0.0210	15
16	0.1069	5.9542	28.2960	9.3576	55.7175	0.1679	0.0179	16
17	0.0929	6.0472	29.7828	10.7613	65.0751	0.1654	0.0154	17
18	0.0808	6.1280	31.1565	12.3755	75.8364	0.1632	0.0132	18
19	0.0703	6.1982	32.4213	14.2318	88.2118	0.1613	0.0113	19
20	0.0611	6.2593	33.5822	16.3665	102.4436	0.1598	0.0098	20
21	0.0531	6.3125	34.6448	18.8215	118.8101	0.1584	0.0084	21
22	0.0462	6.3587	35.6150	21.6447	137.6316	0.1573	0.0073	22
23	0.0402	6.3988	36.4988	24.8915	159.2764	0.1563	0.0063	23
24	0.0349	6.4338	37.3023	28.6252	184.1678	0.1554	0.0054	24
25	0.0304	6.4641	38.0314	32.9190	212.7930	0.1547	0.0047	25
26	0.0264	6.4906	38.6918	37.8568	245.7120	0.1541	0.0041	26
27	0.0230	6.5135	39.2890	43.5353	283.5688	0.1535	0.0035	27
28	0.0200	6.5335	39.8283	50.0656	327.1041	0.1531	0.0031	28
29	0.0174	6.5509	40.3146	57.5755	377.1697	0.1527	0.0027	29
30	0.0151	6.5660	40.7526	66.2118	434.7451	0.1523	0.0023	30
31	0.0131	6.5791	41.1466	76.1435	500.9569	0.1520	0.0020	31
32	0.0114	6.5905	41.5006	87.5651	577.1005	0.1517	0.0017	32
33	0.0099	6.6005	41.8184	100.6998	664.6655	0.1515	0.0015	33
34	0.0086	6.6091	42.1033	115.8048	765.3654	0.1513	0.0013	34
35	0.0075	6.6166	42.3586	133.1755	881.1702	0.1511	0.0011	35
36	0.0065	6.6231	42.5872	153.1519	1014.3457	0.1510	0.0010	36
37	0.0057	6.6288	42.7916	176.1246	1167.4975	0.1509	0.0009	37
38	0.0049	6.6338	42.9743	202.5433	1343.6222	0.1507	0.0007	38
39	0.0043	6.6380	43.1374	232.9248	1546.1655	0.1506	0.0006	39
40	0.0037	6.6418	43.2830	267.8635	1779.0903	0.1506	0.0006	40
41	0.0032	6.6450	43.4128	308.0431	2046.9539	0.1505	0.0005	41
42	0.0028	6.6478	43.5286	354.2495	2354.9969	0.1504	0.0004	42
43	0.0025	6.6503	43.6317	407.3870	2709.2465	0.1504	0.0004	43
44	0.0021	6.6524	43.7235	468.4950	3116.6334	0.1503	0.0003	44
45	0.0019	6.6543	43.8051	538.7693	3585.1285	0.1503	0.0003	45
46	0.0016	6.6559	43.8778	619.5847	4123.8977	0.1502	0.0002	46
47	0.0014	6.6573	43.9423	712.5224	4743.4824	0.1502	0.0002	47
48	0.0012	6.6585	43.9997	819.4007	5456.0047	0.1502	0.0002	48
49	0.0011	6.6596	44.0506	942.3108	6275.4055	0.1502	0.0002	49
50	0.0009	6.6605	44.0958	1083.6574	7217.7163	0.1501	0.0001	50
51	0.0008	6.6613	44.1360	1246.2061	8301.3737	0.1501	0.0001	51
52	0.0007	6.6620	44.1715	1433.1370	9547.5798	0.1501	0.0001	52
53	0.0006	6.6626	44.2031	1648.1075	10980.7167	0.1501	0.0001	53
54	0.0005	6.6631	44.2311	1895.3236	12628.8243	0.1501	0.0001	54
55	0.0005	6.6636	44.2558	2179.6222	14524.1479	0.1501	0.0001	55
56	0.0004	6.6640	44.2778	2506.5655	16703.7701	0.1501	0.0001	56
57	0.0003	6.6644	44.2972	2882.5503	19210.3356	0.1501	0.0001	57
58	0.0003	6.6647	44.3144	3314.9329	22092.8859	0.1500	0.0000	58
59	0.0003	6.6649	44.3296	3812.1728	25407.8188	0.1500	0.0000	59
60	0.0002	6.6651	44.3431	4383.9987	29219.9916	0.1500	0.0000	60
65	0.0001	6.6659	44.3903	8817.7874	58778.5826	0.1500	0.0000	65
70	0.0001	6.6663	44.4156	17735.7200	118231.4669	0.1500	0.0000	70
75	0.0000	6.6665	44.4292	35672.8680	237812.4532	0.1500	0.0000	75
80	0.0000	6.6666	44.4364	71750.8794	478332.5293	0.1500	0.0000	80
85	0.0000	6.6666	44.4402	144316.6470	962104.3133	0.1500	0.0000	85
90	0.0000	6.6666	44.4422	290272.3252	1935142.1680	0.1500	0.0000	90
95	0.0000	6.6667	44.4433	583841.3276	3892268.8509	0.1500	0.0000	95
100	0.0000	6.6667	44.4438	1174313.4507	7828749.6713	0.1500	0.0000	100

