DESIGN QUALITY RESEARCH

Definition ■ Benefits ■ Measurement ■ Model ■ Testing

for

Massachusetts Highway Department
(Contract No. 97410)

December 1999
Pages 76, 80, 81, 100-115, and 118
are PDFs taken from the original

The Engineering Center
One Walnut Street
Boston, Massachusetts 02108

DESIGN QUALITY RESEARCH

Definition, Benefits, Measurement, Model, Testing

Report

by

Melvin E. Jones, P.E.

Evelyn M. Darling, M.A.

Abbie R. Goodman

The Engineering Center

One Walnut Street

Boston, MA 02108

Report of Research Conducted

for

Massachusetts Highway Department

10 Park Plaza

Boston, MA 02116

(Contract No. 97410)

December 1999

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ACKNOWLEDGMENTS

The concepts for the research evolved from partnering between MassHighway and American Consulting Engineers Council of Massachusetts (ACEC/MA)—formerly named ACEC/New England until June 1998.

Project oversight was provided by a six-person steering committee that was jointly staffed by representatives of MassHighway and ACEC/MA.

Steering Committee Members were:

Representing MassHighway:

- Thomas Broderick, Chief Engineer
- Thomas DiPaolo, Assistant Chief Engineer, Project Manager for this Research
- Ross Dindio, District Highway Director, District 1

Representing ACEC/MA:

- Domenic D'Eramo, ACEC/MA, Vice President, Sverdrup Civil, Inc.
- Judith Nitsch, President ACEC/MA 1998-99, President, Judith Nitsch Engineering, Inc.
- William Rizzo, Jr., Past President ACEC/NE 1995-96, President, Rizzo Associates, Inc.

The Engineering Center editorial staff included:

- Traci Sobocinski, Director of Print Production

Focus group participants included:

- Facilitator: Katina Leodas · Katina Leodas and Associates
- Richard Carey · Vanasse Hangen Brustlin, Inc.
- William Carroll · Fay, Spofford & Thorndike, Inc.
- Jennie Lee Colosi · ET&L Construction Corp.
- James Fisher · HNTB Corporation
- Mark Fitzgerald · Daniel O'Connell's Sons, Inc.
- Peter Gammie · Vollmer Associates
- John Gonzalez · Domenech Hicks & Krockmalnic, Inc.
- Kelly Holbrook · Massachusetts Highway Department
- Michael Kerivan · Massachusetts Highway Department
- Robert Joseph · Edwards & Kelcey, Inc.

- Martin Leelman · Massachusetts Highway Department
- Joel Lunger · HDR Engineering, Inc.
- Thomas Loughlin · Massachusetts Highway Department
- Albert Miller · Massachusetts Highway Department
- William Noonan · The BSC Group, Inc.
- Paul Pascucci · Massachusetts Highway Department
- Leo Picard · Massachusetts Aggregate & Asphalt Paving Association
- Alan Perrault · Jay Cashman, Inc.
- Anthony Petronio · SPS New England, Inc.
- John Pourbaix · Construction Industries of Massachusetts
- Marie Rose · Massachusetts Highway Department
- Nick Rubino · EARTH TECH
- Gautam Sen · Massachusetts Highway Department
- Kimberly Sloan · Massachusetts Highway Department
- Paul Stark · Sealcoating, Inc.
- Bruce Sylvia · Massachusetts Highway Department
- Kent Werle · Kiewit Construction Company
- Larry Williamson · Sverdrup Civil, Inc.

Participants in individual or group interviews included:

- Alexander Bardow · Massachusetts Highway Department
- Steven Barton · Connecticut Department of Transportation
- Laurinda Bedingfield · Massachusetts Highway Department
- Robert Benson · Fay, Spofford & Thorndike, Inc.
- John Blundo · Massachusetts Highway Department
- Robert Boagni · Louisiana Department of Transportation and Development
- Cliff Bowers CH2M Hill
- Charlie Brackett · Vanasse Hangen Brustlin, Inc.
- Robert Brown · North Carolina Department of Transportation
- Herb Cole (retired) · Jackson Construction
- Edmund Condon · Vollmer Associates
- Thomas DiPaolo · Massachusetts Highway Department
- Robert Douglas · Maryland State Highway Administration

- Richard Dunne · New Jersey Department of Transportation
- Stan Elkerton · Universal Engineering Corporation
- John Giudicci · Edwards & Kelsey, Inc.
- David Hatem · Burns & Levinson
- John Hendrickson · Fay, Spofford & Thorndike, Inc.
- Michael Hicks · Domenech Hicks & Krocmalnic, Inc.
- Rick Larson · Wisconsin Department of Transportation
- Anthony Lionetta · EARTH TECH
- Tony Marquez · California Department of Transportation
- Michael McGrath · Massachusetts Highway Department
- Steven McLaughlin · Massachusetts Highway Department
- Peter Milano · Massachusetts Highway Department
- Albert Miller · Massachusetts Highway Department
- Bradford Mills · Fay, Spofford & Thorndike, Inc.
- Joseph Mombrun · Massachusetts Highway Department
- David P. Mullen · Massachusetts Highway Department
- Stephen O'Donnell · Massachusetts Highway Department
- Dorri Giles Raposa · HDR Engineering, Inc.
- M.G. Patel · Pennsylvania Department of Transportation
- Paul Patneaude · Massachusetts Highway Department
- William Rizzo, Jr. · Rizzo Associates, Inc.
- Norman Roush · West Virginia Department of Transportation
- John Sacksteder · Kentucky Transportation Cabinet
- David Scott · Vermont Agency of Transportation
- Harris Scott · Tennesse Department of Transportation
- Warren Sick · Kansas Department of Transportation
- James Siebels · Colorado Department of Transportation
- William Simonson · Vollmer Associates
- Robert Skinner · Transportation Research Board
- David Weiner · Edwards & Kelsey, Inc.
- Lawrence Weiss · South Dakota Department of Transportation
- Stanley Wood · Massachusetts Highway Department

LIST OF ABBREVIATIONS

ACDP	Actual Cost of Deliverables Produced
ASCE	American Society of Civil Engineers
BCDP	Budgeted Cost of Deliverables Produced
BCDS	Budgeted Cost of Deliverables Scheduled
BVI	Bid Variation Index
CDQI	Composite Design Quality Index
CPE	Consultant Performance Evaluation
CPEI	Consultant Performance Evaluation Index
CPI	Cost Performance Index
CV	Cost Variance
DOT	Department of Transportation
DQI	Design Quality Index
D-REWI	Design-Related Extra Work Index
EV	Earned Value
EWI	Extra Work Index
EWO	Extra Work Order
FHWA	Federal Highway Administration
ISO	International Organization for Standardization
MassHighway	Massachusetts Highway Department
NQI	National Quality Initiative
OEI	Office Estimate Index
PMI	Project Management Institute
PS&E	Plans, Specifications, and Estimates of Construction Costs
PV	Payment Voucher
QEI	Quantities Estimate Index
SPI	Schedule Performance Index
STDEV	Standard Deviation
SV	Schedule Variance

REPORT SUMMARY

Preamble

The Commonwealth of Massachusetts, acting through the Massachusetts Highway Department (MassHighway), engaged The Engineering Center to research design quality of highway facilities. The overall purpose of this research is to develop a model for measuring highway design quality.

The research was segmented into three phases. In Phase I, we defined design quality, cited its benefits, and identified means for measuring it. In Phase II, we designed a model for measuring design quality. In Phase III, we tested and calibrated the model to confirm its validity in predicting and indicating design quality for highway projects.

For the purposes of this research, the term *highway* refers to all types of facilities managed by MassHighway and municipal highway departments. Bridges, drainage systems, signage, traffic signals, landscaping, visitor centers, and many other facilities are included in the meaning of *highways*. The term *design* means all processes, tasks, and deliverables that communicate what is to be constructed, such as determining initial project requirements, creating plans and specifications, and reviewing shop drawings.

Quality Defined

The term *quality* is not construed consistently by members of the highway design community. Most individuals perceive design quality based on their needs and experiences. Because everyone's experiences, values, and expectations are unique, defining design quality reduces confusion and conflict in highway projects.

Our research revealed two definitions of quality which are particularly relevant to highway design. The International Organization for Standardization (ISO) defines quality as "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs."[i] The American Society of Civil Engineers (ASCE) characterizes quality as "the totality of features, attributes, and characteristics of a facility, product, process, component, service, or workmanship that bear on its ability to satisfy a given need: fitness for purpose. It is usually referenced to, and measured by, the degree of conformance to a predetermined standard of performance."[ii]

Based on the ISO and ASCE definitions, together with our research and knowledge of design for public infrastructure projects, we recommend that MassHighway adopt the following definition:

Design quality for highway construction is the totality of characteristics and features of all preconstruction engineering processes, tasks, and deliverables that bear on satisfying stakeholders' needs.

In order to achieve quality, the needs of all stakeholders must be defined explicitly and addressed. Not every need can be satisfied. Those needs that both the sponsoring and performing organizations agree must be satisfied are the requirements for quality.

People often express quality in terms of their satisfaction. Satisfaction is the result of quality. *Everything* leading to satisfaction is quality.

BENEFITS

There are three types of benefits of highway design quality: (1) the economic benefits to society as a whole, (2) the use benefits to each individual and entity using any part of the highway system, and (3) the occupational benefits to those individuals and entities engaged in planning, constructing, managing, operating, and maintaining highways.

In their statement of National Policy on the Quality of Highways, the Steering Committee of the National Quality Initiative addresses economic benefits and identifies "proper design" as being characteristic of highway quality. Their policy states, "The Nation's highway network is an essential element of our transportation infrastructure and its quality is critical to America's economic growth and its ability to compete in the world marketplace."[iii]

The NQI Steering Committee goes on to address user benefits in defining the intent of the National Policy as "[satisfying] the requirements of the highway user by providing a durable, smooth, safe, aesthetically pleasing, environmentally sensitive, efficient, and economical highway system…."[iv] The public who pays for and uses highways is, therefore, the principal stakeholder having an interest in highway design quality. Their satisfaction with, and support of, the highway system and its individual components and appurtenances are the ultimate benefits of highway design quality.

According to two recent surveys of highway users released independently by the NQI Steering Committee[v] and by MassHighway[vi], drivers want safer and less congested roadway travel conditions. They benefit from:

- Less congestion and fewer delays from construction work,

- Smoother and more stable pavement surfaces,
- Clearer signs and lane markings,
- Access ramps configured for safer speed changes.

Quality also provides benefits to those who are engaged directly in producing, managing, operating, and maintaining highways. Design quality benefits constructors, suppliers, subconsultants, utilities, insurers, public officials, law enforcement, and public safety agencies, as well as MassHighway and design firms.

Design successes are produced from the experiences, knowledge, and skills learned by pursuing quality on previous designs. Individuals (and organizations) who pursue quality as a primary goal use each experience to increase their knowledge and skills. In so doing, they become capable of higher levels of performance on future work. Their capabilities for producing quality and success grow from project to project. More importantly, that growth is compounded by the leverage of expanding knowledge and skills learned from previous experiences. Their constant pursuit of design quality induces more benefits from greater successes.

Overall, on project work design quality in current activities promotes quality in future activities. Design, as the initial process in highway projects, has a great deal of potential to influence quality in succeeding processes. As highway design projects progress, quality has the potential to accumulate, build momentum, and become amplified.

Quality designs induce better construction at predictable costs and lower risks. They compound. Early investments in design quality enhance overall project quality.

MEASUREMENTS

The ultimate overall indicator of quality is the response to the question: "Have the requirements for design in this project been satisfied?" Satisfied requirements are the benefits of quality. Gauging satisfaction assesses quality. Overall design quality is eventually judged by the collective satisfaction (or dissatisfaction) of:

- The traveling public,
- The sponsoring organization (e.g., MassHighway),
- The performing organization (e.g., design firm),
- Others (e.g., contractor, subcontractors, vendors, regulatory bodies).

The purpose of measurements is to assess progress in satisfying requirements. Measurements taken while design is progressing are

predictors of design quality and those taken during construction are *indicators.*

The measurements revealed by this research are summarized below.

The Project Management Institute advises that *earned value analyses* are the most commonly used methods of evaluating project performance. These analyses measure the extent of variations from budgets and schedules. Cost variance is the difference between the budgeted and the actual costs of producing prescribed deliverables. Schedule variance is the difference between the budgeted cost of deliverables actually produced and the budgeted cost of those scheduled to a specified date.

Many state highway departments, including MassHighway, use performance reviews to evaluate design quality. MassHighway's existing system, the Consultant Performance Evaluation, measures the collective judgment of the MassHighway staff professionals who review design submittals. The disciplines represented are: roadway, bridge, traffic, environmental, geotechnical, hydraulics, landscape, right-of-way, and project management. The composite score of the evaluation is the sum of the products of each discipline's score and its weighted value.

Construction contractors advise that their bids are expressions of their satisfaction that plans, specifications, and contract documents are accurate, clear, and thoroughly presented. Variations in bid prices indicate differences in bidders' interpretations of risk. Small differences in bids indicate quality in plans, specifications, and contract documents. Bid variations are a measure of design quality.

The difference between the sponsoring organization's office estimate of the construction cost and the construction bid prices are a measure of the quality of the office estimate.

Construction extra work orders are changes in construction requirements that are authorized by the owner but were not resolved during design. Those extra work orders that are design-related, in that they stem from errors or omissions, are measures of design quality.

Variations in construction quantities between those estimated and those actually furnished and placed in the construction are measures of the quality of the estimates.

MODEL FOR MEASURING QUALITY

Our research found that the most promising predictor of design quality is design schedule variation. Designs that start, proceed, and finish on schedule are characteristic of quality designs. Schedule variations are measures of several important characteristics of the design process, including the quality of project planning and executing the scope of work, staffing, budgeting and uncertainties. The commonly used measure of schedule variation is the *Schedule Performance Index* (SPI) which is computed as the quotient of the cumulative budgeted cost of deliverables produced, divided by the cumulative budgeted cost of deliverables scheduled to have been produced. Expressed in broader terms, the SPI is the ratio of the deliverables produced to the deliverables expected.

Project management professionals cite cost variations as a commonly used measure of performance. That measure did not correlate to other measures in our model. Further testing on more projects may validate cost variations during design as a predictor of design quality. Our conclusions from this research, however, are that variations in design costs from budgets for highway projects are not valid predictors of design quality.

MassHighway's Consultant Performance Evaluation explicitly measures the level of the sponsoring organization's satisfaction with a design and its components and, therefore, is included as a predictive measure in the model. This measure currently produces a composite rating of zero (worst) to ten (best). For the purpose of combining the several indices, we propose that this measure be expressed as an index of zero (worst) to 1.00 (best) and named the *Consultant Performance Evaluation Index* (CPEI).

Our research found that the most objective indicator of design quality is variation among construction bidders' prices. The competitive marketplace demands that bidders identify the least costly means of meeting project requirements. Their prices, however, must include allowances for uncertainties. When pricing contingencies, bidders are usually most influenced by clarity, thoroughness, and consistency of plans, specifications, and contract documents. Contingencies are the primary differences among bidders' prices. We have named the primary indicator of design quality *Bid Variation Index* (BVI). BVI is computed as: 1.00 minus the quotient of the standard deviation of bids divided by the low bid price.

Our research showed that projects having high SPI and BVI indexes (i.e., favorable indexes) are less likely to have construction extra work orders that have been caused by design shortcomings. Unfavorable or low SPI and BVI indexes usually predict design-related extra work orders. We have adopted the *Design-Related Extra Work Orders Index* (D-REWI) as the measure of construction extra work orders that have been caused by design shortcomings. D-REWI is computed as 1.00 minus the quotient of the total dollar cost of design-related extra work orders divided by the low bid price.

Variations in construction quantities are obvious measures of the accuracy of estimates of those quantities. We have adopted the *Quantity Estimate Index* (QEI) as the measure of this aspect of design quality. QEI is computed as 1.00 minus the quotient of quantity variations divided by the low bid price. Quantity variations are computed as the sum of the absolute differences between the final costs and bid amounts for all unit-priced items.

In addition to the five individual indexes, we have developed a composite index that we have named the *Composite Design Quality Index* (CDQI). CDQI is computed as the sum of the weighted values of the individual indexes. We propose that the indexes be weighted, as follows:

BVI (bid variation index).. 40%
D-REWI (design-related extra work index)................... 25%
CPEI (consultant performance evaluation index).......... 15%
SPI (schedule performance index)................................ 15%

QEI (quantity estimate index)... 5%

BVI is the most comprehensive single indicator of design quality because it best indicates the totality of characteristics and features of all preconstruction engineering processes, tasks, and deliverables that bear on satisfying stakeholders' needs. Quality designs reduce bidders' risks. Lower risks induce smaller variations among bids.

D-REWI is ranked second in its weighting influence because, on its face, construction extra work that has been caused by design shortcomings is a clear indicator of failures in design quality.

CPEI and SPI are equally weighted as predictors of design quality. Together, these two indexes share 30% of the overall weighting and are important in alerting design managers to potential design failings. Designs that produce satisfactory deliverables on schedule are likely to have fewer problems during construction. Designs that are not timely or are poorly rated by sponsoring organizations are precursors of construction problems.

QEI measures only the quality of the sponsors' office estimate. This measure is weighted at 5%.

In summary, we propose that CDQI be computed as:

CDQI = (40%)(BVI) +(25%)(DREWI) + (15%)(CPEI) + (15%)(SPI) + (5%)(QEI).

OVERALL CONCLUSION

As a result of this research, we conclude that certain characteristics of highway projects are reliable predictors and indicators of design quality. Designs that proceed on planned schedules and satisfy sponsors' needs, as measured by SPI and CPEI, are likely to lead to satisfactory construction as indicated by:

1. Small differences among construction bid prices;
2. Small variations between estimated and actual construction quantities;
3. No construction extra work orders caused by design deficiencies.

These measures, in aggregate, provide a composite measurement of design quality that is indicative of stakeholders' satisfaction.

Notwithstanding the findings of this research, we believe that further testing will improve the model. The weightings of the measures in the CDQI are based upon our judgement now. Also, in spite of the results of the project tests, we believe that design cost performance (CPI) will, in time, prove to be a predictor of design quality. Additional research and experience are needed to test these theories and improve the model.

CHAPTER 1

INTRODUCTION

The Massachusetts Highway Department (MassHighway), through its Massachusetts Quality Initiative (MQI), has affirmed that quality in design influences quality in constructed projects. To provide a basis for further quality advancement, MassHighway authorized The Engineering Center to research design quality in highway projects. The Engineering Center is a consortium of engineering, surveying, and related associations providing educational programs, resources, and information services for professionals and the public.

We derived the findings in this report from sources in the fields of transportation at-large, highways, quality management, design, construction, and project management. Our research methodology is described in Appendix A

CHAPTER 2: HIGHWAY DESIGN

Chapter 2

HIGHWAY DESIGN

Definitions of Highway, design, and designer

The term *highway*, as used throughout this report, refers to all types of facilities managed by MassHighway and municipal highway departments. Bridges, drainage systems, signage, traffic signals, landscaping, visitor centers, and many other facilities are included in the meaning of highways in this report.

Design, as used in this report, means all processes, tasks, and deliverables that result in producing plans, specifications, construction cost estimates, and construction procurement and contracting documents. *Design* also refers to those tasks performed by designers during construction to help clarify the information on plans and in specifications (e.g., shop drawing reviews).

Designer, as used herein, refers to all persons and organizations who participate in deciding the requirements of, and solutions to, highway projects. *Designer* is an inclusive term meaning all who establish requirements and approve solutions, as well as those who create solutions. For example, on MassHighway projects, designers include MassHighway expediters, project managers, and others who are setting requirements and approving solutions, as well as those engaged to create solutions such as design consultants or MassHighway designers. For municipal and private development road projects, designers may be employees of those entities or consultants.

Projects

Highway design belongs to a family of work processes called projects. Knowledge of project management provides a foundation for understanding highway design quality.