B10.7 LIFE CYCLE COST EXAMPLES

Some short exercises with each type of formula previously discussed illustrates their use and use of interest tables. Assume a discount rate of 7% for each example. Any slight difference is due to rounding.

Example 1

Given that a $40,000 pile jacketing will be required on a bridge in year 20 of its 50 year life, find the Present Worth of that expenditure.

<u>Solution</u>: Find P given F.

$P = 40{,}000[1/(1.07)^{20}] = \underline{\$10{,}337}$
or
P = 40,000 x (P/F, 7%, 20 yrs) = 40,000 x (0.2584) = <u>$10,336</u>.

Example 2

As a check on Example 1, fine the Future Worth in year 20 of an initial outlay of $10,337.

<u>Solution</u>: Find F given P.

$F = 10{,}337 \times (1 + 0.07)^{20} = \underline{\$40{,}001}$
or
F = 10,337 x (F/P, 7%, 20) =
10,337 x (3.8697) = <u>$40,001</u>

Example 3

A new roadway project costs $2,100,000. What is the Annual Worth of this initial cost? Assume a 40 year life.

<u>Solution</u>: Find A given P:

$A = 2{,}100{,}000\{[0.07(1.07)^{40}]/[1.07^{40} - 1]\}$
$= \underline{\$157{,}519}$
or
A = 2,100,000 x (A/P, 7%, 40) =
2,100,000 x (0.0750) = <u>$157,500</u>

Example 4

As a check of Example 3, find the Present Worth of an annual outlay of $157,519.

<u>Solution</u>: Find P given A.

$P = 157,519\{[(1.07)^{40} - 1]/[0.07(1.07)^{40}]\}$
$= \underline{\$2,099,997}$
or
P = 157,519 x (P/A, 7%, 40) =
157,519 x (13.3317) = <u>$2,099,997</u>

Example 5

Find the Annual Worth of a $750,000 bridge widening project in year 50 of a bridge's life.

<u>Solution</u>: Find A given F.

$A = 750,000\{(0.07)/[(1.07)^{50} - 1]\}$
$= \underline{\$1,845}$
or
A = 750,000 x (A/F, 7%, 50) =
750,000 x (0.0025) = <u>$1,875</u>

Example 6

As a check on Example 5, find the Future Worth of an annual outlay of $1,845.

<u>Solution</u>: Find F given A.

$F = 1,845[(1.07^{50} - 1)/(0.07)]$
or
F = 1,845 x (F/A, 7%, 50 =
1,845 x (406.5289) = <u>$750,046</u>

These examples illustrate the use of the formulas defined previously. As shown, the use of interest tables simplifies the problem solving significantly. The tables cannot, however, be used if a discount rate or analysis period is not included in the tables. In this case use the formulas.

NOTE: Example for computational illustration only. The rehabilitation methods, time frames, etc. do not match WVDOH pavement type selection policy.

The WVDOH is attempting to analyze the most cost effective alternative for construction of a four lane Interstate Highway. The two alternatives to be evaluated are the construction of a Portland Cement Concrete Pavement compared with the construction of an Hot-Mix Asphalt Pavement. The following costs per mile of construction are known for each alternative:

Portland Cement Concrete Pavement (Alternative 1)

Initial Construction Cost	$1,200,000
Joint Sealing (year 10 & 20)	$84,000
Routine Annual Maintenance	$1,800
Salvage	($140,000)

Hot-Mix Asphalt (Alternative 2)