According to the Project Management Institute (PMI), a non-profit professional organization dedicated to advancing the state-of-the-art in project management, "projects are temporary endeavors undertaken to create unique products or services."[vii] Projects are *unique* because they involve doing something that has not been done before

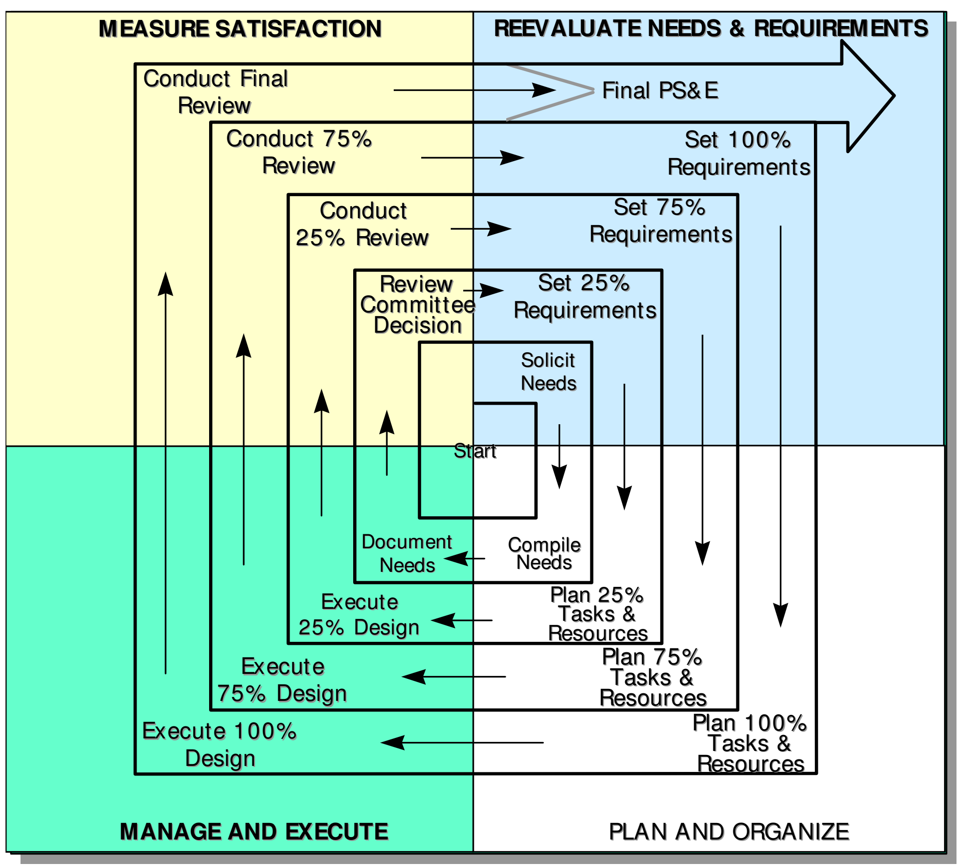
A project is unique even when many others of the same type exist, such as a bridge replacement. There are millions of roadway bridges in the world and nearly all have common elements. Nevertheless, the design, construction, and final products are all unique because of many variables, including differing strengths of supporting soils, topographic configurations, climatic influences, anticipated traffic volumes, lengths of spans, available building materials, and construction skills.

The normal development of a project is from vague images or visions at its beginning to increasingly defined details as the work progresses. A project team's movement from envisioning broad solutions to specifying detailed characteristics occurs as the team develops a better understanding of, and more explicit means for, satisfying needs. This transformation process means that each characteristic of the project begins with a broad concept and is developed through incremental stages to more detail.

The major incremental stages in project development are called phases. A project phase is "a collection of logically related project activities, usually culminating in the completion of a major *deliverable*."[viii] Typically, phases take on the names of the services being provided, such as 25% design and 75% design. See Figure 2-1.

Projects are temporary endeavors undertaken to create unique products or services.

Figure 2-1: Phases of MassHighway's Project Development Process



Deliverables

A deliverable is "any measurable, tangible, verifiable outcome, result, or item that must be produced to complete a project or part of a project."[ix] The term deliverable is commonly used in referring to products subject to being approved by the project sponsor. Plans, specifications, and estimates of construction costs (PS&E) are deliverables. Submittals at 25% and 75% are also deliverables.

A deliverable is any measurable, tangible, verifiable outcome, result, or item that must be produced to complete a project or part of a project.

Design deliverables evolve from work that is recorded on supporting documents. Each document represents a step in the process of visions becoming increasingly specific. These supporting documents, in turn, are the products of supporting data, analyses, and findings. For example, storm water culvert designs are developed from documents of topographic surveys, rainfall data, terrain slopes, soil composition, and other data. Each of these documents is a deliverable to the individual(s) who uses it. The topographic survey is a deliverable from the surveyor to the culvert designer.

Purpose of Design

The purpose of design is to improve the certainty that stakeholders' needs are addressed, appropriate solutions devised, and constructed facilities correspond to requirements. For the most part, design is an intellectual process of determining requirements and crafting solutions. Design documents, PS&Es, and construction procurement and contracting documents are the primary products of design.

The purpose of design is to improve the certainty that stakeholders' needs are addressed, appropriate solutions devised, and constructed facilities correspond to requirements.

In highway construction, there are many needs to which designers must respond. These needs range from rigorous engineering needs, such as analyses for assuring the structural integrity of a bridge, to community needs, such as managing public hearings for assuring consideration of neighborhood interests. Successful highway designs address not only the physical constructable needs of a project but also the human needs. *Any* need which may enhance or impede a project must be considered in the design process.

CHAPTER 3

DEFINING DESIGN QUALITY

After all, when you come right down to it,
how many people speak the same language
even when they speak the same language?

—Russell Hoban
The Lion of Boaz-Jachin and Jachin-Boaz (1973).

differing perspectives in Defining Design Quality

Quality is not defined consistently by members of the highway design community.

Members of the highway design community do not define quality consistently even though they often speak of it. For this research, we asked dozens of transportation professionals involved in the design, administration, and construction of highway projects what constitutes design quality. The characterizations of design quality offered by design consultants, MassHighway project managers and expediters, and contractors are widely divergent. Some highway professionals judge the product delivered. Others relate quality to the systems or processes that produce the product.

Typical examples of the language of quality among highway professionals:

- "A quality design is one that looks right, improves the quality of life and the area, and fulfills its intended function."
- "Precision and accuracy are the baselines for quality."
- "Work done within scope, budget, and allotted time frame."
- "Quality is making money at the end of the project, assuming that it's technically sound."
- "A project which goes to construction on time and without extra work orders."
- "Quality equals the amount of money thrown at a project."
- "From an engineering perspective, there will always be better a design—it's never complete."
- "Meets the requirements defined at the beginning."

- "Good communication between us and the client."
- "Understanding where each one is at."
- "Early on in the project getting everyone on the same wavelength."
- "Quality is two things: 1. It can be constructed; and 2. It meets the Highway Design Manual and AASHTO requirements."
- "It's buildable."
- "[The plans] accurately convey what the client wants."
- "[A] quality job [is one in which] when it [gets] to the final PS&E, it [has] the least amount of revisions."
- "Fits into the environment."
- "The presentation is readable and understandable."
- "Proper expertise."
- "Attitude, motivation, and interest."
- "Looks beautiful."
- "Personal opinion is the driver [of quality]."
- "Teamwork—one team, not 'us' and 'them'."
- "Consistency between the plans and the specs."

Quotations from research interviews and focus groups.

The variability in meaning of design quality prompts confusion, conflict, misalignment, and even mistrust among the many participants in the process.

This wide array of responses demonstrates that *quality* has seemingly differing meanings, or certainly differing emphases, among those who are integral to highway designs. Most individuals perceive design quality on the basis of their needs and experience. Arguably, each of these divergent perspectives provides an element of the definition of design quality. Nevertheless, this diversity, in itself, illustrates the subjective character of quality. The variability in meaning of design quality prompts confusion, conflict, misalignment, and even mistrust among the many participants in the process. The vast complexities of the processes for designing, building, operating, and maintaining highways beg for a common definition.

Mary Devon O'Brien, in the foreword to *Quality Management for Projects and Programs*, a publication of the Project Management Institute, reflects on the challenge of defining quality:

> "In the products we buy, in the work we perform, and in the manner in which we live our lives, each of us has an image or an interpretation of what the word 'quality' means. These images and interpretations are shaped by national, cultural, religious, corporate, and family values and the

expectations that flow from those values. Varied as our expectations may be, a productive process, or way of doing something has 'quality' when it meets or satisfies those expectations, so it is not surprising that the definition of quality appears to be both simple and elusive."[x]

The definition of quality appears to be both simple and elusive.

O'Brien aptly points out that defining quality is difficult because everyone's views of quality are rooted in personal values and expectations. Because everyone's experiences, values, and expectations are unique, it is crucial to formulate widely accepted definitions to avoid confusion.

Consistent language and mutual understanding among all of the participants in the process are essential to routinely achieving design quality. A commonly held definition of quality is the basis for consistent language and a prerequisite to understanding.

Quality Defined

An examination of the field of quality management provides a strong foundation on which to build a definition specific to the highway design industry. At the heart of this discipline are various individuals and organizations whose works on quality have influenced many industries.

Because everyone's experiences, values, and expectations are unique, it is crucial to formulate widely accepted definitions to avoid confusion.

Quality Experts

The three most often cited experts on quality in the United States are W. Edwards Deming, Philip B. Crosby, and Joseph M. Juran. These authorities dedicated their careers to pursuing knowledge about quality and passing it on to others. Each of their approaches is founded upon the precept that customer satisfaction defines quality. They recognize that customers are both internal and external to organizations. While all three experts place an emphasis on customers, each defines quality somewhat differently.

Deming

Deming wrote extensively about the subjective nature and temporary characteristics of quality. He avoided suggesting that quality has a universal definition. He emphasized that each customer individually defines quality. In spite of Deming not specifically defining quality, one can infer that quality to him was a "way of life"—a constant pursuit of satisfying each customer's needs and expectations. Furthermore, he argued that quality is never fully realized. It is, at best, a temporary attribute. The forward march of competition, technological developments, efficiencies, cost reductions, materials improvements, and skills developments continuously challenge the durability of today's quality.

The temporary nature of quality led Deming also to define it by the integrity of the systems which produce the goods and services:

> "The difficulty in defining quality is to translate future needs of the user into measurable characteristics, so that a product can be designed and turned out to give satisfaction....This is not easy, and as soon as one feels fairly successful in the endeavor, he finds that the needs of the consumer have changed, competitors have moved in, there are new materials to work with, some better than the old ones, some worse; some cheaper than the old ones, some dearer."[xi]

The systems include all of the processes that are employed in designing and producing a product or service. The systems also include the translation of future needs of the user into characteristics that can be measured.

Crosby

In contrast to Deming's reluctance to define quality, Crosby is absolute in his definition. His maxim is that, "The definition of quality is conformance to requirements."[xii] He argues that if a product or service conforms to requirements then it satisfies the definition of quality. Thus, according to Crosby, quality is either present or it is absent. It does not occur in degrees or differing levels. He alleges that quality is built on getting everyone to do it correctly at the outset. Crosby coined the acronym DIRFT, emphasizing that the foundation of quality is "doing it right the first time."[xiii] Crosby also says that quality is "not goodness" and should not be evaluated on that basis. The essence of quality is to determine requirements and then to do only that work needed to conform to those requirements—no more or no less. As such, quality can be defined in clear and measurable terms.

Juran

Juran's definition of quality is "fitness for use."[xiv] He places a strong emphasis on products (including services) that meet the customers' needs and expectations. For Juran, quality reflects a balance between features, or technological properties, of products and products free from deficiencies.

Juran's definition suggests that quality can be more or less than conforming to prescribed requirements. The test is "fitness for use" when the product or service is used.

Organizational Approaches

During the last two decades there has been a growing recognition of the importance of emphasizing and examining quality. As industries pushed for greater productivity, organizations aided them in developing formal standards and programs for quality management. Within this context, these professional and trade organizations set about defining quality as guidelines for their constituents. Instrumental in this "quality movement," was the International Organization for Standardization which set the standard other organizations have followed.

ISO

The International Organization for Standardization (ISO) issued a series of quality management standards, the ISO 9000 series, beginning in 1987. The standards were created for manufacturing industries to foster competition in the global marketplace but have since been revised for application in other industries. ISO 9000 quickly gained international acceptance. The aerospace, electronics, engineering, and defense industries are a few of the industries that have adopted the standard.

ISO's definition of quality, as defined in *ISO 8402 Quality Vocabulary* which defines the terms used in the series, states that it is: "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs."[xv] ISO explains that quality is not meant to express excellence in a comparative sense or in quantitative evaluations for ranking.

Included in the explanation of their definition is a recognition of Crosby's and Juran's definitions of quality. According to ISO, "conformance to requirements" and "fitness for use" are "certain facets of quality [which require] fuller explanations."[xvi]

ISO also makes a distinction between *quality* and a term they call *grade*. They define grade as "an indicator of category or rank related to features or characteristics that cover different sets of needs for products and services intended for the same functional use."[xvii] A product or service can be of high quality but of a low grade, or, conversely, a low-quality item can be of a high grade. For example, Jaguar automobiles are graded as luxurious but judged as poor in quality because they require extraordinary repairs and maintenance.

Project Management Institute

The Project Management Institute (PMI) focuses on quality in the project environment. PMI adopted the ISO definition of quality while challenging both Crosby's and Juran's definitions. PMI states that: "In some industries, government agencies, and educational institutions, quality is described as 'fitness for use,' 'fitness for purpose,' 'customer satisfaction,' or 'conformance to requirements.'" They contend that "these terms are the goals of quality programs, not the definition of quality."[xviii]

American Society of Civil Engineers

From 1985 to 1988, the American Society of Civil Engineers (ASCE) engaged in a three-year process of developing a manual of guidelines and recommendations for achieving quality in constructed projects. A preliminary edition of the manual for trial use and comment was published in May 1988, entitled *Quality in the Constructed Project: A Guideline for Owners, Designers, and Constructors*. The trial use period was set for 18 months. Some of the manual's content is very controversial, and it has not been published in its final form. Although the manual has not been adopted into usage, it contains many worthy concepts, principles, procedures, and practices. ASCE addressed the definition of quality in the manual:

> "What is Quality? For the purposes of this manual, quality is defined as the totality of features, attributes, and characteristics of a facility, product, process, component, service, or workmanship that bear on its ability to satisfy a given need: fitness for purpose. It is usually referenced to and measured by the degree of conformance to a predetermined standard of performance. In simple terms, quality is meeting the requirements. The requirements may be simple or complex, or they may be stated in terms of the end result required or as a detailed description of what is to be done. But, however expressed, quality is obtained if the stated requirements are adequate, and if the completed project conforms to the requirements."[xix]

ASCE elaborated on ISO's definition of quality to relate it specifically to the civil engineering discipline. In addition, they incorporated Juran's and Crosby's definitions into their explanation of quality.

Defining Quality for Massachusetts Highway Projects

While "fitness for use" and "conformance to requirements," the definitions offered by Juran and Crosby, are very succinct and easy to remember, they only represent the end result of quality. PMI criticizes these terms as being the goals of quality rather than its definition. Also, Crosby's and Juran's definitions are too general to be directly useful in providing a common language for those involved in highway designs.

It is important to recognize, as Deming aptly pointed out, that quality (or lack thereof) is intrinsic to the systems that produce products or services. Quality is not adequately defined by measuring satisfaction with end-products.

Both ISO and ASCE have built on, and improved upon, the experts' definitions of quality. Their definitions are more precise characterizations of the exact nature of quality. Both organizations use the term *totality*. This word does not appear in the experts' definitions even though the concept of totality is clearly central to Deming's, Crosby's, and Juran's characterizations of quality. In addition, by the use of the word *facility*, ASCE relates their definition to the construction industry.

Based upon the quality experts' definitions, the work of the ISO and ASCE, and the particular needs of the highway industry, the appropriate definition of quality for highway design is: **the totality of characteristics and features of all preconstruction engineering processes, tasks, and deliverables that bear on satisfying stakeholders' needs**.

The **"totality of characteristics and features"** means the entirety, sum total, or aggregation of everything produced by the preconstruction work. For example, compliance with MassHighway's design standards could be considered a characteristic of the process of preparing plans and specifications and is one of the elements of totality. Metric dimensioning on plans is a feature of the deliverables and, as such, is an element of the totality. Trust-based interactions among the project staffs are characteristics of the project communication processes and are also segments of the totality. Each of these characteristics fulfills needs.

Highway design quality is the totality of characteristics and features of all preconstruction engineering processes, tasks, and deliverables that bear on satisfying stakeholders' needs.

"All preconstruction engineering processes, tasks, and deliverables" refers to all services provided and products produced from the very earliest notions of the project until construction begins, including reviews of construction contractor shop drawings, submittals, and construction field reviews by designers. Procuring design consultant services for project concept studies, securing right-of-way easements for site drainage, conducting a hydraulic analysis of a culvert, and estimating construction costs are examples of preconstruction processes, tasks, and deliverables. Although some highway projects may have only a few preconstruction processes, tasks, and deliverables, most projects have many or sometimes thousands. Quality depends upon all of these being done *right*, individually and collectively.

"That bear on satisfying stakeholders' needs." The goal of quality is to satisfy needs of those individuals or organizations who participate in a project or whose interests may be affected by it. These individuals/organizations are the project stakeholders. The aggregate of everything that is done to address their needs is the essence of quality.

Needs and Requirements

A major challenge when building any project, particularly a highway project, is to define and address stakeholders' needs specifically. Sometimes needs are explicit and very clear. Often, many needs are undefined and obscure, especially in the early stages of the project. As projects progress from visions to detailed plans, needs usually become better defined, clearer, and more complete. The "business" of quality is to manage each process, task, and deliverable to collectively fulfill needs.

Needs may be either stated or implied. Stated needs are expressed as mandates, desires, or aspirations. The need to provide a "25%" submittal of design documents is an example of a stated need. Implied needs are more elusive but, nevertheless, can be essential to achieving quality. For example, "fitness for use" is often implied. Another example of an implied need is the need for "creativity." Needs that are left in the state of a hope, wish, or desire, however, are at risk and may not receive sufficient attention to be fulfilled.

It is not possible or desirable to satisfy every need, stated *or* implied. Some needs may conflict. Furthermore, in some instances the benefits of fulfilling certain needs are outweighed by the perceived costs, time, resources, or effort needed to satisfy them. At times needs are unnecessary and tend to become distractions. For example, terms and conditions in contracts that are not truly relevant can consume resources and contribute to poor quality.

Quality is achieved by fulfilling those needs that are chosen as requirements for each project. Requirements are needs that the sponsoring organization (e.g., MassHighway) and the performing organization (e.g., design firm) mutually agree must be satisfied to achieve project success. These are the needs that must be fulfilled to provide quality. Unsatisfied needs are often those that have not been elevated to the status of requirements.

In highway design, state highway department standards are predetermined requirements. These requirements, in turn, usually reference and explicitly incorporate other requirements. The requirements of the Federal Highway Administration (FHWA) and the guidelines developed by the American Association of State Highway and Transportation Officials (AASHTO) are usually incorporated in the design requirements, by reference. Conformance (or non-conformance) of highway plans to AASHTO guidelines is a characteristic of design deliverables. As such, conformance to AASHTO guidelines is one element of quality.

Requirements are those needs that the sponsoring and performing organizations mutually agree must be satisfied to achieve project success.

Categories of Requirements in Projects

Although many requirements differ from project to project, virtually all project requirements can be classified, as follows:

- **Scope**. Requirements relating to deliverables and the work required to produce them.
- **Cost**. Requirements relating to financial matters (e.g., labor, overhead, fee, and expenses).
- **Time**. Requirements relating to timely completion.
- **Human Resources**. Requirements relating to staffing and effective use of people.
- **Communications**. Requirements relating to generating, recording, and transferring project information to others.
- **Procurement**. Requirements relating to acquiring services (and goods) for the project.

These categories provide a template for grouping similar types of needs when formulating requirements. The template also is used to see that every category is being addressed when setting requirements. Benefits are fully realized when the requirements in every category are satisfied. For projects of the same type (e.g., bridge replacements), requirements from project to project are often similar or even identical.

conclusionS

Individual experts and organizations have defined quality differently. A useful definition of quality, while having some generic tenets, must be tailored to the unique attributes and challenges of a particular discipline. For the purposes of the highway transportation industry, design quality is the totality of characteristics and features of all preconstruction engineering processes, tasks, and deliverables that bear on satisfying stakeholders' needs.

In order to achieve quality, the needs of everyone having interest in a given highway project must be defined explicitly and addressed. Not every need can be satisfied. Those needs that both the sponsoring and performing organizations agree must be satisfied are the requirements for quality.

CHAPTER 4

THE BENEFITS OF QUALITY

Benefits of Highway Design Quality

Highway design quality directly influences the quality of the highway system as a whole. It sets the stage for quality in construction, operations, and maintenance. The Steering Committee of the National Quality Initiative (NQI) cites design for its influence on the quality of the United States' transportation system. In their statement of National Policy on the Quality of Highways, they identify "proper design" as being characteristic of highway quality. The policy further states that "The Nation's highway network is an essential element of our transportation infrastructure and its quality is critical to America's economic growth and its ability to compete in the world marketplace."[xx]

Public Satisfaction

While the nation's economic growth is an important benefit of highway quality, the NQI Steering Committee, however, goes on to define the intent of the National Policy as "[fulfilling] the requirements of the highway user by providing a durable, smooth, safe, aesthetically pleasing, environmentally sensitive, efficient, and economical highway system…."[xxi] The public who pays for and uses highways is, therefore, the principal stakeholder having an interest in highway design quality. Their satisfaction with, and support of, the highway system and its individual components and appurtenances are the ultimate benefits of highway design quality.

According to two recent surveys of highway users released independently by the NQI Steering Committee[xxii] and by MassHighway[xxiii], drivers want safer and less congested roadway travel conditions. Some of the benefits that drivers expect are:

- Less congestion and fewer delays from construction work,
- Smoother, more stable pavement surfaces,
- Clearer signs and lane markings,
- Access ramps configured for safer speed changes.

Design quality sets the stage for satisfying drivers' needs. Some examples are:

- Thoughtful planning of construction sequencing during design sets the stage for managing traffic and reducing congestion.
- Appropriate selection and specifications of pavement materials and placement methods affect the strengths, durability, and smoothness of pavement surfaces.
- Appropriate designs of wording, size, materials, and colors on highway signage improve drivers' comprehension of the information and instructions provided.
- Appropriate designs of curvatures, slopes, sight distances, and transition lanes on ramps improve driver safety when accessing highways.

Who Else Benefits?

There are, additionally, many stakeholders of highway design quality who derive benefits not only as highway users but also as highway producers. These stakeholders are both internal and external to the sponsoring and performing organizations, including:

- **Sponsoring organization** (e.g., MassHighway, municipality).
- **Performing organization** (e.g., design firm, MassHighway).
- **Subconsultants** (e.g., geotechnical engineers, surveyors).
- **Constructors** (e.g., general contractors, subcontractors, vendors, suppliers).
- **Other government agencies** (e.g., environmental, utilities, law enforcement, public safety, mass transit).
- **Political leaders** (e.g., municipal, state, federal).
- **Financiers and insurers** (e.g., bankers, liability insurers).

Stakeholders in highway design projects have *supplier/customer* relationships with other stakeholders. The highway civil engineer is a customer of the land surveyor who supplies the engineer with topographic maps. These maps satisfy the engineer's need for elevations and other data in design. All *customer* stakeholders benefit from quality when their needs are satisfied by *suppliers*. Suppliers/customers are also referred to as performers/sponsors or providers/users.

Some examples of benefits to highway producers are:

- When design organizations provide quality by furnishing fully developed plans and specifications, sponsoring organizations benefit from more successful projects.

- When sponsoring organizations provide quality by carefully describing all of their needs to designers, design organizations benefit by having more complete information for creating solutions.
- When project managers provide quality by managing communications among stakeholders, all stakeholders benefit from more productive engagement of their people, budgets, and schedules.
- When stakeholders' organizations provide quality in administrative processes that are streamlined and effective, project design stakeholders benefit from having more time to concentrate on project needs and from requiring less time to negotiate administrative needs.

Benefits to Highway Stakeholders

Highway stakeholders realize many benefits from design quality. Benefits fall into several categories:

- End products, deliverables, or task management (i.e., scope);
- Cost management (i.e., cost);
- Time management (i.e., time);
- Staffing management (i.e., human resources);
- Communications management;
- Procurement management.

Some specific benefits in each category are:

Scope.

- Conformance of submittals to MassHighway's design manual.
- Reduction of rework.
- All services provided and deliverables produced within the requirements.
- Better potential for more competitive construction bids.

Cost.

- Lower design and construction costs for MassHighway.
- Reduction in the potential of cost overruns.
- Potential profit improvements for design consultants and constructors.

Time.

- Fewer schedule overruns.
- Less time lost to rework.
- More predictable time schedules.

Human Resources.

- Better use of people and their skills.
- More productivity and work satisfaction.
- Less adversity, conflict, and stress.

Communications.

- Better understandings, agreement, and commitment.
- Clearer and more complete documents throughout the process.
- More skillful use of media and tools for communicating.

Procurement.

- Better integration of design consultants with MassHighway.
- Better potential for consultants "doing it right the first time."

Benefits from Integrating Requirements

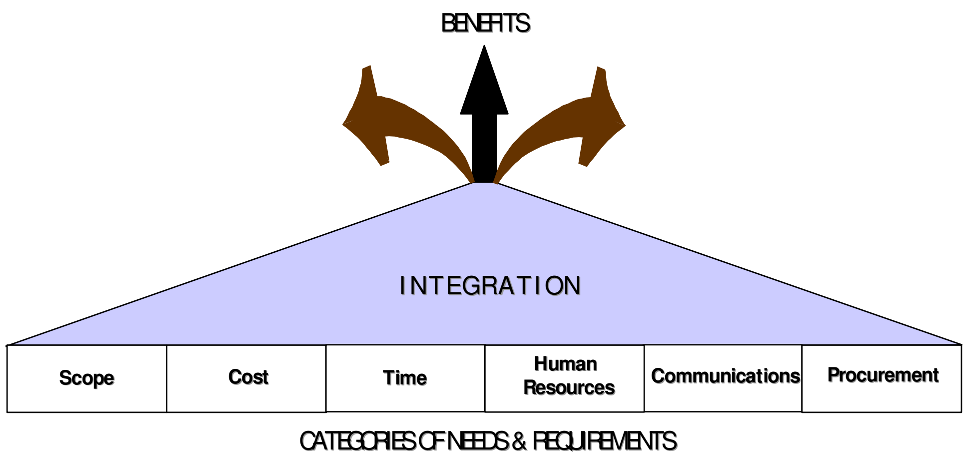
Every project requirement relates to other requirements. Project quality always depends upon successfully integrating solutions for the various requirements in different categories. Benefits result from successful integration. See Figure 4-1. For example:

- Success in producing satisfactory deliverables depends, in large part, upon success in staffing with people having suitable skills, motivation, and commitment.
- Success in timely deliveries depends upon success in procuring and coordinating the services of subconsultants.
- Successful communications favorably influence staff performance, costs, timeliness, deliverables, and procurement success.

Success in meeting any single requirement nearly always requires success in fulfilling other requirements. Likewise, failure in satisfying one category of requirements usually triggers failures in satisfying other categories. For example:

- Inappropriate staffing causes misaligned communication and poor task execution.
- Poor task execution affects overall productivity.

Figure 4-1: Benefits Result from Integrating Requirements



- Decreased productivity results in cost and schedule problems.

When requirements in one category are not being satisfied, then requirements in other categories are also at risk.

Quality Builds Momentum

The public's satisfaction with highways is built on the successive achievements of satisfaction among other stakeholders. For example, smooth and durable highway pavements result from progressive successes and benefits in sound pavement design research, precise design specifications, correct materials, and skillful batching, mixing, placement, and maintenance.

In project work, specifically in highway and other construction projects, quality in current activities promotes quality in succeeding activities. A quality 25% submittal promotes the expectation and achievement of a quality 75% submittal. Quality today begets more quality tomorrow.

As a quality highway design project progresses, quality accumulates, builds momentum, and becomes amplified. An important benefit of design quality is its potential to induce and amplify total project quality. Quality in the decision process of selecting the designer induces quality in project planning, organization, execution, and control. Quality plans and specifications induce the interest of constructors, suppliers, vendors, and subcontractors. In this sense, the results of quality are like the benefits of regular investments of money. By starting early and investing regularly, the benefits become compounded. Conversely, poor quality at the beginning of a project is like accumulating debt. The ramifications of poor quality are:

- Forsaking an early opportunity to realize quality.
- Impairing the potential to realize long-term benefits.

- Exponentially compounding small costs into potentially exorbitant expenses.

Potential to Influence Quality

All processes, tasks, and deliverables are not equal in their potential to influence quality. In general, decisions made early in projects have more influence on quality than those made later. For example:

All processes, tasks, and deliverables are not equal in their potential to influence quality. In general, decisions made early in projects have more influence on quality than those made later.

- The decision to acquire enough land to provide for eight travel lanes rather than four has more potential to influence the lasting satisfaction and quality of a roadway than the subsequent decision to build four lanes now rather than eight.
- The decision to reduce lane widths to accommodate an additional lane for turning has more potential to influence quality than the subsequent decision to mark the turning lane with painted arrows.
- The decision to install a signal system on an arterial roadway has more potential to influence quality than the decision to adjust signal timing during operations.

Twenty key project processes are listed below. They are ranked in order of their relative potential to influence quality, with the first having the most potential.

1. Determine needs (e.g., report of road improvement need).
2. Decide to proceed with project (e.g., MassHighway Project Review Committee action).
3. Evaluate areas of expertise to address needs (e.g., knowledge/qualifications).
4. Involve knowledgeable resources to evaluate needs (e.g., design consultant).
5. Evaluate needs for importance to project success.
6. Decide which needs are requirements (e.g., scope of work for design).
7. Plan and organize tasks and resources to satisfy requirements (e.g., design work plan).
8. Create solutions to satisfy requirements (e.g., 25% design submittal).
9. Measure satisfaction (e.g., 25% design review).
10. Reexamine and refine requirements (e.g., refine geometry following 25% submittal).
11. Accept that design meets requirements (e.g., review and acceptance of 25% submittal or 100% PS&E).
12. Involve constructor (i.e., constructor procurement).

The potential to influence project quality is much greater during design than in later phases of construction and facility operations.

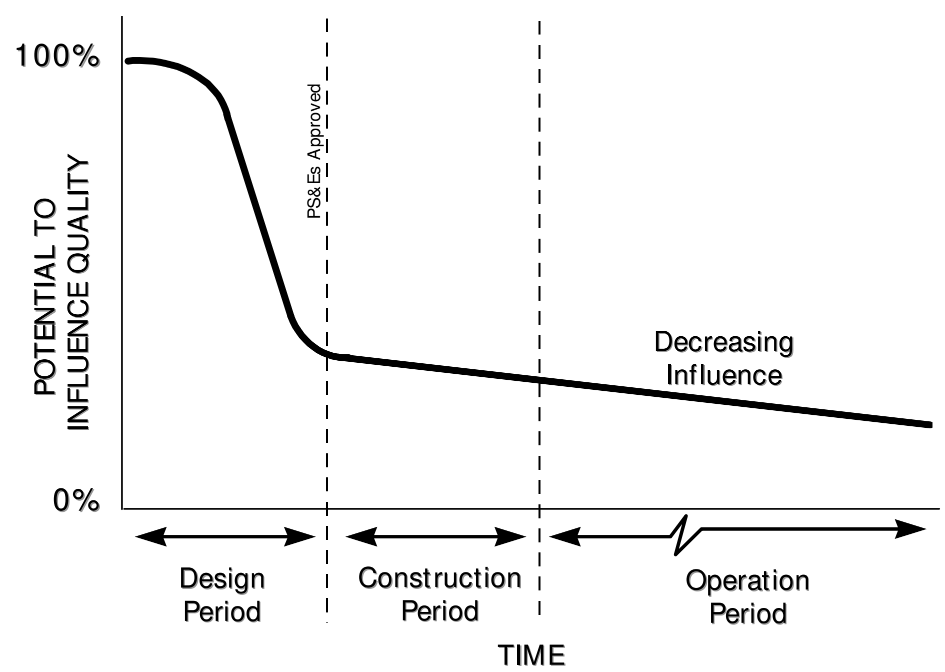
13. Plan and organize for construction (i.e., constructor work plan).
14. Confirm requirements (e.g., shop drawing submittals and reviews).
15. Manage and construct.
16. Measure satisfaction (e.g., field inspection).
17. Accept constructed facility.
18. Place facility into operation.
19. Maintain facility (e.g., replace worn signage, restripe lanes, patch pavement cracks).
20. Rehabilitate facility, as required (e.g., design and build bridge widening).

Steps 6, 7, 8, 9, 10, and 11 are repeated progressively for the 25%, 75%, and 100% submittals as more detail is incorporated into the solutions.

Figure 4-2 illustrates the decrease in potential to influence quality as a project progresses. As shown, the potential to influence quality not only decreases as the project progresses but is significantly reduced when PS&Es are approved at the end of the design period. Every design task potentially *adds* quality to the project but also *eliminates* one more opportunity to influence quality.

The potential to influence project quality (or non-quality) is much greater during design than in later phases of construction and facility operations. This does not mean, however, that design is more important than either

Figure 4-2: Decreasing Potential to Influence Quality[xxiv]



construction or operations. Quality during construction, startup, maintenance, and operations are all vital to satisfying needs. The principle of decreasing influence simply means that the potential to affect quality is much greater up through the completion of PS&Es than in subsequent activities.

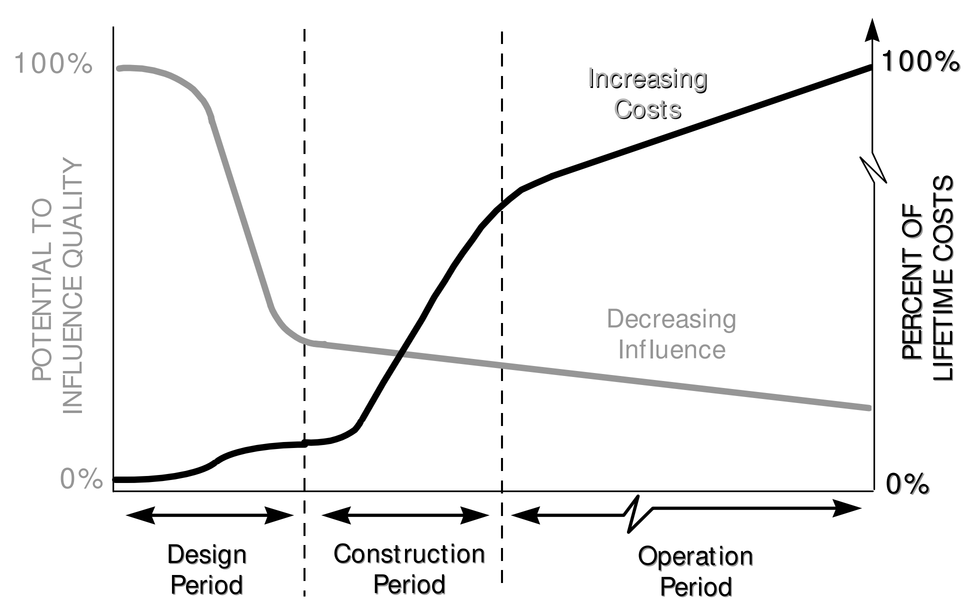
The lifetime costs of highway facilities accumulate slowest during design when the potential to influence quality is greatest. As shown in Figure 4-3, the lowest cost and the slowest rate of cost growth occur during design. Investments in design quality offer much greater potential to influence overall highway quality than any other cost component.

Conclusions

There are many benefits of highway design quality. The ultimate benefits of design quality accrue to highway users who expect benefits of durable, smooth, safe, aesthetically pleasing, environmentally sensitive, efficient, and economical highways. Constructors, suppliers, subconsultants, utilities, insurers, public officials, and especially MassHighway and design firms also derive benefits from design quality. The benefits to stakeholders are as varied and far-reaching as smoother and more durable pavements, to accurate and complete PS&Es, to more profitable design firms.

The most potential to influence quality occurs during design. Design quality has long-term effects on highway quality. Benefits of design quality accumulate and amplify. Early investments in design quality are compounded to produce more substantial overall project quality. Design

Figure 4-3: Increasing Cumulative Cost vs. Decreasing Opportunity to Influence Highway Quality



quality induces total project quality.

Quality on today's project creates the potential for even better quality for future projects. Individuals and organizations who have the pursuit of quality as their primary goal induce experiences, knowledge, and skills to continually raise their levels of performance on future work. Quality improvements are the result of applying today's learning experiences to tomorrow's needs and requirements.

CHAPTER 5

MEASURING QUALITY

Overall Measure

The most comprehensive measure of quality is the response to the question: "Have the design requirements in this project been satisfied?" Stakeholders' satisfaction is the benefit of quality. Quality is measured by gauging it.

Overall design quality for a highway project is ultimately measured by the collective satisfaction (or dissatisfaction) of:

- Traveling public;
- Sponsoring organization (e.g., MassHighway, municipality);
- Performing organization (e.g., design firm);
- Others (e.g., contractor, subcontractors, vendors, regulatory bodies).

Satisfaction is the benefit of quality.

Quality is measured by gauging satisfaction.

As discussed in Chapter 2, highway designs are not simply the domain of those who produce plans, specifications, and estimates. Highway designs are the products of the joint efforts of all who participate in establishing and fulfilling design requirements. Many stakeholders are involved in design.

Highway stakeholders perceive quality somewhat differently from one another. Stakeholders measure quality based upon the extent that projects satisfy their needs. The traveling public may be satisfied and pleased that a stretch of rehabilitated and realigned roadway is smoother, safer, more attractive, and pleasurable for driving. However, the construction contractor may be dissatisfied with the results because large quantities of rock were much more difficult and costly to remove than was implied by the contractor's bid. MassHighway officials and designers may be dissatisfied because the rock issue caused delays and extraordinary conflict with the contractor during construction.

Measuring Design Quality During Design

Throughout each phase of the design and especially at phase completions, one can measure whether requirements are being fulfilled. PMI has built upon the work of the quality experts and ISO to formulate quality measurements that are appropriate for managing highway design projects. These measures are published in PMI's *Guide to the Project*

Management Body of Knowledge. These measures should be employed to evaluate design quality in highway projects as they can be taken while design services are progressing. They provide timely means for taking economical remedial steps to improve design quality.

Cost Variances Measure Quality

CV is an indicator of quality because it measures the success (or failure) of integrating scope, cost, and schedule.

It also indicates of success (or failures) in managing staff, communications, and procurement.