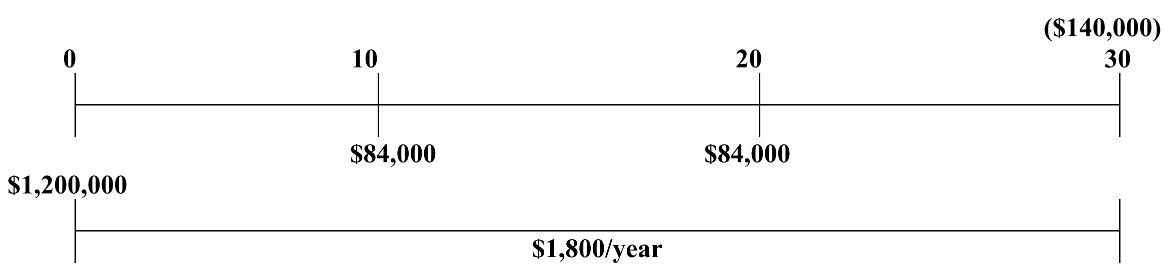
Initial Construction Cost	$900,000
Stage II Construction (year 10)	$350,000
Recycle Pavement (year 20)	$290,000
Routine Annual Maintenance	$1,000
Salvage	($280,000)

The estimated life of each alternative is 30 years. Use a 4% discount rate to find the best alternative.

Solution:

The alternative may be evaluated using either the Present Worth Method or the Annual Worth Method. Both solutions are shown. The first step is to construct a time line using the above costs. Then plug the appropriate values into the associated formula.

Alternative 1



Present Worth Method

P = $1,200,000 + $84,000 (P/F, 4%, 10) + $84,000 (P/F, 4%, 20)
+ $1,800 (P/A, 4%, 30) - $140,000 (P/F, 4%, 30)

= 1,200,000 + 84,000 (0.6756) + 84,000 (0.4564) + 1,800 (17.2920) - 140,000 (0.3083)

= $1,283,045 **ANSWER**

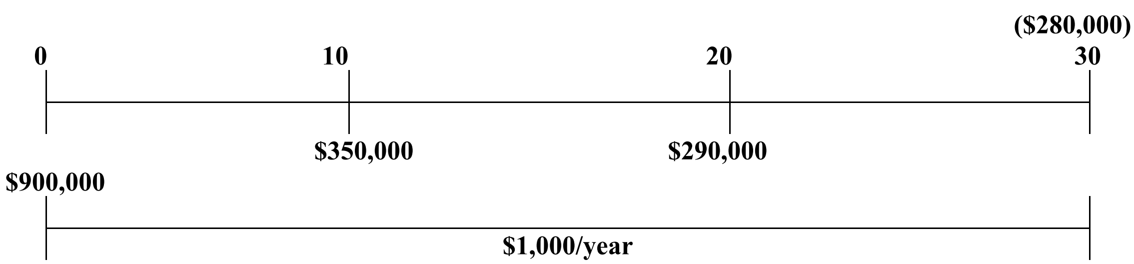
Annual Worth Method

A = $1,200,000 (A/P, 4%, 30) + $84,000 (P/F, 4%, 10) (A/P, 4%,30)
+ $84,000 (P/F, 4%, 20) (A/P, 4%, 30) + $1,800 - $140, 000 (A/F, 4%, 30)

= 1,200,000 (0.0578) + 84,000 (0.6756) (0.0578) + 84,000 (0.4564) (0.0578)
+ 1,800 - 140,000 (0.0178)

= $74,199 **ANSWER**

Alternative 2



Present Worth Method

P = $900,000 + $350,000 (P/F, 4%, 10) + $290,000 (P/F, 4%, 20)
+ $1,000 (P/A, 4%, 30) - $280,000 (P/F, 4%, 30)

= 900,000 + 350,000 (0.6756) + 290,000 (0.4564) + 1,000 (17.2920) - 280,000 (0.3083)

= $1,199,762 **ANSWER**

Annual Worth Method

A = \$900,000 (A/P, 4%, 30) + \$350,000 (P/F, 4%, 10) (A/P, 4%,30)
+ \$290,000 (P/F, 4%, 20) (A/P, 4%, 30) + \$1,000 - \$280, 000 (A/F, 4%, 30)

= 900,000 (0.0578) + 350,000 (0.6756) (0.0578) + 290,000 (0.4564) (0.0578)
+ 1,000 - 280,000 (0.0178)

= \$69,382 **ANSWER**

Comparison of Alternatives

	Alternative 1	**Alternative 2**
Present Worth	\$1,283,045	\$1,199,762
Annual Worth	\$74,199	\$69,382

Conclusion

As can be seen in the comparison above, Alternative 2 is the least expensive alternative. This example also illustrates that the use of either the annual worth or present worth method leads to the same conclusion.

Sensitivity Analysis

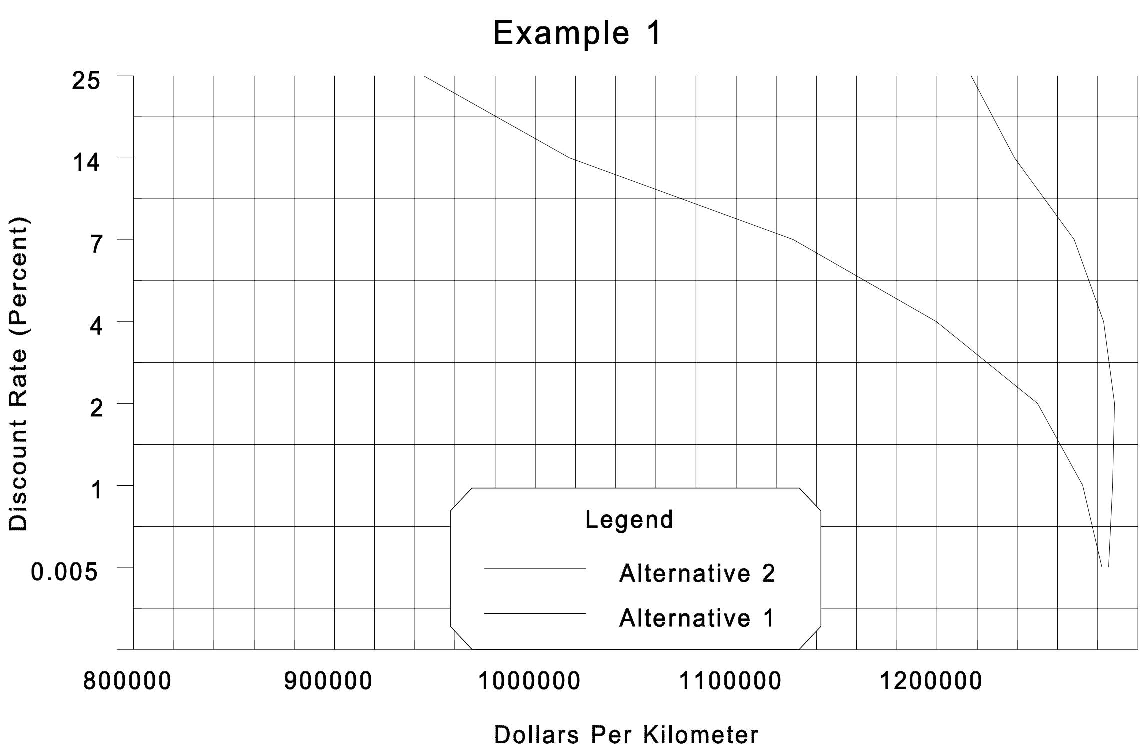
Cost Benefit Variable
Discount Rate
Analysis Period
Maintenance Cost
User Cost

Present Worth Method Example 1

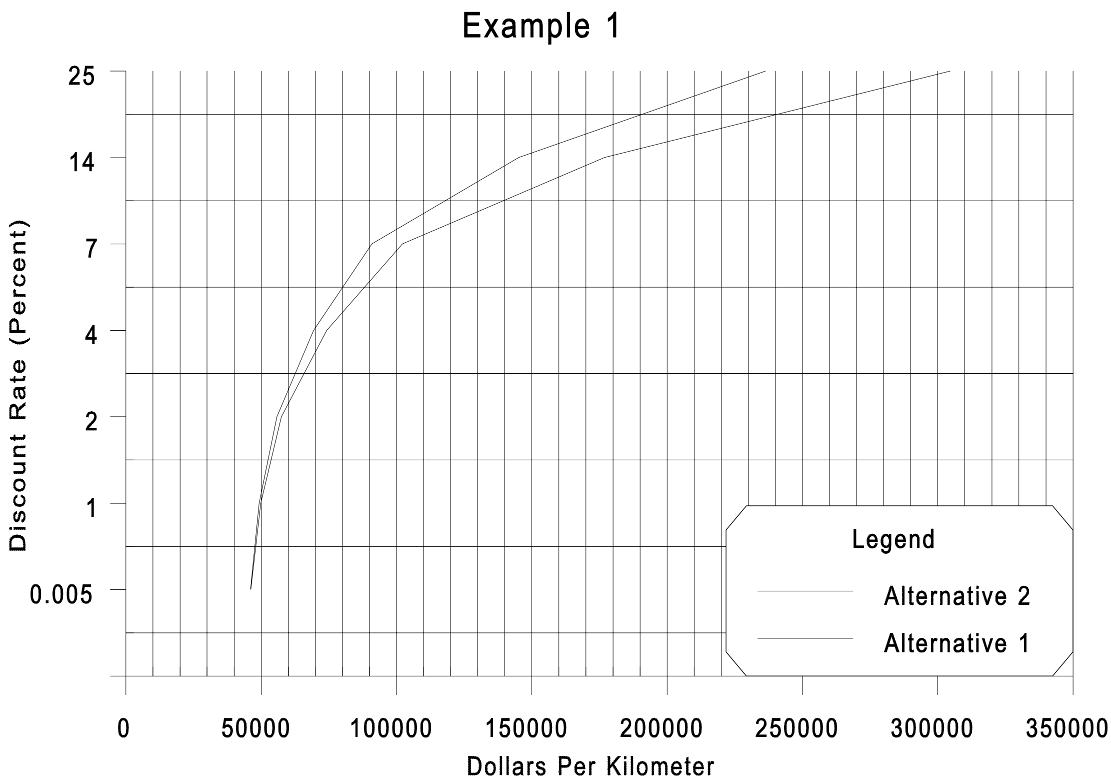
Discount Rate	**Alternative 1**	**Alternative 2**
0.5%	\$1,285,424	\$1,282,146
1%	\$1,287,471	\$1,272,588
2%	\$1,288,463	\$1,250,100
4%	\$1,283,045	\$1,199,762
7%	\$1,268,353	\$1,128,490
14%	\$1,238,627	\$1,017,018
25%	\$1,217,006	\$944,573