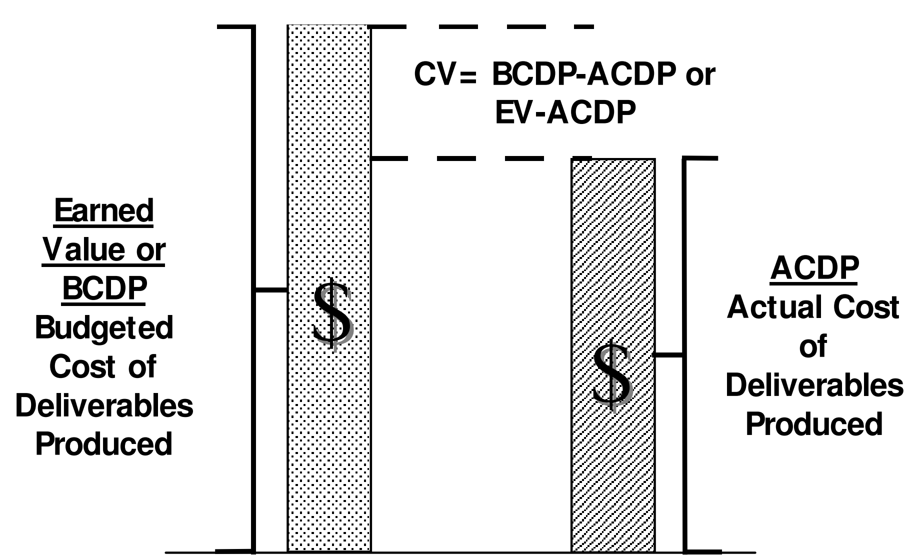
An important benefit of quality is the efficient use of resources (i.e., doing the right thing right, the first time). PMI has documented a measure for resource efficiency, which is calculated from deviations of actual costs from budgeted costs—usually called cost variance (CV). This concept is represented by the equation CV = BCDP - ACDP where cost variance equals the budgeted cost of deliverables produced minus the actual cost of deliverables produced.[xxv] BCDP also is known as earned value (EV) which represents the cumulative equity of the deliverables produced. Cost variance is the cost difference between the amount budgeted and the amount spent on an individual deliverable or a group of deliverables. See Figure 5-1.

CV is not only an indicator of resource efficiencies but also measures success or failure in integrating scope, cost, and schedule. Little or no CV for individual tasks (e.g., less than a few percent) normally indicates that processes, tasks, and their interfaces are being successfully managed and human resources, communications, and procurement are being administered effectively.

CV is not only a reliable indicator of resource efficiencies, but it is also a

powerful means of measuring success or failure of integrating scope, cost, and schedule. Little or no CV for individual tasks (e.g., less than a few percent) normally indicates that processes, tasks, and their interfaces are

Figure 5-1: Cost Variance (CV)



being successfully managed. It also indicates that human resources, communications, and procurement are being administered effectively.

CV is also a reliable measure of many characteristics of non-quality. Large CVs (e.g., double-digit percentages) indicate that at least one of the characteristics of quality is lacking. Some examples of the underlying causes of troublesome CVs are:

- Tasks are inconsistent with those planned and budgeted (scope management problem).
- Staffing costs are more or less than planned (wage cost problem).
- Tasks are out of the logical sequence (scheduling problem).
- Staff is making unsupported assumptions and causing rework (staffing problem).
- Project manager is not holding staff meetings for on-going exchanges of requests and information and the work is uncoordinated (communications problem).
- Subconsultant's products are not yet fit for use (procurement problem).

Major design cost underruns also may signal quality problems. For example:

Major design cost underruns may also signal quality problems.

- Maybe too little time is being spent because the solution being devised is not adequate to satisfy requirements (scope understated).
- Quality reviews may have been neglected (cost problem).
- Risky assumptions may have produced short-cut solutions (schedule problem).
- Staff is inexperienced (human resources problem).
- All requirements may not be fully understood by the team (communications problem).
- Costs measured may not include all of subconsultants' costs (procurement problem).

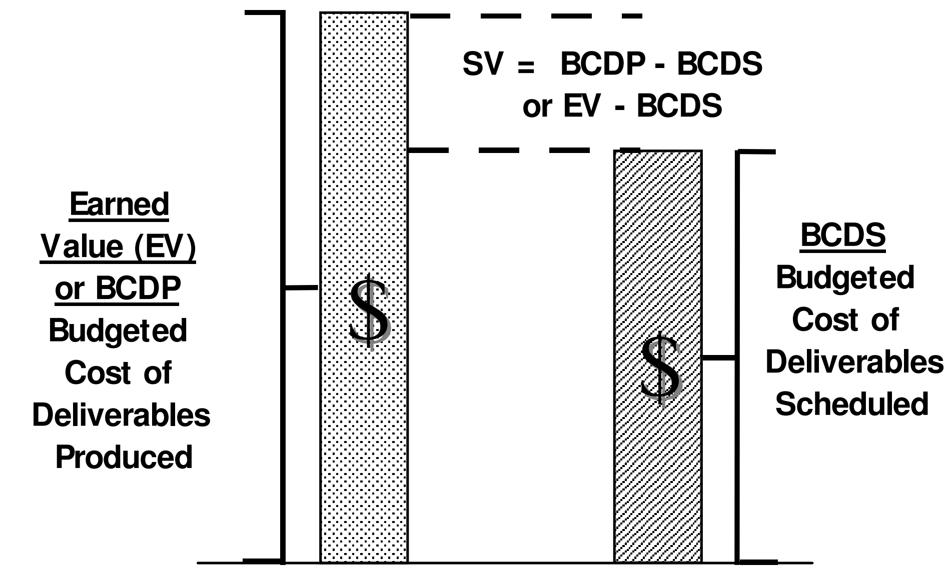
Schedule Variances Measure Quality

The commonly used measure of timeliness is schedule variance (SV).

Departures from planned schedules also indicate quality problems. The commonly used measure of timeliness is schedule variance (SV) which is the difference between the budgeted cost of deliverables produced and the budgeted cost of deliverables scheduled. It is represented by the equation: SV = BCDP - BCDS or SV = EV - BCDS. See Figure 5-2.

SV measures in units of cost (e.g., dollars) the difference between the budget for the deliverables produced (BCDP) and the budget for the deliverables scheduled to be done (BCDS) at a chosen date in the schedule. Thus, the SV (as of a chosen date) is the earned value minus the

Figure 5-2: Schedule Variance (SV)



value that was scheduled to have been earned (BCDS) by that date. A positive SV means more work has been completed than was scheduled by that date, whereas a negative SV means less work has been completed.

Earned Value Trends

Figure 5-3 shows trends of budgeted, actual, and scheduled costs. This example shows that the actual cost for all deliverables completed (ACDP) on the measurement date is less than either budgeted costs (BCDP) or scheduled costs (BCDS). This example also shows the increasing variances between budgeted and actual costs. It indicates that quality is accumulating. Curves showing earned value trends provide graphic indicators of the "well being" of a project.

Cost Performance Index

The cost performance index (CPI) is the ratio of the earned value (BCDP) to the actual cost (ACDP). When the CPI is greater than 1.0, it means that the deliverables completed have cost less than budgeted. When the CPI is less than 1.0, actual costs are exceeding budgeted costs. See Table 5-1.

Figure 5-3: Earned Value Trends

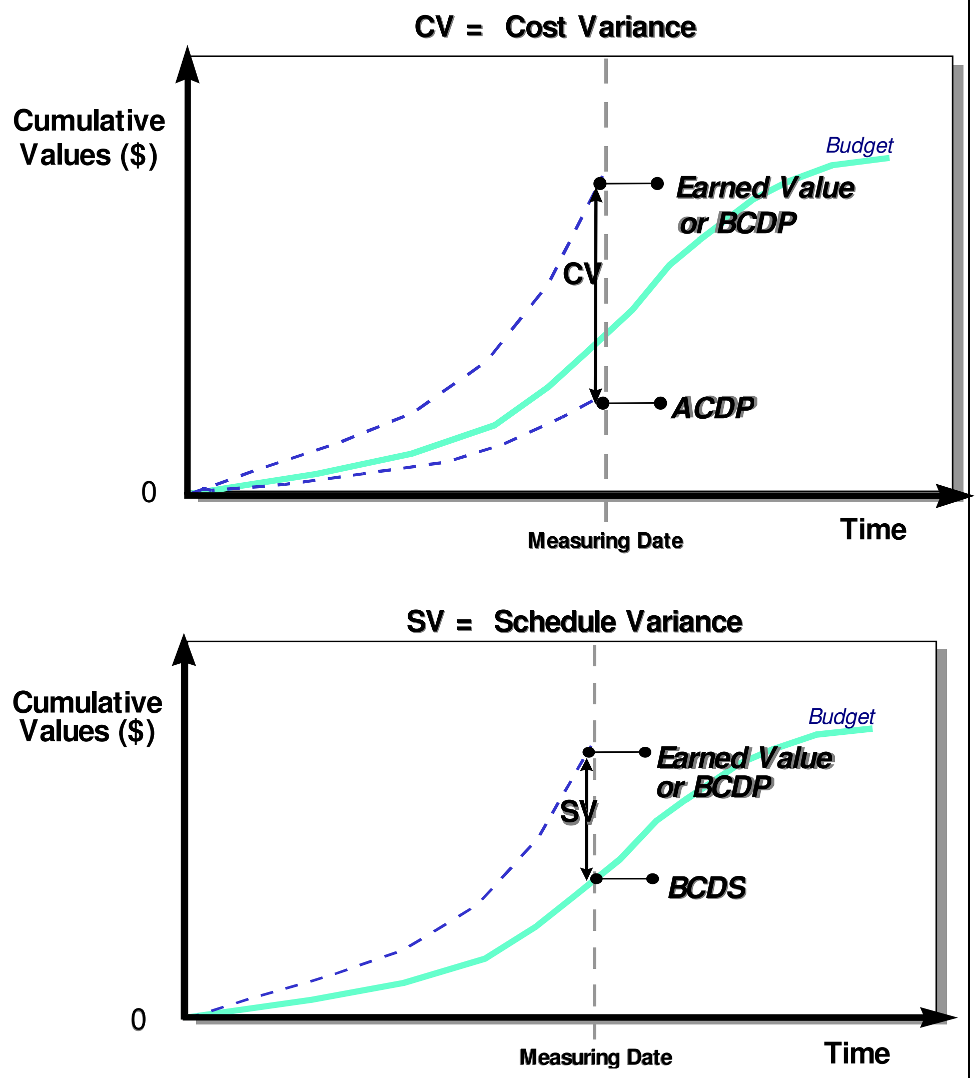


Table 5-1: Project Director's CPI Report

Project	Cost Variance	Schedule Variance	CPI	
Project A	$4,000	<$2,000>	1.20	**?**
Project B	<$3,000>	<$4,000>	0.75	
Project C	$1,300	$200	1.05	

The CPI is an effective measure for helping directors of project managers decide which projects need their attention.

The CPI is an effective measure for helping directors of project managers decide which project managers and projects need their attention. A project with a CPI significantly below 1.0, like Project B in Table 5-1, needs attention. Whereas, Project C with a CPI of 1.05 is probably OK.

Project A probably needs the director's attention. Its CPI of 1.20 may signal quality problems associated with major cost underruns. Examples of such quality problems are described above (see section "Cost Variances Measure Quality"). Project managers who have many projects with quality problems need the director's attention.

Schedule Performance Index

Schedule Performance Index (SPI) is the ratio of earned value (BCDP) to the value scheduled to a chosen date (BCDS). When SPI exceeds 1.0, it means that more deliverables have been produced than were scheduled. When SPI is less than 1.0, deliverable production is behind schedule.

Performance Reviews

Many state highway departments, including MassHighway, are using performance reviews to evaluate design quality. These review processes are discussed below.

MassHighway's Performance Evaluation System

MassHighway's existing system for measuring design quality, the Consultant Performance Evaluation system, was implemented in March 1998 through the Chief Engineer's formal policy directive No. E-98-001. It replaced a similar but less robust measuring process. The system is based on studies by a joint task force of ACEC/NE and MassHighway representatives and described in a report prepared by MassHighway's Architects & Engineers Review Board, entitled *Evaluating the Quality of Consultant Designs: A Plan for Improving the Highway Department's Current Evaluation System*. Copies of the Report and the Engineering Directive are included herein. See Appendix G.

The evaluation system is founded on the premise that stakeholders' satisfaction is a measure of quality. Stakeholders are represented by those engineers and scientists on MassHighway's staff who review consultants' submittals. The MassHighway engineer or scientist who is responsible for reviewing a submittal is also responsible for rating its quality. The disciplines represented in the reviewing and scoring submittals are: roadway, bridge, traffic, environmental, geotechnical, hydraulics, landscape, right-of-way, and project management.

The reviewers base their evaluations on their respective discipline's criteria with emphasis on characteristics of deliverables. For example, the environmental division rates the quality of the Environmental Impact Report. In other instances, reviewers rate the design process. The project manager rates the designer's performance at public hearings.

Reviewers score submittals on a scale of 0 (worst) to 10 (best). The project manager calculates a composite score for each submittal from all of the reviewers' scores. It is the sum of the products of each discipline's score multiplied by its predetermined weighting value. The project manager allocates weighted values at the beginning of the design by assigning values that represent the relative importance of each discipline's submittal to the entire design. For those projects negotiated by MassHighway, weighted values usually are based on the ratio of budgeted labor hours (for each discipline) to the total budgeted labor hours, with the exception that project management systematically is assigned 20% of the weighted value and all other disciplines share the remaining 80% proportional to their relative budgeted labor hours. For projects negotiated by others (i.e., municipalities), weighted values are based upon the project type. For example, a bridge project may be weighted in the following manner: bridge at 40%, project management at 20%, roadway at 20%, and all other disciplines at 20%.

The project manager is responsible for sharing the results of the performance evaluations with the consultant at each stage of the design. This allows consultants the opportunity to improve design quality during the project and understand how they are viewed by their client.

The near-term objective of this system is to improve the designer evaluation process by providing scoring feedback from each of the stakeholder disciplinary interests. Improved designer evaluations will provide MassHighway's A&E Review Board and its designer selection committees with more accurate information for selecting design consultants for each new project. The system provides information to the Board that is needed for coupling consultant selection more specifically to consultants' performance on recent MassHighway projects.

The long-term goal of the evaluation system is to improve design performance and reduce disciplinary design review time (e.g., reworking designs) and constructability problems (e.g., construction change orders). This system now in use by MassHighway for measuring design quality concentrates on evaluating fulfillment of scope-of-work requirements by measuring stakeholders' satisfaction with design deliverables. This system, used in conjunction with earned value analysis, would provide explicit measurements of scope, schedule, and cost performance.

Performance Reviews of Other States

Through our interviews with highway officials in other states, we learned that many highway departments conduct some form of design performance review. States differ in how, when, and for what purpose they use performance evaluations. Like MassHighway, some highway departments use reviews to evaluate and grade design consultant performance. The results of state performance reviews are employed as one criterion in ranking design firms for future procurements.

Some highway departments conduct performance evaluations periodically during the design process. These departments use the evaluation reviews to both rank design firm performance and to provide direction to the project team.

Some departments use standard criteria and explicit instructions, while others have less structured methods. The highly structured formats have standard rating criteria, such as:

- Knowledge of department needs,
- Cooperation,
- Adequacy of personnel,
- Creative work,
- Quality of work,
- Clarity of work,
- Completion within budget,
- Accurate billing,
- Overall quality,
- DBE compliance.

The person(s) performing the evaluation varies somewhat from state to state. In some states, project managers from the state highway department prepare evaluations without direct involvement of others. In these situations, their evaluations usually are reviewed by another (often the project manager's superior). In other states, the state project manager and the general contractor in construction (assumed to be the contractor's project manager) prepare design evaluations jointly. In one state, the state's project managers interview construction contractors and then separately interview design project managers before preparing design performance evaluations. These separate interviews replaced joint meetings because those meetings induced too much unproductive conflict among the parties.

Characteristics of Effective Review Processes

Effective review processes have some common elements:

- Design reviews are conducted frequently throughout design.
- Each review addresses project progress, status, direction, and next steps.
- Composition of the review team varies for each review depending on technical issues.
- Highway department's project manager and the design project manager lead all reviews.
- Emphasis is on jointly anticipating needs, remedial actions, prevention, and efficient means to satisfying requirements.

- Rating designer performance is an on-going by-product of project reviews, rather than a post mortem.

An important goal of a measuring system is to improve objectivity. All state DOTs that we interviewed, including MassHighway, conduct performance evaluations based on subjective judgment. Some states use standard arithmetic weightings to reach an overall grading of the design consultant's performance. However, these gradings are used to simplify the comparisons among consultants rather than as a mechanism for objectivity. Others use broader performance ratings (e.g., excellent, good, fair, poor). Using larger numbers of reviewers and increased frequencies of reviews improves the objectivity of the rating system. Alternatively, basing ratings on quantifiable measures reduces subjectivity.

Review Meetings

Many state highway departments are using performance review meetings to discuss the results of performance reviews and to address problems. Review meetings are vital to measuring and achieving design quality. There is no substitute for these person-to-person meetings to assess project progress and to reaffirm direction. To be effective, these meetings must be capably managed. According to PMI, performance reviews typically are used in conjunction with earned value analyses.

A very productive approach to getting to the heart of quality issues is to begin every performance review meeting by discussing the results of a current earned value analysis.

Review meeting agendas should concentrate on issues from the requirements categories to answer questions such as:

- What deliverables are complete?
- Is the staffing suitable?
- Do the documents completed conform to the Design Manual?
- Do the design solutions address the requirements in the contract scope?
- Have new needs been revealed?

Each performance review meeting could begin by discussing a current earned value analysis. Earned value analysis is the term used to describe the computations of CV, SV, CPI, and SPI. Earned value discussions are powerful tools for directing the performance review. They examine underlying causes for cost or schedule variances. These discussions set the stage for remedial actions. See the box on the following page and the example presented in Appendix B.

Project managers (and other people responsible for the projects) focus on quality when they are accountable for where money and time are spent. Frequent performance review meetings instill accountability. To avoid conflict in such meetings, people learn to become more productive between meetings. They sharpen their focus on understanding requirements and creating solutions. They find means for getting more done for less. They reduce rework.

Frequency of Measurements

How often should project progress be measured? Projects are produced in progressive steps of:

1. Determining needs and requirements,
2. Planning and organizing,
3. Managing and executing,
4. Measuring satisfaction.

These steps are repeated in each phase as the project progresses. These steps also are repeated for each task. In design work, tasks produce recorded information (e.g., documents). The measure of quality of each task is its products' "fitness for use" in subsequent tasks. For example, the suitability of load computations for use in a bridge footing design is a measure of the computation's quality. Their fitness for use can be determined by asking the questions, such as:

- Are the loads rational?
- Do they meet MassHighway standards?
- Is the math correct?
- Have the computations been checked in detail?
- Is the information appropriate and therefore satisfactory?

If the designer can answer each question affirmatively, then the load documentation is satisfactory. If not, then quality is impaired and rework is required.

Earned value analysis in its various forms is the most commonly used method of performance measurement.

EARNED VALUE ANALYSIS

Earned value analysis in its various forms is the most commonly used method of performance [vis-à-vis, quality] measurement. It integrates scope, cost, and schedule measures to help the project management team assess project performance. Earned value involves calculating three key values for each activity:

- The budget, also called the budgeted cost of [deliverables] scheduled (BCDS), is that portion of the approved cost estimate planned to be spent on the activity during a given period.
- The actual cost, also called the actual cost of [deliverables produced] (ACDP), is the total of direct and indirect costs incurred in accomplishing work on the activity during a given period.
- The earned value, also called the budgeted cost of [deliverables produced] (BCDP), is a percentage of the total budget equal to the percentage of the [deliverables] actually completed. Many earned value implementations use only a few percentages (e.g., 30 percent, 70 percent, 90 percent, 100 percent) to simplify data collection. Some earned value implementations use only 0 percent or 100 percent (done or not done) to help ensure objective measurement of performance.

These three values are used in combination to provide measures of whether or not work is being accomplished as planned. The most commonly used measures are the cost variance (CV = BCDP - ACDP), the schedule variance (SV = BCDP - BCDS), and the cost performance index (CPI = BCDP/ACDP). The cumulative CPI (the sum of all individual BCDPs divided by the sum of all individual ACDPs) is widely used to forecast project cost at completion. In some application areas, the schedule performance index (SPI = BCDP/BCDS) is used to forecast the project completion date.

From: Project Management Institute Standards Committee. (1996). *A Guide to the Project Management Body of Knowledge.* Upper Darby, PA: Project Management Institute, p. 108.

Frequent measurements of earned value provide the best assurances that quality is being managed. The reviews of 25%, 75%, and 100% submittals provide definitive points for measuring progress and quality. At these design milestones, one can take precise measurements of services performed and the associated budgets, actual costs, and schedules. However, additional measurements are needed when there is more risk. Large projects or projects with complex uncertainties require more frequent measurements. Small and uncomplicated projects require fewer measurements. A reasonable guideline is that earned value measurements be taken at least once each month on most design projects until the 100% PS&E submittal, every two weeks on larger projects, and weekly on very large projects.

Frequent measurements of earned value provide the best assurances that quality is being managed.

Measuring Design Quality During Construction

Constructors of highway projects, including general contractors, subcontractors, vendors, and material suppliers, gauge design quality by their satisfaction that the plans, specifications, and contract documents reliably represent the project and its risks. For example, they ask:

- Do the plans, specifications, and contract documents accurately and thoroughly represent the existing site, its features, and characteristics?
- Are the facilities to be constructed accurately and thoroughly represented in the plans and specifications?
- Do plans, specifications, and contract documents correspond to one another?
- Can the project be constructed as designed?
- Will responses to submittals be prompt?

They demonstrate their interpretations of risks in a project during bidding and construction through:

1. **Differences among bidders' prices (bid spreads)**. Differences in prices among bidders for a project may manifest differences in bidders' interpretations of risk.
2. **Office estimates**. Differences between contractors' bid prices and office estimates of construction costs may indicate differing interpretations of project risks. The quality of cost estimates, plans, specifications, and/or contract documents contribute to the magnitude of these differences.
3. **Construction extra work orders (EWOs)**. Owners authorize changes in construction requirements to address needs that were not resolved during design.
4. **Final quantities and costs**. The differences between estimated and constructed quantities and costs may be indicative of the quality of the designer's estimates.

Bid Spreads

There are many reasons why bidders quote prices that differ from one another. One reason is that they differ in their assessment of the risks associated with the project. Design documents significantly affect bidders' interpretations of risks. "Good" documents are interpreted as low risk. "Bad" documents are considered high risk.

Bidders express their opinions of risk in their price proposals. Price differences among proposals reflect these differing opinions. Small differences between bids indicate that bidders have comparable understandings of project requirements and the means for fulfilling those requirements. Small bid spreads indicate quality in plans, specifications, and contract documents.

Large variations among bids indicate that bidders perceive risks differently than one another. The cause for their differences is often rooted in unanswered design questions or unclear or conflicting information in the bid documents.

Highway cost data, submitted for this research by highway departments from 29 states, provide a basis for distinguishing between "small" and "large" bid spreads. Of 65 projects analyzed, the low bid price was, on average, 11% below the average of the higher bids. No project had a spread over 34% or less than 0.4% between the low bid and the average of the other bids. In 5% of the projects, the spread was less than 1.2%; in 10%, the spread was less than 3%; in 20%, it was less than 5%; in 30%, it was less than 5.8%; and in 50% of the projects, the bid spread was less than 9.6%. The median ratio of the standard deviation among bids to the low bid was 8.2% of the low bid price.

Differences in bid prices among bidders may manifest differences in bidders' interpretations of risk.

Standard deviation (STDEV) is commonly used to measure variations in a set of values. The ratio of STDEV to the low bid has been adopted as the measure of bid variation for this research. Referencing STDEV to the low bid allows measurement comparisons among projects.

Office Estimates

MassHighway prepares an office estimate of the project cost as one of the final steps in completing a design. The estimate provides a gauge for evaluating bids and a plan for managing project costs.

Differences between bids and estimates provide another indicator for evaluating design quality. Bids that are close to estimates indicate that bidders understand the design as the designer intended. Closely aligned bids and estimates indicate that the designer has successfully communicated the design to the bidders. Also, the designer has correctly estimated the resources required to construct the project in accord with the design.

At the other extreme, the estimate is most imperfect when *all* bids are significantly less than or greater than the estimate (e.g., more than a few percent difference). Either the design documents or the estimate are deficient. Significant differences between bids and estimates indicate that the designers and bidders do not agree on the construction requirements and/or uncertainties. This indicator means that the designer either does not understand the construction requirements or has not adequately communicated the requirements to the bidders. They may be disagreeing on tangible uncertainties, such as the quantities or the unit costs of some items of work. They also may be disagreeing on intangible risks, such as the potential of neighbors causing work stoppages. Nonetheless, the bidders' and designers' understandings of the construction requirements are not aligned with one another.

The estimate is less effective as an indicator of design quality when it falls in among several bids. This is especially true when the estimate is considerably higher than the two lowest bids but is less than the other bids.

The "perfect" estimate lies between the lowest bid and the second lowest bid. This indicates that the designer and two bidders mutually understand the construction requirements and the attending uncertainties. The difference between the estimated total cost and the mean of the two lower bids measures the extent of agreement between the estimator and the more competitive of the bidders.

The ratio of the office estimate to the low bid price was adopted as a measure of the quality of the office estimate for this research.

Construction Extra Work Orders

Actual construction conditions often differ in some respect from the conditions anticipated during design. For example, soils, buried utilities, weather, or the nature of materials can differ. It is usually impractical and sometimes impossible to develop designs that fully represent every condition that may arise during construction.

Project owners prepare for uncertainties in construction by budgeting contingent funds. These funds provide resources for addressing unexpected conditions during construction and financial allowances to acknowledge the imperfections inherent in economical design.

When properly managed, expenditures from contingency funding require explicit authorization by the owner or the owner's agent. MassHighway calls such authorizations construction extra work orders (EWOs).

> "A [construction extra work order] is a written order to the constructor signed by the owner and/or by his agent or representative, issued after execution of a contract, authorizing a change in the work or an adjustment in the contract sum or the contract time."[xxvi]

There are many underlying causes for EWOs. Some causes can be foreseen and should have been addressed in plans and specifications rather than by change orders. For example, new elevated lighting for a roadway intersection requires a power source. The design should identify and specify the source of power and the responsibilities of the construction contractor in cooperating with the electric utility to establish the power connections. This situation should be managed in the design—not during construction through extra work orders.

Some construction conditions, however, are not necessarily foreseeable during design. For example, soils sampling during design does not always reveal the presence of contaminated soils. It is impractical and uneconomical during design to sufficiently sample soils to assure that soils contamination is fully revealed. However, contaminated soils may be cause for an expensive construction change. Such a change is not necessarily caused by design oversight.

MassHighway currently analyzes extra work items to determine their causes. The analysis has two basic purposes:

1. Categorize the cause of the extra work order:
    - Design error or omission,
    - Unforeseen condition, or
    - MassHighway request for out of scope of work.
2. Obtain official approvals for changing the project requirements from:
    - MassHighway
    - Federal Highway Administration.

The conclusions of this analysis are reported by the project's resident engineer on MassHighway's Form 683, entitled "Resident Engineers Report of Changes in Design, Specifications or Preliminary Estimate Features." See Appendix H.

The information carried on Form 683 provides additional "data points" for evaluating design quality. When the cause for a change order is categorized as a design error or omission, design quality is judged adversely.

The cost of construction changes is a reasonable comparative measure for evaluating design quality when the cause for the change is a design error or omission.

Two measures of EWOs were adopted for this research. One is the ratio of the cost of design-related EWOs to the low bid. The other is the ratio of the total cost of all EWOs to the low bid.

Quantity Variations

Compensation to construction contractors is typically based, in part, on the quantities of items that the contractor furnishes and/or installs. The estimates of these items are provided in the documents furnished to each bidder. The contractor's compensation is determined by the actual quantities furnished and installed. The difference between the actual cost and the estimated cost is a measure of the quality of the estimates.

The ratio of the *absolute* sum of the cost variations for unit priced items to the total low bid price was adopted as the measure of the quality of the office estimate for this research.

Conclusions

The eventual measure of highway design quality is public satisfaction with the facilities constructed.

Measurements chosen for testing as indicators and predictors of design quality, include:

- Cost Performance Index (measures variations from design costs budgets).
- Schedule Performance Index (measures variations from design schedules).
- Consultant Performance Evaluation (measures sponsor's satisfaction).
- Bid Spreads (measures variations among construction bids).
- Office Estimates (measures variations between office estimates and bid prices).
- Construction Extra Work Orders (measures cost of extra work relative to bid price).
- Quantity Variations (measures variations between estimated and actual quantities).

CHAPTER 6

A MODEL FOR MEASURING QUALITY

introduction

This chapter presents a model for the measurements that were proposed in Chapter 5. The term *model*, as used here, refers to the entire system of processes that produce design quality measurements. It includes all management processes needed to measure design quality. The discussions in this chapter concentrate on project planning, cost and schedule measures during design, and measurements of various elements of costs during construction.

Governing Principles

The principles governing the development of this model are:

1. Design quality is *everything* prior to construction that bears on satisfying stakeholders' needs.
2. Everything that leads to (or detracts from) satisfying stakeholders' needs should be indicated by measurements.

The term *model* includes all management processes needed to measure design quality.

Premises

The underlying premises used in creating the model are:

- *Acceptable* deliverables produced on time and on budget indicate design quality.
- Design deficiencies are rooted in defects in project management processes, including: planning, organizing, executing, and measuring scopes, work products, schedules, costs, people, communications, and subconsulting.
- Cost and schedule variations usually indicate design quality variations. Both overruns and underruns may indicate departures from quality.
- Departures from quality may be proportional to cost and schedule variations.
- Accuracy improves with repeated measurements.
- An important purpose of measuring is to evaluate progress in achieving planned objectives and to remediate, as necessary.

Overview

The model has two basic components:

1. Measurements during design.
2. Measurements during construction.

Measurements taken during design are predictors of design quality. Measurements during construction are indicators of quality in design.

Indexing

The model expresses measurements by indexing which is a common method of distilling data to improve its intelligibility. Indexes are widely used in referencing and measuring trends of data. In the model, indexes have no units because they are the quotient of two values having the same unit (e.g., dollars divided by dollars).

Measuring During design

For measuring during design, the model includes both planning and indexing. Planning establishes baselines. Indexing compares results to baselines.

Planning establishes baselines. Indexing compares results to baselines.

Planning

Planning is an essential process in measuring design quality. Planning significantly affects the accuracy of measuring. Plans are expressions of stakeholders' needs and the means to satisfy them. They provide targets of expectations. Adequate planning produces baselines of expected deliverables, costs, and time durations. Conversely, inadequate planning sets the stage for disappointing results. Planning deficiencies produce imprecise baselines of expected results. Measurements reflect the quality of design planning together with the quality of design execution.

Characteristics of Plans

A plan is a program for accomplishing specific objectives. The elements of suitable programs for highway designs include descriptions of and commitments to:

- Stakeholders' needs,
- Deliverables required to fulfill those needs,
- Staffing needed to produce deliverables,
- Time schedules needed by staff,
- Budgets,
- Interrelationships of these elements.

The steps for producing a plan for highway design are:

1. Describe the overall purpose of the project.
2. Describe objectives (i.e., What must be achieved, preserved, or avoided to satisfy stakeholders' needs?).
3. Describe the scope of work, including deliverables, components, and tasks.
4. Describe the staffing skill levels needed.
5. Estimate the time required for each skill level and task/component/ deliverable.
6. Estimate time duration required to produce each component and deliverable.
7. Integrate scope, cost, and schedules.

Budget Baselines

Expending funds as budgeted is an indicator of quality. The term budget, as used herein, means an expenditure plan for defined purposes. Budgets provide the means for expressing value in common units (e.g., dollars). For the purposes of measuring design quality, budget baselines are expressions of planned values for a design and its individual deliverables.

MassHighway's design budget format is well-suited for measuring cost variances.

Budget baselines that are suitable for measuring cost variances have certain common characteristics:

1. Budgeted costs correspond to finite design deliverables and are based on resource usage. For example:

Design deliverable:	Computations for Cross Sections
Staffing needed:	Design Engineer
Budgeted labor:	4 hours
Salary rate:	$22.15/hour
Budgeted baseline:	$88.60 (in salary cost units)

2. Budgets are recorded in finite parts for use in measuring. For example:

Design deliverable:	Base Plans, Profiles, and Sections
Section:	204
Budgeted salary cost:	$337

3. Budgets are prepared electronically to permit convenient analyses.

MassHighway's current design budget format is well-suited for use in measuring cost variances. See Appendix C. These budgeting documents provide tabulations showing the basis of the design budget. Cost budgets are supported by and integrated with design deliverables, staffing requirements, labor hours, and unit costs. The budgeting package of spreadsheets tabulates the detailed tasks, corresponding staffing categories, and planned hours. Tasks and hours are summarized to major sections of work and labor hours. The data are readily available to compute a budgeted cost baseline for each task, division of work, and the design as a whole.

Schedule Baselines

Timeliness is an indicator of quality. The term schedule, as used here, means a plan for using time for defined purposes. A schedule baseline is an expression of the planned orderliness and duration of a design and its individual deliverables.

Schedule baselines that are suitable for measuring schedule variances have three common characteristics:

1. Design deliverables are ordered sequentially. Subordinate deliverables precede their parent deliverables. The schedule for the entire design project is ordered so that each deliverable builds upon its predecessors. Examples:
    - Bridge Type Study precedes Bridge Sketch Plan.
    - Bridge Sketch Plan precedes Public Hearing.
    - Detail Cost Estimates precede 75% Highway Submittal.
2. Schedules incorporate elapsed times for reviewing and reworking deliverables. For example: MassHighway's review of the 25% Highway Submittal has a scheduled duration of four weeks.
3. Schedules are integrated with budgets and scope.

Rigorously developed schedules provide precise baselines for measuring and improving design quality.

Currently, the schedules being produced by MassHighway's project planning processes are not adequate for use as baselines in measuring design schedule variances. Unlike the Department's budgeting requirements, the scheduling requirements are not sufficiently rigorous to produce design time schedules that correspond with tasks to be performed, deliverables to be produced, staffing needs, and cost budgets. To be suitable, baseline schedules need to incorporate these interdependencies. More rigorous scheduling requirements will provide more precise baselines for measuring and improving design quality.

Planning Software

The design planning system employed in the research, uses project planning software as the vehicle for integrating design deliverables and tasks with their ascribed resources, costs, durations, and interdependencies. Illustrations of the software's output are in Appendix D. Some advantages of using project planning software are:

- Schedules are more comprehensible. The software graphically illustrates the relationships and orderly progression of tasks and deliverables.
- The software keeps track of the planned attributes for each task and deliverable, including:
  - Durations and schedules,
  - Starting and finishing relationships to other tasks,
  - Knowledge disciplines,
  - Labor classifications,
  - Salary rates,
  - Staffing requirements,
  - Budgeted costs,
  - Milestones and "parent/child" deliverables.
- The software integrates tasks, deliverables, resource needs, costs, and schedules.
- Changes to individual tasks are extended to the entire plan.
- Each plan can serve as the starting template for a future plan. The work required to develop a plan for a particular type of project (e.g., "footprint" bridge) is an investment in reducing the work required to prepare plans for future projects of the same type.

A sound plan for design is the first step in accurately measuring and improving design quality.

A sound plan for design is the first step in accurately measuring and improving design quality. Project planning software vastly improves the integrity of the plan while sharply reducing the work needed to prepare it.

The documents in Appendix D, The Design Planning System, are products of Microsoft's project management software, Project 98. The data used to produce the planning model were derived from an actual project in MassHighway's "footprint" bridge program, a program to restore and rehabilitate the state's bridges.

Figure D-1 is a document generated from the model that contains baseline data for the scope, budget, and schedules for the design. This document provides:

1. Lists of:
   - Summary divisions of work (e.g., Hydraulics),
   - Design deliverables (e.g., Hydrologic Computations),
   - Submittals (e.g., Bridge Sketch Plans),
   - Tasks (e.g., Borings),

- Milestone events (e.g., PS&E Submission).

2. A baseline budget for each item, including "rolled-up" budgets.
3. Graphics showing:
    - The relationship between tasks, work components, deliverables, divisions of work, and milestones. The vertical lines linking items to one another indicate the relationships between them.
    - Planned schedules of individual items. The different types of horizontal bars indicate beginning, ending, and duration of each item.
    - The schedule overlaid on a calendar displays the duration, beginning, and ending of each item relative to the calendar.

Figure D-2 illustrates the schedule baseline, showing:

1. Durations assigned to tasks, deliverables, and divisions of work.
2. Scheduled start and finished dates.
3. Interdependencies among schedules.

Indexing During Design

Indexing is a common means for distilling data to improve intelligibility. Indices are widely used in referencing and measuring data trends.

The indexing system, presented here, produces three indices of design quality during the design phase:

- Cost Performance Index (CPI),
- Schedule Performance Index (SPI),
- Design Quality Index (DQI).

CPI and SPI were introduced in Chapter 5. These two indices are established measures of performance in the project management body of knowledge.

In our research, we found no measures that combine CPI and SPI to produce a single measure of quality. DQI is a derivative of these two established indices. We have developed DQI as a composite index for measuring the combined influences of cost and schedule variations. A full discussion of DQI is presented later in this chapter.

CPI and SPI

The CPI is the ratio of the planned value of completed deliverables to the actual cost of producing those deliverables. Value means the expected results expressed in dollars. In the language of project management, CPI is the ratio of earned value to the actual cost of deliverables produced where earned value is the baseline, or budgeted cost, of the deliverables. When the CPI equals 1.0, actual costs are precisely on budget; when the CPI is less than 1.0, actual costs are over budget; and when the CPI is greater than 1.0, actual costs are less than budgeted costs.

The SPI is the ratio of the earned value to the budgeted cost of deliverables scheduled, which is the baseline budgeted cost, or planned value, that was scheduled to the date of measuring. It is the ratio of the value received relative to the value expected as of the measuring date. When the SPI equals 1.0, the value earned to date equals the planned value to that date; when the SPI is less than 1.0, earned value is less than planned value; and when the SPI is greater than 1.0, earned value is greater than planned value.

As indices, CPI and SPI reveal more information about projects than simply the variances from baseline costs and schedules. CPI and SPI serve as indicators of the overall well-being of the project as it progresses. They indicate whether or not all elements of the design are working together toward fulfilling expectations.

CPI and SPI reveal more information about projects than simply the variances from baseline costs and schedules—they serve as indicators of the overall well-being of the project as it progresses.

For designs in progress, measuring CPI and SPI may indicate the presence or absence of design quality. In turn, that information provides opportunities to economically remediate quality problems before construction begins.

Computing CPI and SPI

Appendix E is an example from the design indexing system for computing CPI and SPI. The prototype uses data from an actual “footprint” bridge project.

Some data are simply carried forward from the design planning system. These data are in the columns headed:

- Scope of Work,
- Baseline Budget,
- Scheduled Finish.

The remaining data in the prototype are generated as the design work progresses by determining:

- Date (measuring date),
- ACDP (actual cost of deliverables produced),
- Percent Complete,
- Earned Value (BCDP),
- Baseline Schedule (BCDS).

The steps in the indexing process to determine these data are as follows:

1. **Date**. Decide an appropriate date for measuring. The various data need to be synchronized to the same date. A convenient method for selecting the date is to align the data with the monthly cut-off for payment voucher invoices.
2. **ACDP (Actual Cost of Deliverables Produced)**. Record the cumulative total actual costs to date. In the prototype, we have used the direct salary cost. Another option is to account for and measure the actual direct salary cost by each item in the scope of work.
3. **Percent Complete**. Determine the percent complete for each deliverable listed in the Scope of Work. Objectivity in estimating completion improves with:
   - Finite breakdowns of deliverables into subordinate deliverables (e.g., Hydrologic Computations as subordinate to Hydraulics Report). People are more objective in judging the completion of finite work products than in judging the completion of tasks or deliverables that have many subordinates.
   - Restricting expression of percent complete to 0%, 25%, 50%, 75%, and 100%—but no percentages in between. This rule helps to discourage the practice of slightly overstating progress of many deliverables to create the appearance of a greater overall progress.
4. **Earned Value (BCDP)**. Compute the earned value from the product of the baseline budget and the percent complete. This is a measure of "what you got for your money." Our example shows that $21,457 of value was received for actual costs of $29,240.
5. **Baseline Schedule (BCDS)**. Select this data as 1) the earned value when the measuring date precedes the scheduled finish, or 2) as the baseline budget when the measuring date is later than the scheduled finish.