<u>Annual Worth Method</u> Example 1		
Discount Rate	**Alternative 1**	**Alternative 2**
0.5%	$46,248	$46,130
1%	$49,887	$49,310
2%	$57,530	$55,817
4%	$74,199	$69,382
7%	$102,212	$90,941
14%	$176,880	$145,233
25%	$304,629	$236,436

COMPARISON - PRESENT WORTH ALTERNATIVE



COMPARISON - ANNUAL WORTH ALTERNATIVES



Example 7 **NOTE:** Example for computational illustration only. The rehabilitation methods, time frames, etc. do not match WVDOH pavement type selection policy.

A Value Engineering Study has identified two alternative solutions for rehabilitating a principal arterial highway. Given the following information about each alternative, select the most cost effective. The following costs per kilometer of construction are known for each alternative:

<u>Alternative 1</u>

Provide a bituminous surface treatment (BST) for the next 12 years, followed by reconstruction with hot-mix asphalt pavement.

BST Applications (6 year cycles)	$97,000
Reconstruction (year 12)	$483,000
Annual Maintenance (years 1 - 12)	16,000
Annual Maintenance (years 13-30)	4,000
Resurfacing (year 24)	$266,000
Salvage	($132,000)

__Alternative 2__

Provide reconstruction now with rehabilitation in 12 years.

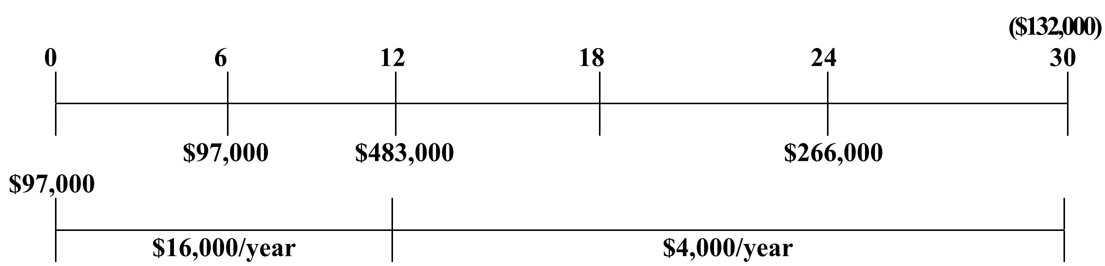
Reconstruction	$483,000
Rehabilitation (year 12)	$306,000
Annual Maintenance (year 1 -12)	$4,000
Annual Maintenance (year 13 - 30)	$1,600
Resurface (year 24)	$266,000
Salvage	$(132,000)

The estimated life of each alternative is 30 years. Use a 4% discount rate to find the best alternative.

__Solution__:

The alternative may be evaluated using either the Present Worth Method or the Annual Worth Method. Both solutions are shown. The first step is to construct a time line using the above costs. Then plug the appropriate values into the associated formula.