The CPI is then computed by dividing the earned value (BCDP) by the actual cost of deliverables produced (ACDP):

CPI = (BCDP / ACDP).

In our example,

CPI = ($21,457 / $29,240) = 0.73.

The SPI is computed by dividing the earned value (BCDP) by the baseline schedule (BCDS):

SPI = (BCDP / BCDS).

In the example,

SPI = ($21,457 / $31,243) = 0.69.

Interpreting CPI and SPI

In using indices, the challenge is to appropriately interpret their values. In measuring CPI and SPI, what are their meanings to design quality? As mentioned previously, CPIs and SPIs at 1.0 indicate that the design is right on target for the time and money spent to date. In tandem with proper project reviews, this indicates that quality is probably being achieved.

When CPI or SPI vary significantly from 1.0, what is the meaning? When either of these indices is less than 1.0, design accomplishments are lagging behind baseline expectations. The requirements for satisfying stakeholders' needs are not being fulfilled. Design quality is faltering. When CPI and/or SPI exceed 1.0, design quality also may be at risk. Less time and/or effort is being expended than expected. Although there are many possible causes, a common source of underruns is short cutting the expected scope of work. We theorize that impairment in quality is proportional to the variation of CPI and SPI from 1.0. For example, when CPI and SPI are each 0.80, then the quality is "twice" as impaired as when the indices are 0.90.

We also theorize that the meanings of the values will vary from one type of project to another. Some types of projects are inherently riskier than other types. For example, a project to rehabilitate a bridge in the same footprint as an existing bridge poses fewer uncertainties and risks than a project to develop a new highway (e.g., land takings or environmental issues).

When CPI or SPI vary significantly from 1.0, design quality may be faltering.

The meanings of the various values of the indices will become clearer with usage. CPI and SPI variations correlate well with quality issues in the design of the "footprint" bridge used in the prototype model.

Introducing DQI

Variations in CPI and SPI on either side of 1.0 indicate departures from quality. We theorize that combining these indices into a single index will provide a more explicit measure of quality than each one interpreted individually. We are calling this composite index the *Design Quality Index* (DQI). This index provides a measure of the mean of the *absolute* differences of CPI and SPI from 1.0. For ease in interpretation, we propose that the convention for this index be 1.0 minus this value. Thus, the DQI is computed as 1.0 minus the mean of the absolute differences between CPI and 1.0 and SPI and 1.0:

$$DQI = 1.00 - (|1.00 - CPI| + |1.00 - SPI|) / 2.$$

In calculating DQI, when the value of CPI (or SPI) is less than 1.0, subtract that value from 1.0. When it is greater than 1.0, subtract 1.0 from the CPI (or SPI). The result is the "absolute" variation from 1.0. For example, if CPI = 0.83 and SPI = 1.09, then the mean absolute difference is 1.0 minus 0.83 *plus* 1.09 minus 1.0, all divided by 2 for a result of 0.13. The DQI is 1.0 minus 0.13, which equals 0.87.

In our example the mathematical expression is:

$$DQI = 1.00 - (|1.00 - CPI| + |1.00 - SPI|) / 2$$

$$= 1.00 - (|1.00 - 0.83| + |1.00 - 1.09|) /2$$

$$= 1.00 - (0.17+ 0.09) / 2$$

$$= 1.00 - 0.13$$

$$= 0.87$$

The theory of DQI is that the smaller the value of DQI, the further design quality has departed from expectations. For example, if the DQI equals 0.95, design quality should be nearly meeting expectations; whereas, if DQI equals 0.75, design quality is faltering and the project needs attention.

Frequency of Indexing

The Design Quality Index (DQI) is a composite of the CPI and the SPI.

We recommend that indices be computed at least once each month throughout the design of each highway project from inception to submission of acceptable PS&Es. More frequent indexing may be valuable during the first 35% of each design and throughout the design of larger projects. On most projects, indexing concurrent with preparing payment vouchers appears to be timely and efficient.

Indexing Tools for Use During Design

Spreadsheets provide convenient tools for indexing. This software is readily available in the marketplace at reasonable cost.

Appendix F, *The Indexing System,* is a product of Microsoft Excel. The prototype's input data was derived from the same "footprint" bridge project referenced earlier in this chapter.

Each table, except the first, in the appendix provides indexing computations for one payment voucher cycle. The data in those columns entitled Scope of Work, Baseline Budget, and Scheduled Finish are from the design planning system. The data for Date and ACDP (upper right corner) are input from the Payment Voucher (PV). The Date is the most recent date of labor charges to design, usually the last day of the PV cycle. ACDP is the direct salary cost from the Total-to-Date column of the PV's *Invoice Summary* form.

Data for Percent Complete is provided by the design project manager from reviews of the design status. Earned Value is the product of the Baseline Budget multiplied by the Percent Complete. Percent Complete is the most subjective data element in the indexing system. Care in developing the design plan and rigor in evaluating the status of work will improve accuracy.

The first page in Appendix F is a summary of the indexes. This table also shows the index averages for the entire design period. Correlations between the index values and quality issues will be discussed in Chapter 7.

Consultant Performance Evaluation

MassHighway's Consultant Performance Evaluation is incorporated in the model as an indicator of sponsor satisfaction and a predictor of eventual design quality. This measure of design quality is the result of consolidating assessments of many discreetly identified deliverables.

In its existing form, the rating scale of the Consultant Performance Evaluation is zero (worst) to ten (best). For the consistency of indexing measurements, we have adopted a rating scale of zero (worst) to 1.0 (best), called the *Consultant Performance Evaluation Index (CPEI).* Consequently, CPEI is computed simply as one-tenth of the individual and or composite scores from the existing evaluation process.

Measuring During Construction

The design quality model measures five variables during construction:

- Variations among construction bids (bid spreads).
- Differences between office estimates and bids.
- Total cost of construction extra work orders.
- Cost of design-related construction extra work orders.
- Cost variations in construction quantities.

The index for each of these variables is computed as its ratio to the lowest bid price to compare the indexes among different projects. These five indexes are indicators of design quality.

Bid Spreads

The index for measuring variations in bid prices is computed as the ratio of the standard deviation of the bid prices to the lowest bid price. We have named this measure *Bid Variation Index* (BVI):

BVI = [1.0 – (STDEV of bids / low bid)].

Office Estimates

The index for measuring the difference between an office estimate and the low bid is computed as the ratio of the office estimate to the low bid. We have named this measure *Office Estimate Index* (OEI):

OEI = [1. 0 – (absolute difference of OE and low bid) / (low bid)]

Construction Extra Work Orders

The index for measuring construction extra work orders is computed as the ratio of the total cost of construction extra work orders to the low bid price. We have named this measure *Extra Work Index* (EWI):

EWI = [1.0 – (total $ extra work orders / low bid price)].

Design-Related Construction Extra Work Orders

The index for measuring design-related extra work orders is computed as the ratio of the cost of design-related construction extra work orders to the low bid price. We have named this measure *Design-Related Extra Work Index* (D-REWI):

D-REWI = [1.0 – (design-related extra work $ / low bid price)].

Variations in Construction Quantities

The index for measuring variations in construction quantities is measured as the ratio of the total of the absolute differences between bids and actual costs for the sum of all unit-priced construction items to the low bid price. We have named this measure *Quantity Estimate Index* (QEI):

QEI = [1.0 – (total absolute variation in quantities $ / low bid price)].

Conclusions

An effective model for measuring design quality includes all management processes needed to measure quality accurately. The model that we propose for measuring design quality while design is in progress has two integral components—a planning system and an indexing system. Planning establishes baselines for measuring. Indexing compares results to baselines.

Scope of work, budget, and schedule are the baselines produced by planning. The planning system uses project planning software to integrate schedules with the scope of work and costs and to reflect the interdependencies among deliverables and time.

Indexing is a common means for improving the intelligibility of data. The model includes nine indexes, four as predictors to be measured during design and five as indicators to be measured during construction.

The indexes to be measured during design include:

1. Cost Performance Index (CPI) that measures variations from design budgets.
2. Schedule Performance Index (SPI) that measures variations from design schedules.
3. Design Quality Index (DQI) that measures a composite of CPI and SPI.
4. Consultant Performance Evaluation Index (CPEI) that measures MassHighway's satisfaction with the design. CPEI is an indicator of the sponsoring organization's satisfaction and a predictor of eventual design quality.

Indexes to be measured during construction include:

1. Bid Variation Index (BVI) that measures variations among construction bids.
2. Office Estimate Index (OEI) that measures variations of bids from estimates.
3. Extra Work Index (EWI) that measures total cost of construction extra work.
4. Design-related Extra Work Index (D-REWI) that measures the cost of construction extra work related to design deficiencies.
5. Quantity Estimate Index (QEI) that measures variations from construction quantity estimates.

CHAPTER 7

MODEL TESTING

types of tests

The model tests were conducted using three types of tests:

1. One type measured variations in costs and schedules consumed in producing designs. The theory in this measure is that design quality results from effectively planning and executing design services. Cost and schedule variations are measures of effectiveness. These tests were conducted in search of predictors of design quality.
2. The second type of test measured stakeholders' satisfaction with the design services and the characteristics of the design deliverables. These tests were based upon MassHighway's "Consultant Performance Evaluation." These tests were conducted in search of indicators of sponsors' acceptance and predictors of stakeholders' satisfaction.
3. The third type of test measured variations in costs relating to the construction phase of each project. The costs measured included office estimates, bids, total construction, quantities, and extra work orders. These tests were conducted in search of indicators of design quality.

projects tested

Six "footprint" bridge projects were used in testing the model. The term "footprint" is used to connote that a new or rehabilitated bridge is to be constructed in the same area as an existing bridge.

Six "footprint" bridge projects were used in testing the model.

All six projects had more in common than usual for constructed projects:

- Each of these bridges had been complete and was in service when the model was tested. Measurements of costs and times are based on actual results.
- The compensation for design for each project was subject to a maximum hourly rate and a maximum overhead rate. There were no "lump-sum" projects among the six. The compensation for design was based on cost plus a fixed fee to an upper limiting cost. Design budgets and schedules were developed using the same codified breakdown of tasks, deliverables, and labor classifications from project to project.

- The processes for designing each bridge were similar and the standards for the design of all six projects were the same. The design milestones were the same from project to project and deliverables were prescribed by the same standards.
- The construction bids and payments used identical descriptions of payment items and limits of payments for all six projects, as applicable to each.
- Contract terms for both design and construction were virtually the same for every project.

There were some distinguishing characteristics among the bridges:

- Some were larger and more costly to build than others. Construction costs ranged from $268,000 to $756,000.
- Different personnel designed, administered, and constructed each project except two which were served by the same MassHighway expediter.
- Four of the bridges are over waterways and two are over rails.

In spite of some differences, the similarities among the bridges provided more comparability for data analyses than one could normally expect among construction projects.

In this report, the projects tested are referenced by the names: Alpha, Beta, Epsilon, Lambda, Omega, and Sigma.

HYPOTHESES AND FINDINGS

The underlying hypotheses, test results, and findings for each of the model's indexes are discussed in this section. The general order of discussing the indexes is by predictors that are measured during design (CPI, SPI, CPEI, and DQI), followed by the indicators that are measured during construction (OEI, EWI, D-REWI, and QEI). Even though BVI is one of the indicator indexes, it is discussed first because we have concluded that BVI is the most reliable single measure of design quality. We have used the BVI findings in evaluating the reliability of the other indexes. The reasons for our high rating of BVI are explained below in the next section.

Variations in Construction Bid Prices

During a focus group session conducted with construction contractors, they said that their bid prices include contingent amounts to protect them against uncertainties or perceived risks in projects. Further, they indicated that the quality of plans, specifications, and contract documents heavily influence their perceptions of risks. They ascribe lower risk to projects having documents with clear and complete information and, thus, bid more competitively for those projects. Conversely, they bid less competitively for projects having greater risks, resulting in a wider variation among the bid prices. Clarity, thoroughness, and consistency of plans, specifications, and contract documents are major factors in the competitiveness among bids.

Small variations among construction bids demonstrate that bidders mutually understand the meaning of the plans, specifications, and contract documents.

The cause for large variations in bids often is rooted in shortcomings in plans, specifications, and contract documents.

Hypothesis: Bid Variations Are a Measure of Quality

Small variations among construction bids demonstrate that bidders mutually understand the meaning of the plans, specifications, and contract documents. As such, small variations indicate that the designer has successfully satisfied the bidders' needs to understand the project requirements. Large variations in bidders' prices *probably* demonstrate that contractors do not mutually understand project requirements. The cause for large variations in bids often is rooted in shortcomings in plans, specifications, and contract documents.

Test Findings

Variations among bids for each project were measured by standard deviation (STDEV). Comparisons among projects were measured by expressing the STDEV for each project as a percentage of the lowest bid price for that project. The percentage measurement provides a method for leveling the cost differences among the projects. The results of this measurement are tabulated in Table 7-1.

Project Epsilon had the smallest variation in bids (8.2%) and project Omega had the largest (32.9%). As such, by this measure, Epsilon ranks highest for design quality and project Omega ranks lowest. Expressed in another way, the bidders for Epsilon might be thought of as 91.8% (100% - 8.2%) in agreement with one other regarding the costs represented by the documents, whereas, bidders for Omega were only 67.1% in agreement. The rankings by BVI are tabulated and charted in Table 7-2.

Table 7-1: Bid Variations

Project	STDEV	Low Bid	STDEV as % of Low Bid
Alpha	$ 40,002	$342,930	11.7%
Beta	$ 52,635	$307,554	17.1%
Epsilon	$ 58,968	$717,756	8.2%
Lambda	$ 77,693	$761,096	10.2%
Omega	$168,022	$510,039	32.9%
Sigma	$ 32,688	$244,582	13.4%

Table 7-2: Ranking by BVI

Project	BVI
Epsilon	0.918
Lambda	0.898
Alpha	0.883
Sigma	0.866
Beta	0.829
Omega	0.671

Objectivity, Accuracy, and Reliability

The extent to which construction bidders' prices align or vary from one another is an objective, accurate, and reliable indicator of design quality.

Variations among bidders' prices are reliable indicators of design quality. The competitive marketplace for construction demands that bidders seek the least costly means of constructing in accord with their understanding of the projects' requirements. On the other hand, the unforgiving characteristics of business economics demand that bids provide for contingent risks. Plans, specifications, and contract documents are generally the most significant factors that influence bidders' perceptions of contingent risks. The extent to which construction bidders' prices align or vary from one another is an objective, accurate, and reliable indicator of design quality. For these reasons, we consider BVI to be the most comprehensive single indicator of design quality.

Variations in Design Costs

If variations in construction bids are indicators of design quality, do variations in the cost of design serve as precursors of bid variations and, therefore, predict design quality?

Hypothesis: Variations in Design Costs Are a Measure of Design Quality

Variations in design costs from design cost budgets predict variations in construction bids.

Test Findings

Variations in design costs were measured by the Cost Performance Index (CPI). CPI measures the relationship between budgeted and actual costs and is computed as the ratio of the budget to the actual cost of producing design deliverables. Three sets of CPIs were computed for each project, including:

- The average CPI at the closing date of each payment voucher period.
- The median CPI at the closing date of each payment voucher period.

- CPI at 25%, 50%, 75%, and 100% complete.

The results of these tests, ranked by BVI, are tabulated in Table 7-3.

Although PMI considers CPI to be an indicator of project performance, the model testing did not confirm that design cost variations are measures of highway design quality.

Measurements of CPI do not correlate with measurements of bid spreads. Omega ranked very poorly by BVI but very well by CPI measures. Sigma was average with regard to BVI but was very good to excellent in CPI measures. Project Lambda was highly ranked by BVI but ranked low on the CPI scale.

Although PMI considers CPI to be an indicator of project performance, the model testing did not confirm that design cost variations are measures of highway design quality. Additional testing may validate CPI as a measure of design quality. Our conclusions from this research, however, do not support this hypothesis.

Variations in Design Schedules

If design cost variations are not reliable predictors of bid spreads, are variations from design schedules precursors of bid variations and, therefore, predictors of design quality?

Hypothesis: Variations in Design Schedules Are a Measure of Design Quality

Design schedule variations are predictors of variations in bids and quality. Close alignment between scheduled and actual production of interim and final design deliverables predict design quality. Large deviations from schedules predict large bid variations and design shortcomings.

Table 7-3: CPI versus BVI

Project	BVI	CPI at 25%	CPI at 50%	CPI at 75%	CPI at 100%	Average CPI Per PV	Median CPI Per PV
Epsilon	0.918	0.82	0.99	1.16	0.92	0.97	1.02
Lambda	0.898	0.70	0.66	0.68	0.89	0.84	0.72
Alpha	0.883	0.70	0.75	0.80	0.93	0.79	0.81
Sigma	0.866	0.99	1.16	0.94	0.80	1.02	0.96
Beta	0.829	0.76	0.84	0.90	0.78	0.85	0.86
Omega	0.671	0.73	0.85	1.02	1.10	0.94	0.96

Test Findings

Variations in design schedules were measured by the Schedule Performance Index (SPI). SPI is computed as the ratio of the Budget of Deliverables Produced to the Budget of Deliverables Scheduled. When SPI is 1.0, deliverables are on schedule; less than 1.0, behind schedule; and greater than 1.0, ahead of schedule.

Two sets of SPIs were computed for each project, including:

- The average and median SPI on the closing date of each payment voucher period.
- SPI at 25%, 50%, 75%, and 100% complete.

The results of these tests as compared to BVI are tabulated in Table 7-4.

The ranking order for the projects by SPI at 25% and by the Median 25-50-75 SPIs align well with the order by Bid Spreads. Except for project Epsilon, all projects fall into the same order for each of these three measures.

The ranking by the Median SPI Per Pay Voucher compares especially well with the BVI. First-ranked Epsilon, second-ranked Lambda, fifth-ranked Beta, and sixth-ranked Omega hold the same positions for both measures. The only differences among the rankings are that the middle-ranking positions, third and fourth, are reversed. Alpha is ranked third by BVI and fourth by the median SPI measurement, and Sigma moves from fourth to third. The differences between BVI and the SPI median measurements for these two projects are insignificant. As a practical matter, the measurements show the same results for both Alpha and Sigma.

Table 7-4: SPI versus BVI

Project	BVI	SPI at 25%	SPI at 50%	SPI at 75%	Median SPI 25-50-75	Average SPI Per Pay Voucher	Median SPI Per Pay Voucher
Epsilon	0.918	0.75	0.53	0.75	0.75	0.86	0.95
Lambda	0.898	0.91	1.08	0.75	0.91	0.91	0.87
Alpha	0.883	0.71	0.77	0.77	0.80	0.80	0.80
Sigma	0.866	0.66	0.95	0.76	0.76	0.83	0.84
Beta	0.829	0.52	0.65	0.75	0.65	0.78	0.79

Omega	0.671	0.24	0.50	0.75	0.50	0.80	0.60

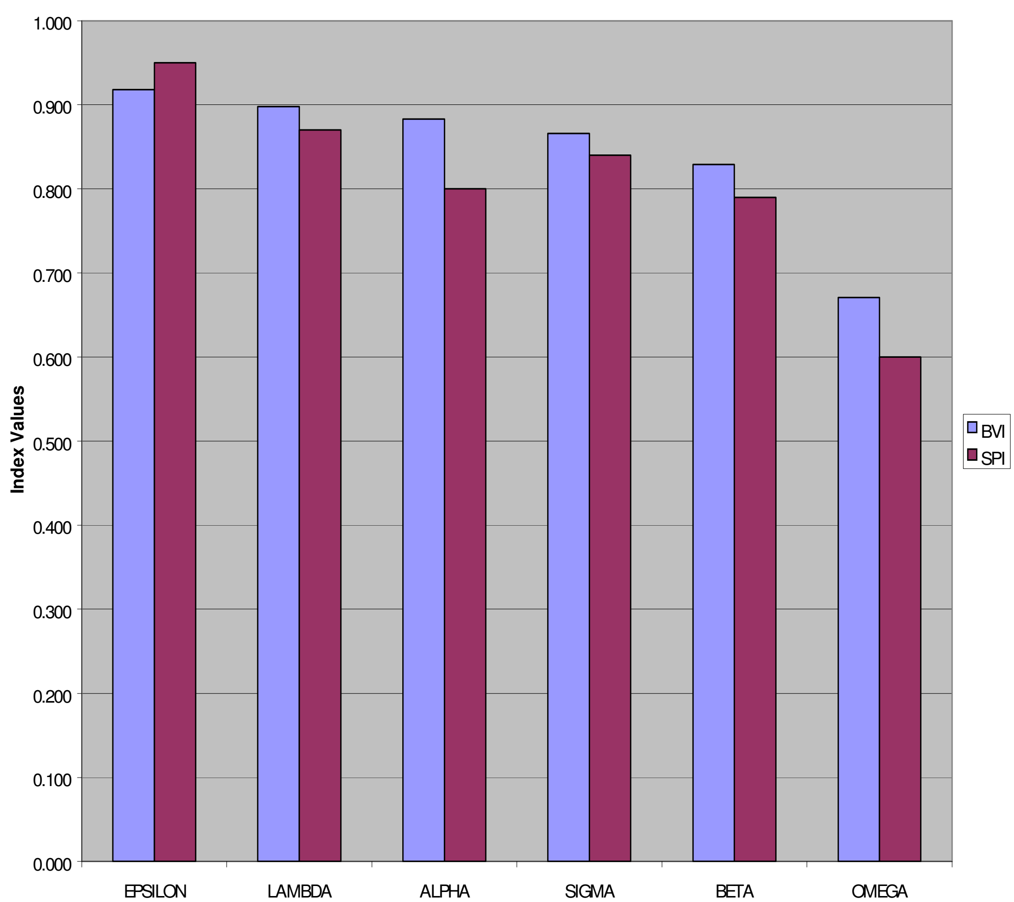
The results of correlating SPI and BVI are graphically illustrated in Figure 7-1.

These results indicate that timeliness in producing design deliverables predicts higher ratings of design quality by construction bidders. On-time deliveries throughout the design process are predictive of more tightly grouped construction bid prices, which, in turn, are indicative of bidders' endorsing the design's quality.

Design Quality Index

If design schedule variations are predictors of design quality, but design cost variations are not, does an index that combines CPI and SPI predict design quality?

Figure 7-1: BVI Versus SPI



Hypotheses: Combined Variations in Design Cost and Design Schedules Are a Measure of Design Quality

DQI was devised in this research as a composite measure of CPI and SPI. The hypothesis is that when the DQI is equal to 1.0, it predicts that design quality will turn out "perfectly." Departures from design quality will be directly proportional to the variation of DQI from 1.0, *either more or less.* In combining these two indexes, we hypothesized that DQI might provide a more distinct predictor of design quality than the other two indices measured separately.

Test Findings

Test results of DQI are listed in Table 7-5. Projects are listed by BVI rankings.

Average and median values of DQI for every project except Epsilon are virtually identical.

The ranking order of projects by DQI compared favorably to that of BVI for the highest and lowest ranked projects (Epsilon and Omega, respectively). The rankings of the remaining four projects, however, correlated poorly between BVI and DQI. Lambda ranked very high by BVI, but very low by DQI. Beta ranked next to lowest by BVI was in the middle of the rankings by DQI.

These results indicate that DQI is less reliable than and offers no advantage to SPI as a predictor of design quality.

These results indicate that DQI is less reliable than and offers no advantage to SPI as a predictor of design quality.

Table 7-5: DQI versus BVI

Project	BVI	DQI Average	DQI Median
Epsilon	0.918	0.88	0.94
Lambda	0.898	0.77	0.77
Alpha	0.883	0.80	0.81
Sigma	0.866	0.84	0.86
Beta	0.829	0.82	0.84
Omega	0.671	0.59	0.57

Consultant Performance Evaluation

MassHighway's Consultant Performance Evaluation process was created to formally rate designers' performances in each of several disciplines, as well as the design as a whole. MassHighway staff score and rate design performance as they review submittals.

Hypothesis: MassHighway's Consultant Performance Evaluation Process Predicts Design Quality

Sponsoring organization's ratings of designs predict design quality.

Test Findings

six projects we tested for this research were all completed before MassHighway implemented its current evaluation process. During our model testing, MassHighway's expediters provided ratings for project management performance for five of the six projects. No ratings, however, are available for the eight other disciplines that review designs. Nor were the project management ratings submitted at the same time as the submittals. A fully developed consultant performance evaluation normally has 15 to 20 data points depending upon the disciplines required. A single data point for project management performance is much too limited for appropriate model testing. The results of testing the Consultant Performance Evaluation measurement are inconclusive.

Office Estimate

MassHighway prepares an office estimate of the construction cost prior to receiving construction bids for each project. The office estimate provides a gauge for evaluating bids and a budget for managing project costs.

Hypotheses: Variations Between Office Estimates And Bid Costs Are Measures of Design Quality

An office estimate is one of the deliverables in design. Differences between office estimates and bids are, on their face, measures of the quality of the estimates and, therefore, a quality measure of at least one element of design. Does this measure or OEI, however, indicate quality in the design as a whole? OEI is equal to 1.0 minus the quotient of the absolute difference between the office estimate and the low bid price, divided by the low bid.

Test Findings

Test results of OEI are listed in Table 7-6. Projects are listed by BVI rankings.

Table 7-6: BVI versus OEI

Project	BVI	OEI
Epsilon	0.918	0.931
Lambda	0.898	0.850
Alpha	0.883	0.976
Sigma	0.866	0.977
Beta	0.829	0.850
Omega	0.671	0.995

We conclude that OEI is a definite measure of one, relatively small, element of design quality but is not a measure of design quality, as a whole.

Ranking by OEI is wholly incomparable to ranking by BVI. Epsilon ranks first by BVI and fourth by OEI. Omega ranks last by BVI and first by OEI. Lambda moves from second by BVI to lowest by OEI, while Sigma moves from fourth to second.

We conclude that OEI is a definite measure of one, relatively small, element of design quality but is not a measure of design quality, as a whole.

Total Extra Work Orders

An extra work order is a formal order from the project owner to the contractor authorizing adjustments in the work, schedules, or compensation. Does the total number of, or the total cost of, extra work orders indicate design quality?

Hypothesis: Total Cost or Total Quantity of Construction Extra Work Orders are Measures of Design Quality

EWI is computed as 1.0 minus the total cost of extra work orders divided by the low bid price.

Test Findings

The results of these tests are tabulated in Table 7-7. Projects are ranked by BVI.

EWI correlated reasonably well to BVI. Epsilon and Lambda were highly ranked and Omega was ranked lowest by both indexes. Beta is the only project that moved significantly as it was ranked fifth by BVI but third by EWI.

Design-Related Extra Work Orders

Those construction extra work orders that stem from design errors or omissions, are, on their face, indicators of design quality.

Table 7-7: EWI versus BVI

Project	BVI	EWI	Total EWOs
Epsilon	0.918	0.979	1
Lambda	0.898	0.982	1
Alpha	0.883	0.941	2
Sigma	0.866	0.923	2
Beta	0.829	0.967	2
Omega	0.671	0.598	6

Hypotheses: Total Cost of Design-Related Extra Work Orders are Measures of Design Quality

Total cost of design-related extra work orders is measured by the D-REWI which is computed as 1.0 minus the ratio of the total cost of design-related extra work orders to the low bid price.

Test Findings

The results of these tests are tabulated in Table 7-8. Projects are listed in the order of their rank by BVI.

Rankings by D-REWI correlate especially well with rankings by BVI. The only difference in the rankings by the two indexes is that fourth and fifth place Sigma and Beta are in reversed positions in the two rankings.

From these findings, we conclude that D-REWI is a reliable measure and is superior to EWI as a measure of design quality.

Table 7-8: D-REWI versus BVI

Project	BVI	D-REWI	Design-Related EWOs
Epsilon	0.918	1.000	0
Lambda	0.898	1.000	0
Alpha	0.883	0.995	1
Sigma	0.866	0.923	2
Beta	0.829	0.967	2

Omega	0.671	0.875	2

Variations in Quantities

The bid documents for "footprint" bridges include some work items that are priced and paid for as a lump sum and other items that are priced and paid for at unit prices. The actual total amount paid for unit-priced items depends on the bid price and the *actual* quantity provided by the contractor. The bid documents, when furnished to prospective bidders, include estimates of the quantities that will be required for each unit-priced item of work.

Hypothesis: Variations in Quantities Are a Measure of Design Quality

Measurements of variations in quantities between those estimated by MassHighway and those actually provided by the contractor indicate the presence or absence of design quality.

Test Results

The measure for this test is the ratio of the *sum* of absolute cost overruns plus cost underruns to the sum of the bid amounts for *unit priced items*, expressed as a percentage. Lump sum items have been excluded from the measurement.

The results of these measurements, in the order of most competitive to the least competitive bid spreads, are tabulated in Table 7-9.

Of the six projects, Epsilon was the only project that held the same ranking position for both measurements with the most competitive bid spread and the least variation in quantities. Lambda had the second most competitive bid spread but was fourth when ranked by variations in quantities. Alpha was third in bid spreads but ranked lowest in quantity variations.

Table 7-9: BVI versus Quantity Variations

Project	Estimated Quantities at Bid Prices	Actual Total Quantity Overruns plus Underruns at Bid Prices	Measurement of Percent Variation of Quantities	BVI
Epsilon	$389,369	$47,844	12.3%	0.918
Lambda	$255,840	$61,011	23.8%	0.898
Alpha	$105,319	$41,726	39.6%	0.883
Sigma	$116,582	$17,759	15.2%	0.866
Beta	$122,883	$26,530	21.6%	0.829

Omega	$ 87,039	$26,693	30.1%	0.671

Quantity variations are obvious measures of the quality of cost estimates and, as such, are measures of the quality of one element of designs. The tests show, however, that quantity variations are unreliable as measures of design quality, as a whole.

Conclusions and Composite Index

Variations among construction bid prices reliably indicate design quality. Quality plans, specifications, and contract documents reduce bidders' uncertainties, prompt more competitive bidding, and lead to narrower differences among bidders' prices.

Variations in bid prices are precursors of design-related extra work during construction. Projects having more competitive bids have fewer design-related extra work orders at lower cost than projects having wide bid variations.

Variations in design schedules are predictors of design quality. Designs that proceed on schedule are likely to be more competitively bid and have fewer and less costly design-related construction extra work orders. Schedule overruns during design are likely to be followed by less competitive bids and more design-related extra work during construction.

The tests show that quantity variations are unreliable as measures of design quality, as a whole.

Variations in the cost of quantities of unit-priced items in construction as compared to the office estimates are, on their face, measures of the quality of the estimates. These variations, however, are not necessarily indicative of the quality of other elements of the design or the design as a whole.

Data were not available for testing MassHighway's Consultant Performance Evaluation (CPE) process and correlating the results with the other measures. Nevertheless, this evaluation provides the feature of *explicitly* measuring sponsor satisfaction (or dissatisfaction) which is not represented by any of the other measures. The Consultant Performance Evaluation should be one of the factors in the composite index for measuring design quality.

We conclude that the overall index for measuring design quality should be composed of five indexes, namely:

- Schedule Performance Index (SPI)

  measured as: median of monthly SPI

  SPI = Budgeted Cost of Deliverables Produced divided by Budgeted Cost of Deliverables Scheduled

- Consultant Performance Evaluation Index (CPEI)

  measured as: [Overall CPE score / 10]

- Bid Variation Index (BVI)

  measured as: [1.00 - (STDEV of bids / low bid)]

- Design-related Extra Work Index (D-REWI)

  measured as: [1.00 – (design-related EWO / low bid price)]

- Quantity Estimates Index (QEI)

  measured as: [1.00 – ($ sum of absolute quantity variations / low bid price)]

The computation of each of these indexes, except the SPI, produces a value of 1.00 or less. SPI can exceed 1.00 when the design is ahead of schedule for most months.

These indexes are not equal to one another in representing design quality as a whole. In determining a composite index, each individual index should be factored to weight its influence. In our judgment, the order of influence and relative weightings of the indexes should be as follows:

1. BVI 40%
2. D-REWI 25%
3. CPEI 15%
4. SPI 15%
5. QEI 5%

The indexes for the projects that we tested are shown in Table 7-10. The composite index is the sum of the products of the individual indexes multiplied by their respective weightings. CPEI values were not available for testing and have been estimated for the purpose of illustration. The composite index produces the same ranking order as the Bid Variation Index.

We have named the composite index the *Composite Design Quality Index* (CDQI). CDQI is computed as:

CDQI = (40%)(BVI) +(25%)(D-REWI) + (15%)(CPEI) + (15%)(SPI) + (5%)(QEI).

Table 7-10: Composite Design Quality Index

Project	BVI	D-REWI	CPEI	SPI	QEI	Composite
Weighting	**40%**	**25%**	**15%**	**15%**	**5%**	**100%**
Epsilon	0.918	1.000	0.930	0.950	0.935	0.95
Lambda	0.898	1.000	0.910	0.870	0.920	0.92
Alpha	0.883	0.995	0.890	0.800	0.879	0.90
Sigma	0.866	0.923	0.880	0.840	0.927	0.88
Beta	0.829	0.967	0.870	0.790	0.914	0.87
Omega	0.671	0.876	0.750	0.600	0.948	0.74

Note: Index for Consultant Performance Evaluation assumed to test its effect on composite.

As a result of this research, we conclude that certain characteristics of highway projects are reliable predictors and indicators of design quality. Designs that proceed on the planned schedule and satisfy sponsoring organizations' reviews are likely to lead to satisfactory construction as indicated by small differences among construction bid prices, small variations between estimated and actual construction quantities, and no construction extra work that has been caused by design deficiencies. These five characteristics, in aggregate, provide a composite measurement of design quality that is indicative of the level of stakeholders' satisfaction.

Notwithstanding the findings of this research, we believe that experience in using this model, as well as further testing on various types of construction projects under differing procurement conditions, will produce improvements to the model. The weightings of the several measures in the Composite Design Quality Index are based upon our judgement at this time. Also, in spite of the results of the project tests, we believe that design cost performance (CPI) will, in time, prove to be a predictor of design quality. Additional research and experience in applying the model are needed to tests these theories.

APPENDIX A

METHOD

The research for this report was performed in three sequential phases.

The objectives of the initial phase were to define, identify benefits, and determine potential predictors and indicators of design quality.

We achieved these objectives through:

1. In-person, telephone, and focus group interviews with approximately 80 individuals, including consulting engineers, MassHighway personnel, representatives of other state highway departments, contractors, vendors, representatives of transportation related organizations, and attorneys.
2. Literature searches for writings on highway and bridge design/preconstruction processes, project management, and quality management from both the transportation community and quality and project management experts. Where possible, we used original source material rather than interpretations by others. We obtained writings from both transportation and business libraries, including the Volpe Transportation Library, the Massachusetts State Transportation Library, and the Boston Public Library including its Kirsten Business Branch. We also used Internet Web sites of university and engineering library catalogs, FHWA, transportation-related organizations, in conjunction with Internet search engines to locate documents on design quality, quality initiatives, and quality management. A full listing of our information sources appears in the Bibliography.
3. Analyses of information and data formed the basis of our findings. We drafted these findings and our conclusions into a written report.
4. The Steering Committee reviewed the draft written report. We incorporated their comments into the final report.

The purpose of the second phase of the research was to develop a model for measuring highway design quality based upon the findings of the first phase. We created the model in Project 98, Microsoft's project management software, and Excel. Initially, we designed the model to include measurements for predicting design quality based upon cost and schedule variations. Upon review by the Steering Committee, we enhanced the model by adding measurements of variations in construction cost estimates and bids, construction quantities, extra work orders, and MassHighway's evaluation of the project design quality.

In the third phase of the research, we tested the model using actual data from six highway bridge projects that had been designed and constructed.

All six were from the same family of projects, “footprint” bridges—new or rehabilitated bridges constructed in the same area as an existing bridge. These projects had more in common with one another than is typically the case among construction projects, which aided in reducing the influence of other variables on our measurements.

One of the more challenging aspects of the research was to determine the measurement standards for each predictor and indicator index. We concluded that the most comprehensive measurement of design quality is the variation among prices bid by construction contractors. We further concluded that the clarity, consistency, and thoroughness of plans, specifications, and bidding documents comprehensively represent overall design quality. Documents that are lacking in these characteristics cause greater disparities among the bidders’ degree of certainty and, consequently, greater spreads in their prices. We adopted the Bid Variation Index (BVI) as the baseline for ranking the quality among the six projects that were tested. The validity of each of the other potential indices was determined by its correlation to the project rankings by BVI measurement. The results of these analyses are documented in this report.

APPENDIX B

EARNED VALUE ANALYSIS EXAMPLE

Table B-1 shows an example of an earned value analysis.
In this example, measurement occurs at the end of the twelfth week of the project. Measurements are based on the progress of producing documents and deliverables. (See columns labeled “As of wk 12.”) Deliverables are comprised of several documents in a series (e.g., Documents 1.1 + 1.2 + ... = Deliverable #1). Document 1.2 did not begin until Document 1.1 was completed.
Rather than use incremental or partial percentages for estimates of completion, percentages of 0%, 50%, or 100% were assigned for the sake of simplicity and objectivity. When costs were incurred in the production of a document, but virtually no progress toward completion was discernible, 0% progress was recorded. See Earned Value and Actual Cost of Document 3.1.

In the example, the cost variance is -$1,320 (-5%) which means that the actual cost for the deliverable production was $1,320 or 5% more than the budget. The Schedule Variance of -$7,860 (-22.5%) means that 22.5% more value had been scheduled than was accomplished by the end of week 12. This shortfall was caused primarily by no work being done on Documents 3.1, 3.2, and 3.3 which were slated for completion. What is important to note is that these incremental shortfalls in both cost and schedule variances may be indicators of *overall quality* (or lack thereof.)