Alternative 1



Present Worth Method

P = \$97,000 + \$97,000 (P/F, 4%, 6) + \$483,000 (P/F, 4%, 12) + \$266,000 (P/F, 4%, 24) + \$16,000 (P/A, 4%, 12) + 4,000 (P/A, 4%, 18) (P/F, 4%, 12) - \$132,000 (P/F, 4%, 30)

= 97,000 + 97,000 (0.7903) + 483,000 (0.6246) + 266,000 (0.3901) + 16,000 (9.3851) + 4,000 (12.6593) (0.6246) - 132,000 (0.3083)

= __$720,204__ **ANSWER**

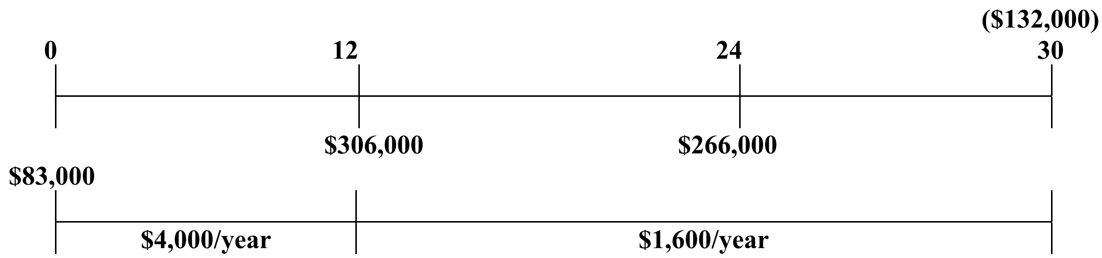
Annual Worth Method

A = \$97,000 (A/P, 4%, 30) + \$97,000 (P/F, 4%, 6) (A/P, 4%,30)
+ \$483,000 (P/F, 4%, 12) (A/P, 4%, 30) + \$266,000 (P/F, 4%, 24) (A/P, 4%, 30)
+ 16,000 (P/A, 4%, 12) (A/P, 4% 30) + 4,000 (P/A, 4%, 18) (P/F, 4%, 12)
(A/P, 4% 30) - \$132, 000 (A/F, 4%, 30)

= 97,000 (0.0578) + 97,000 (0.7903) (0.0578) + 483,000 (0.6246) (0.0578)
+ 266,000 (0.3901) (0.0578) + 16,000 (9.3851) (0.0578)
+ 4,000 (12.6593) (0.6246) (0.0578) - 132,000 (0.0178)

= \$41,650 **ANSWER**

Alternative 2



Present Worth Method

P = \$483,000 + \$306,000 (P/F, 4%, 12) + \$266,000 (P/F, 4%, 24)
+ 4,000 (P/A, 4%, 12) + \$16000 (P/A, 4%, 18) (P/F, 4%, 12)
- \$132,000 (P/F, 4%, 30)

= 483,000 + 306,000 (0.6246) + 266,000 (0.3901) + 4,000 (9.3851)
+ 1,600 (12.6593) (0.6246) - 132,000 (0.3083)

= \$787,392 **ANSWER**

Annual Worth Method

A = \$483,000 (A/P, 4%, 30) + \$306,000 (P/F, 4%, 12) (A/P, 4%,30)
+ \$266,000 (P/F, 4%, 24) (A/P, 4%, 30) + \$4,000 (P/A, 4% 12) (A/P, 4%, 30)
+ 1,600 (P/A, 4%, 18) (P/F, 4%, 12) (A/P, 4%, 30) - \$132, 000 (A/F, 4%, 30)

= 483,000 (0.0578) + 306,000 (0.6246) (0.0578) + 266,000 (0.3901) (0.0578)
+ 4,000 (9.3851) (0.0578) + 1,600 (12.6593) (0.6246) (0.0578) - 132,000 (0.0178)

= \$45,535 **ANSWER**

Comparison of Alternatives

	Alternative 1	Alternative 2
Present Worth	$720,204	$787,392
Annual Worth	$41,650	$45,535

Conclusion

As can be seen in the comparison above, Alternative 1 is the least expensive alternative. This example also illustrates that the use of either the annual worth or present worth method leads to the same conclusion.

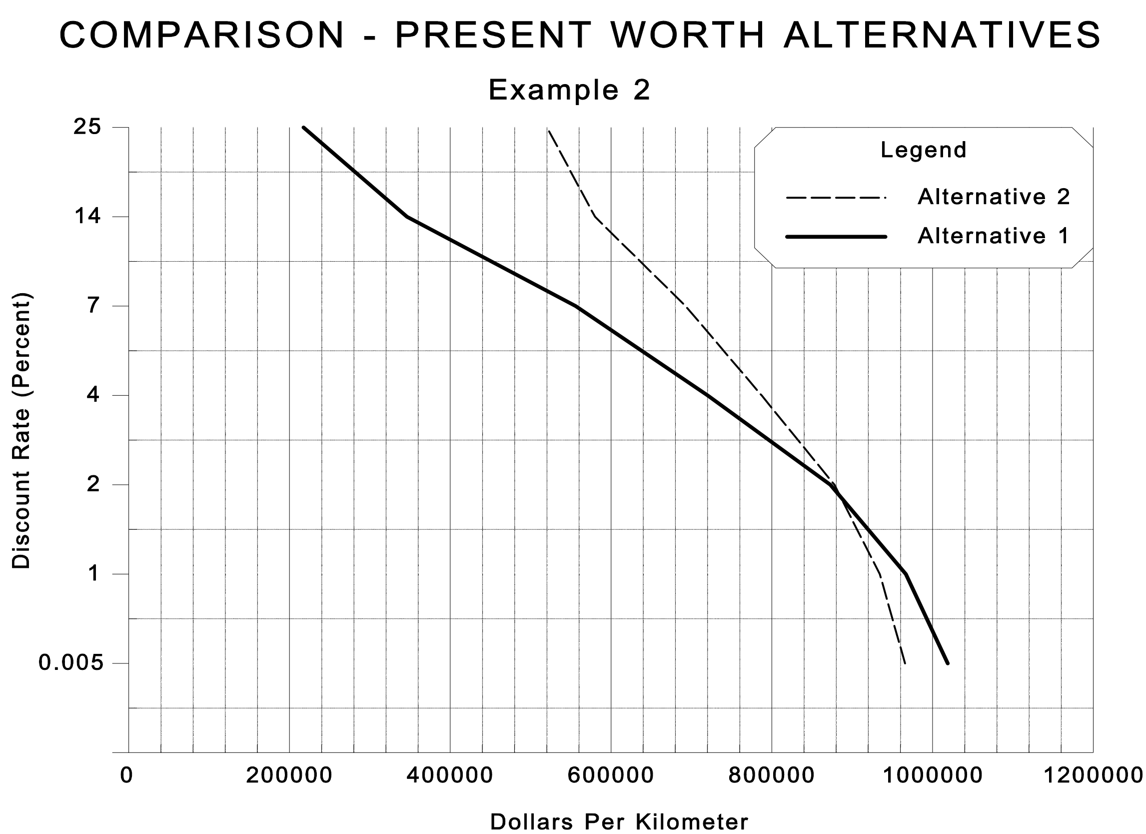
Sensitivity Analysis

Cost Benefit Variable

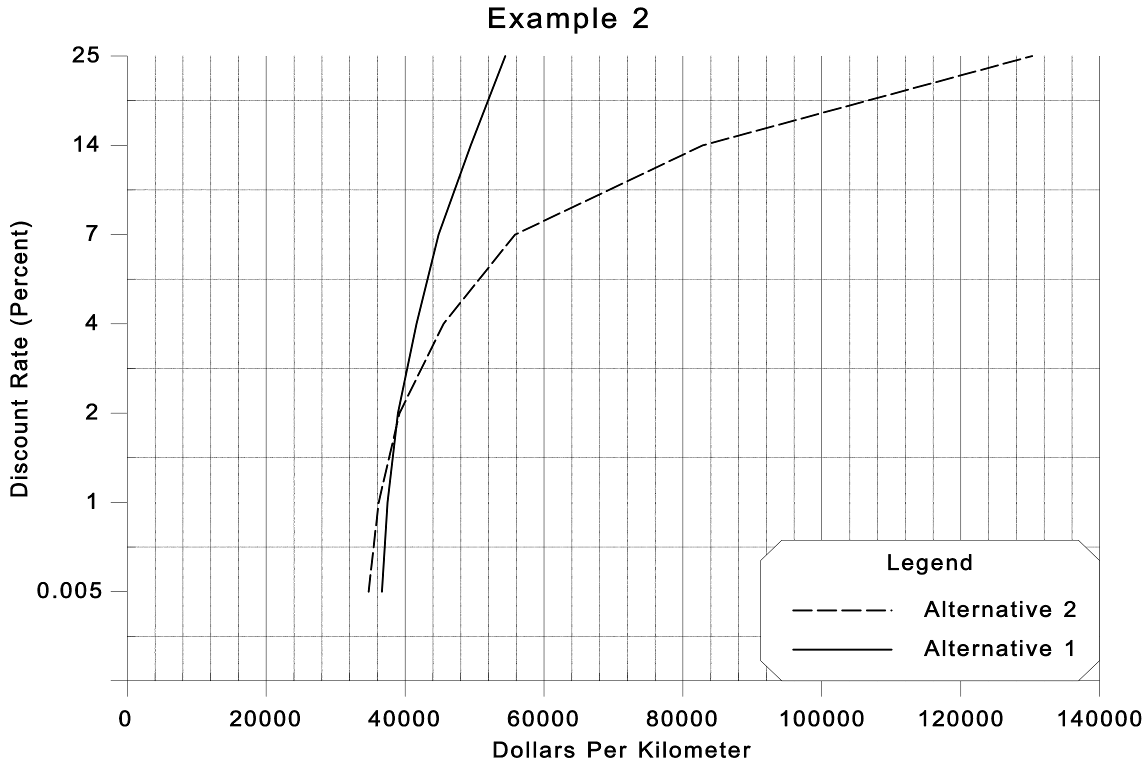
Discount Rate
Analysis Period
Maintenance Cost
User Cost

Present Worth Method Example 2		
Discount Rate	**Alternative 1**	**Alternative 2**
0.5%	$1,019,019	$965,914
1%	$966,867	$934,423
2%	$872,970	$877,999
4%	$720,204	$787,392
7%	$556,142	$692,885
14%	$346,246	$580,171
25%	$217,394	$520,453

Annual Worth Method Example 2		
Discount Rate	**Alternative 1**	**Alternative 2**
0.5%	$36,663	$34,753
1%	$37,464	$36,207
2%	$38,978	$39,203
4%	$41,650	$45,535
7%	$44,817	$55,837
14%	$49,445	$82,850
25%	$54,416	$130,275



COMPARISON - ANNUAL WORTH ALTERNATIVES



B10.8 REFERENCES

1. Winfrey R. and C. Zellner, NCHRP Report 122: *Summary and Evaluation of Economic Consequences of Highway Improvements*, Highway Research Board, National Research Council, Washington, D.C., 1971.

2. Stanford Research Institute, *Economics of Asphalt and Concrete for Highway Construction*, Report No. SRI Project IE-3153, American Petroleum Institute, New York, 1961.

3. Oglesby, C.H. and R.G. Hicks, *Highway Engineering*, 4th Edition, Wiley, New York, 1982.

4. Wellington, A.M., *The Economic Theory of the Location of Railways*, Wiley, New York, 1877.

5. Dell'Isola, A.J. and S.J. Kirk, *Life Cycle Costing for Design Professionals*, McGraw-Hill, New York, 1981.

6. Lindow, E.S., *Systems Approach to Life-Cycle Design of Pavements*, Vol I, *Life 2 Users Manual*, Report No. CERL-TR-M-253, Construction Engineering Research Laboratory, Dept of Army, 1978.

7. Peterson, Dale E., National Cooperative Highway Research Program Synthesis of Highway Practice No. 122: "Life-Cycle Cost Analysis of Pavements," Highway Research Board, National Research Council, Washington, D.C., 1985.

8. Veshosky, David and Nickerson, Robert L., "Life-cycle costs versus life-cycle performance," Better Roads Magazine, Vol. 63, No. 5, May 1993.

9. Cady, P.D., "Inflation and Highway Economic Analysis," *ASCE Journal of Transportation Engineering*, Vol. 109, No. 5, Paper No. 18248, 1983.

10. Grant, Eugene L., W. Grant Ireson, and Richard S. Leavenworth, "Principles of Engineering Economy," Wiley, 1982.

11. Kleskovic, Peter Z., "A Discussion of Discount Rates for Economic Analysis of Pavements," Draft Report, FHWA Pavement Division, February 1990.

12. Lindeburg, Michael R., P.E., *Civil Engineering Reference Manual, 5th Edition*, "Engineering Economic Analysis," Professional Publications, California, 1989.

13. Keely, B.J. and J.W. Griffith, "Life Cycle Cost-Benefit Analysis: A Basic Course in Economic Decision Making," Report N. HEW/OFEPM-75/06, Department of Health, Education, and Welfare, Washington, D.C., 1975.

14. McNeil, S. and C. Hendrickson, *Three Statistical Models of Pavement Management Based on Turnpike Data with an Application to Roadway Cost Allocation*, Federal Highway Administration, Department of Transportation, Washington, D.C., 1981.

15. Transportation Research Board, *NCHRP Synthesis 46: Recording and Reporting Methods for Highway Maintenance Expenditures*, Transportation Research Board, National Research Council, Washington, D.C., 1977.

16. Transportation Research Board, *NCHRP Synthesis 110: Maintenance Management System*, Transportation Research Board, National Research Council, Washington, D.C., 1984.

17. Transportation Research Board, *NCHRP Synthesis 77: Evaluation of Pavement Maintenance Strategies*, Transportation Research Board, National Research Council, Washington, D.C., 1981.

18. Transportation Research Board, *NCHRP Synthesis 58: Consequences of Deferred Maintenance*, Transportation Research Board, National Research Council, Washington, D.C., 1979.