Table B-1: Example of Earned Value Analysis

Document/ Deliverable	No.	Budgeted Cost ($)	Completed As of wk 12 (%)	Earned Value As of wk 12 (BCDP)	Actual Cost As of wk 12 (ACDP)	Cost Variance (BCDP-ACDP)	Scheduled Completion (week #)	Budgeted Cost Work Sched. (BCDS)	Schedule Variance (BCDP-BCDS)	Cost Perf. Index (BCDP/ACDP)	Sched. Perf. Index (BCDP/BCDS)
Document:	1.1	$ 3,030	100%	$ 3,030	$ 3,166	$ (136)	5	$ 3,030	$ 0	0.96	1.00
"	1.2	$ 2,550	100%	$ 2,550	$ 2,492	$ 58	6	$ 2,550	$ 0	1.02	1.00
"	1.3	$ 2,425	100%	$ 2,425	$ 2,620	$ (195)	7	$ 2,425	$ 0	0.93	1.00
"	1.4	$ 4,050	100%	$ 4,050	$ 3,920	$ 130	8	$ 4,050	$ 0	1.03	1.00
"	1.5	$ 4,430	50%	$ 2,215	$ 2,632	$ (417)	10	$ 4,430	$ (2,215)	0.84	0.50
Total Deliverable:	#1	$ 16,485	87%	$ 14,270	$ 14,830	$ (560)	11	$ 16,485	$ (2,215)	0.96	0.87
Document:	2.1	$ 2,370	100%	$ 2,370	$ 2,432	$ (62)	3	$ 2,370	$ 0	0.97	1.00
"	2.2	$ 2,675	100%	$ 2,675	$ 2,985	$ (310)	4	$ 2,675	$ 0	0.90	1.00
"	2.3	$ 1,065	100%	$ 1,065	$ 1,080	$ (15)	4	$ 1,065	$ 0	0.99	1.00
"	2.4	$ 1,365	100%	$ 1,365	$ 1,420	$ (55)	5	$ 1,365	$ 0	0.96	1.00
"	2.5	$ 3,795	100%	$ 3,795	$ 3,900	$ (105)	7	$ 3,795	$ 0	0.97	1.00
"	2.6	$ 1,535	100%	$ 1,535	$ 1,548	$ (13)	9	$ 1,535	$ 0	0.99	1.00
Total Deliverable:	#2	$ 12,805	100%	$ 12,805	$ 13,365	$ (560)	12	$ 12,805	$ 0	0.96	1.00
Document	3.1	$ 2,500	0%	$ 0	$ 200	$ (200)	11	$ 2,500	$ (2,500)	0.00	0.00
"	3.2	$ 1,845	0%	$ 0	$ 0	$ 0	12	$ 1,845	$ (1,845)	#DIV/0!	0.00
"	3.3	$ 1,300	0%	$ 0	$ 0	$ 0	12	$ 1,300	$ (1,300)	#DIV/0!	0.00
"	3.4	$ 1,215	0%	$ 0	$ 0	$ 0	13	$ 0	$ 0	#DIV/0!	#DIV/0!
"	3.5	$ 1,700	0%	$ 0	$ 0	$ 0	13	$ 0	$ 0	#DIV/0!	#DIV/0!
"	3.6	$ 2,475	0%	$ 0	$ 0	$ 0	16	$ 0	$ 0	#DIV/0!	#DIV/0!
Total Deliverable:	#3	$ 11,035	0%	$ 0	$ 200	$ (200)	16	$ 5,645	$ (5,645)	0.00	0.00
Summary											
Deliverable	#1	$ 16,485	87%	$ 14,270	$ 14,830	$ (560)	11	$ 16,485	$ (2,215)	0.96	0.87
"	#2	$ 12,805	100%	$ 12,805	$ 13,365	$ (560)	12	$ 12,805	$ 0	0.96	1.00
"	#3	$ 11,035	0%	$ 0	$ 200	$ (200)	16	$ 5,645	$ (5,645)	0.00	0.00
Totals:		$ 40,325	67%	$ 27,075	$ 28,395	$ (1,320)	16	$ 34,935	$ (7,860)	0.95	0.78
% Variance:						-5%			-22.5%		

(A negative **Cost Variance** means that actual incurred costs are over budget for the work completed to the measuring date.)
(A negative **Schedule Variance** means that less has been completed than was scheduled to the measuring date.)

APPENDIX C

DESIGN BUDGET FORMAT

Table C-1 illustrates an excerpt from the design budget data currently available in MassHighway's project control documents. Labor hours are budgeted by deliverable and staff labor category. These data are summarized by sections and converted to dollars.

Table C-1: Example of Partial Design Budget

Section 200 Preliminary Highway Design									
		Labor Hour Budget							Budgeted
	Section	Pr	Sr	Ds	Jr	Sr	Jr		Labor
Deliverable Description	No.	Mgr	Eng	Eng	Eng	Dft	Dft	Total	Cost
Project Initiation	201	2	4	4	4			14	$ 328
Data Compilation & Evaluation	202		1	4	1			6	$ 132
Survey Coordination & Controls	203		2	4	2			8	$ 175
Base Plans Profiles & Sections	204		2	4	4	8		18	$ 337
Site Investigation & Field Trips	205		4	4				8	$ 198
Meetings & Liaison	206	2	4	4				10	$ 266
Horizontal Geometry-Graphical	207		2	8		12		22	$ 429
Preliminary Profiles-Graphical	208		2	6		10		18	$ 352
Typical X-sections & Details	209				2	6	2	10	$ 130
Cross Section Studies	210							0	$ -
Traffic Assignments & Analysis	211							0	$ -
Lane Arrangements	212							0	$ -
Traffic Signals	213							0	$ -
Preliminary Drainage/Util Studies	214		2	8	8			18	$ 356
Plot Proposed Layout Lines	215			4			4	8	$ 89
Preliminary ROW	216		4	6	4	10		24	$ 469
Preliminary Design Reviews	217		2	8	2			12	$ 263
Comps for BL & X-sections	218			4				4	$ 89
Boring Coordination & Cont Prep	219							0	$ -
Preliminary TMP	220	2	2	6	2			12	$ 287
Cost Estimate	221		2	6		4		12	$ 254
Hydrological Studies / Report	222		8	4				12	$ 308
Modifications & Revisions	223		4	4		6	2	16	$ 297
Public Hearings	224	4	4	4		6	2	20	$ 433
Subtotal (Prel Highway Design):		10	49	92	29	62	10	252	$ 5,191

		Summary - Labor Hour Budget							Budgeted
	Section	Pr	Sr	Ds	Jr	Sr	Jr		Labor
Section	No.	Mgr	Eng	Eng	Eng	Dft	Dft	Total	Cost
Project Development-Eng	100	0	0	0	0	0	0	0	$ -
Project Development-Environ	150	0	0	0	0	0	0	0	$ -
Preliminary Highway Design	200	10	49	92	29	62	10	252	$ 5,191
Final Highway Design	250	22	70	98	66	100	20	376	$ 7,508
Bridge Type Study	300	4	34	34	24	12	0	108	$ 2,391
Bridge Sketch Plans	310	4	48	36	12	44	16	160	$ 3,159
Final Bridge Design	320	10	86	282	174	182	64	798	$ 14,642
Environ Studies & Permits	400	4	10	32	2	0	0	48	$ 1,150
Geotechnical Design	500	0	4	4	60	0	0	68	$ 1,131
Total Budget Design:		54	301	578	367	400	110	1810	$ 35,173

APPENDIX D

DESIGN PLANNING SYSTEM

The figures of Appendix D illustrate examples of output from the design planning system. These two figures provide concise baseline data for scope, budget, and schedule and their interrelationships.

Figures D-1 and D-2 are identical with the exception that D-1 lists the baseline budget and D-2 lists the schedule baseline, including the duration of each scope item and start and finish dates.

The scope of work in both figures is arrayed in a hierarchy of submittals and their deliverables. Scope items listed in bold type represent either submittals (e.g., ID 4: Bridge Type Study) or “summary” design processes (e.g., ID 2: Bridge Process). Deliverables are shown indented in regular type (e.g., ID 10: Base Plan). Submittals and summary processes are shown outdented in bold type (e.g., ID 4: Bridge Type Study and ID 2: Bridge Process). The format for the scope of work in the planning model aids in understanding the relationships among deliverables.

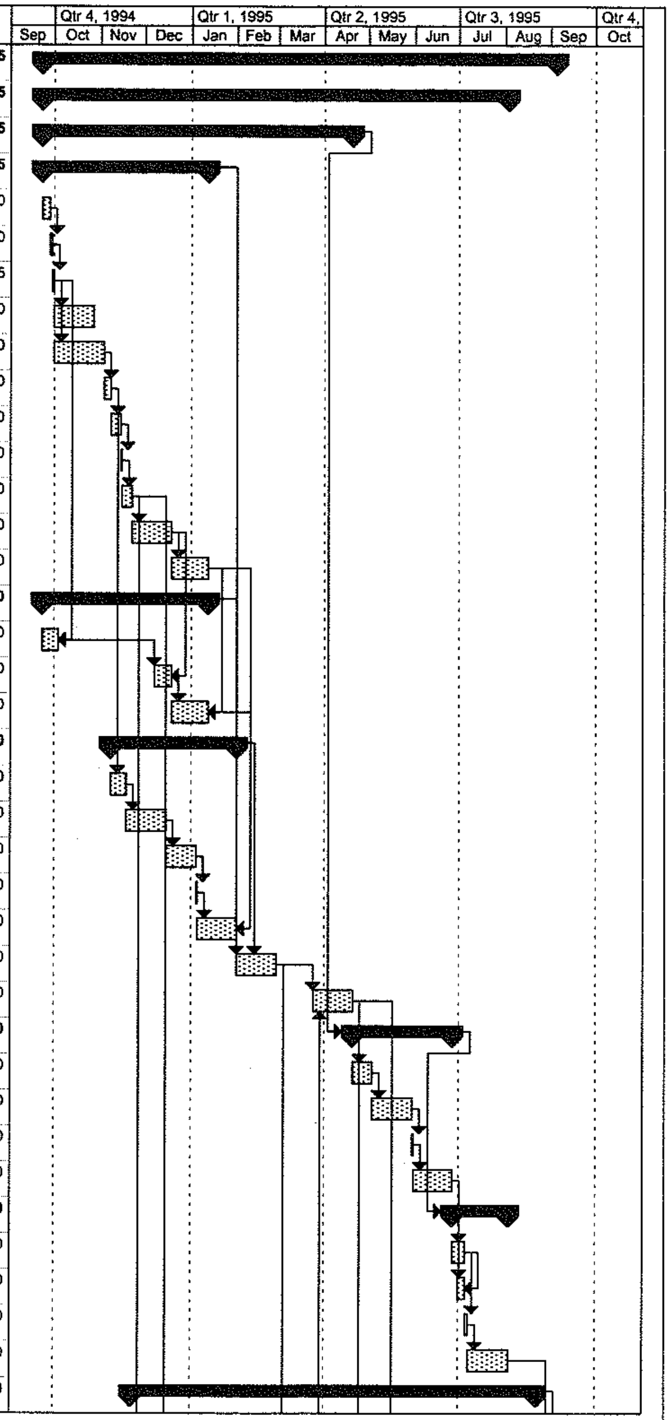
The graphical illustration on the right-hand side of each figure is known as a Gantt Chart. It illustrates the logical progression of the production of deliverables. The horizontal bars represent the planned durations of their corresponding scope items (e.g., the planned duration of ID 16: Hydraulics is from late September 1994 to mid January 1995). The vertical lines and arrows illustrate the relationships between items in the scope of work. For example, the line and arrow connecting the bars for ID 17 and ID 18 mean that Hydrologic Computations must be produced before the Hydraulics Report Submittal. The software also has a “zooming” feature, which permits viewing the schedule in shorter or longer time increments, if desired.

The power of the project planning software lies in its capacity to sort out and display the interrelationships among many types of data. The proposed planning system has great potential for aiding highway design professionals in preparing more accurate and useful baselines plans for highway designs and in communicating the sequence of design steps to stakeholders.

Plans that are expressed in this level of detail reduce the risk that the intent of the design will be misunderstood by stakeholders.

Figure D-1: Baseline Budget and Network Diagram Example

ID	Scope of Work	Baseline
1	**Footprint Bridge Design Process**	**$35,730.95**
2	**Bridge Process**	**$23,483.15**
3	**Bridge Sketch Plans**	**$8,890.05**
4	**Bridge Type Study**	**$4,080.85**
5	Scope of Work Provided by MHD	$594.60
6	Project Design Parameters and Site Visit	$396.40
7	Notes and Data from Site Visit	$131.55
8	Wetlands Delineations	$0.00
9	Field Survey	$174.50
10	Base Plan	$337.20
11	Alternative Bridge & Roadway Designs	$749.70
12	Issues Evaluations (utilities, ROW, TMP)	$198.20
13	Preliminary Cost Comparisons	$659.30
14	Bridge Type Study Report	$839.40
15	MassHighway's Approval: Bridge Type Study	$0.00
16	**Hydraulics**	**$1,782.00**
17	Hydrologic Computations	$307.80
18	Hydraulics Report Submittal	$1,474.20
19	MassHighway's Approval: Hydraulics Report	$0.00
20	**Geotechnical**	**$1,306.60**
21	Proposed Subsurface Investigation Plan	$1,108.40
22	MassHighway's Approval: Subsurface Soils Invest.	$0.00
23	Borings	$0.00
24	Geotechnical Report Submittal	$198.20
25	MassHighway's Approval: Geotechnical Report	$0.00
26	Sketch Plans	$1,720.60
27	MassHighway's Approval: Bridge Sketch Plan	$0.00
28	**1st Bridge Submittal**	**$10,925.00**
29	Structural Analysis & Geometry	$4,998.00
30	Bridge Plans	$5,420.80
31	Designer's 1st Structural Submittal	$506.20
32	MassHighway's Approval: 1st Structural Submittal	$0.00
33	**2nd Bridge Submittal**	**$3,668.10**
34	Bridge Special Provisions	$2,300.40
35	Bridge Quantities & Estimates	$763.40
36	Designer's 2nd Bridge Submittal	$604.30
37	MassHighway's Approval: 2nd Bridge Submittal	$0.00
38	**Highway Process**	**$8,582.80**



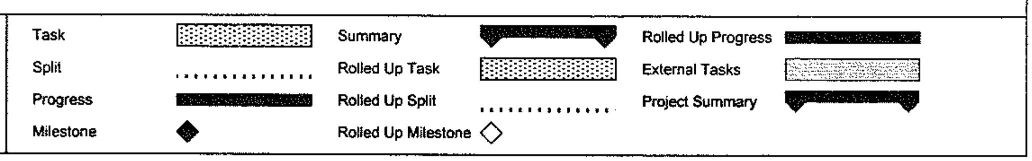
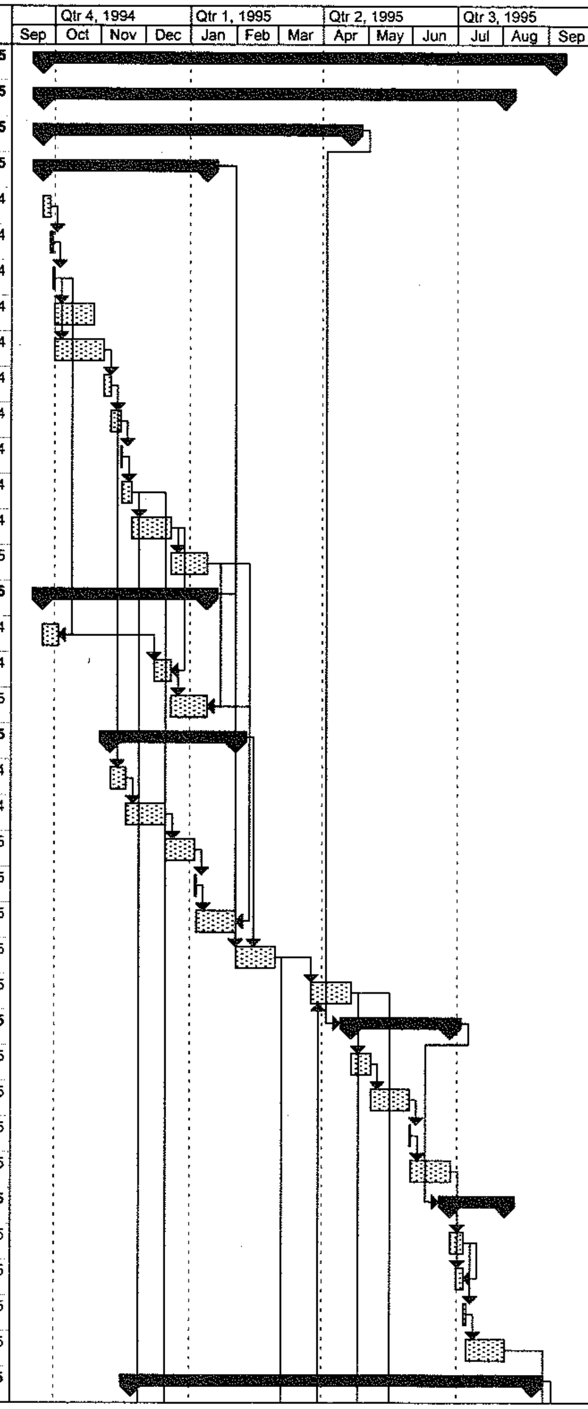


Figure D-2: Baseline Schedule and Network Diagram Example

ID	Scope of Work	Duration	Start	Finish
1	**Footprint Bridge Design Process**	**264 days**	**Fri 9/23/94**	**Tue 9/5/95**
2	**Bridge Process**	**239 days**	**Fri 9/23/94**	**Thu 8/3/95**
3	**Bridge Sketch Plans**	**159 days**	**Fri 9/23/94**	**Thu 4/20/95**
4	**Bridge Type Study**	**85 days**	**Fri 9/23/94**	**Thu 1/12/95**
5	Scope of Work	3 days	Fri 9/23/94	Tue 9/27/94
6	Project Design Parameters	2 days	Wed 9/28/94	Thu 9/29/94
7	Notes and Data from Site Visit	1 day	Thu 9/29/94	Fri 9/30/94
8	Wetlands Delineations	20 days	Fri 9/30/94	Thu 10/27/94
9	Field Survey	25 days	Fri 9/30/94	Thu 11/3/94
10	Base Plan	3 days	Thu 11/3/94	Tue 11/8/94
11	Alt. Bridge & Roadway Designs	5 days	Tue 11/8/94	Mon 11/14/94
12	Issues Evaluations	1 day	Mon 11/14/94	Tue 11/15/94
13	Preliminary Cost Comparisons	5 days	Tue 11/15/94	Tue 11/22/94
14	Bridge Type Study Report	20 days	Tue 11/22/94	Mon 12/19/94
15	MassHighway's Approval	20 days	Mon 12/19/94	Thu 1/12/95
16	**Hydraulics**	**85 days**	**Fri 9/23/94**	**Thu 1/12/95**
17	Hydrologic Computations	7 days	Fri 9/23/94	Mon 10/3/94
18	Hydraulics Report Submittal	8 days	Wed 12/7/94	Mon 12/19/94
19	MassHighway's Approval	20 days	Mon 12/19/94	Thu 1/12/95
20	**Geotechnical**	**65 days**	**Tue 11/8/94**	**Tue 1/31/95**
21	Proposed Subsurface Investigation	9 days	Tue 11/8/94	Fri 11/18/94
22	MassHighway's Approval	20 days	Fri 11/18/94	Thu 12/15/94
23	Borings	15 days	Thu 12/15/94	Wed 1/4/95
24	Geotechnical Report Submittal	1 day	Wed 1/4/95	Thu 1/5/95
25	MassHighway's Approval	20 days	Thu 1/5/95	Tue 1/31/95
26	Sketch Plans	20 days	Wed 2/1/95	Mon 2/27/95
27	MassHighway's Approval	20 days	Fri 3/24/95	Thu 4/20/95
28	**1st Bridge Submittal**	**51 days**	**Thu 4/20/95**	**Tue 6/27/95**
29	Structural Analysis & Geometry	10 days	Thu 4/20/95	Wed 5/3/95
30	Bridge Plans	20 days	Wed 5/3/95	Tue 5/30/95
31	Designer's 1st Structural Submittal	1 day	Tue 5/30/95	Wed 5/31/95
32	MassHighway's Approval	20 days	Wed 5/31/95	Tue 6/27/95
33	**2nd Bridge Submittal**	**29 days**	**Tue 6/27/95**	**Thu 8/3/95**
34	Bridge Special Provisions	7 days	Tue 6/27/95	Wed 7/5/95
35	Bridge Quantities & Estimates	3 days	Fri 6/30/95	Wed 7/5/95
36	Designer's 2nd Bridge Submittal	2 days	Wed 7/5/95	Fri 7/7/95
37	MassHighway's Approval	20 days	Fri 7/7/95	Thu 8/3/95
38	**Highway Process**	**208 days**	**Tue 11/22/94**	**Tue 8/22/95**



Task · Split · Progress · Milestone · Summary · Rolled Up Task · Rolled Up Split · Rolled Up Milestone · Rolled Up Progress · External Tasks · Project Summary

APPENDIX E

CPI, SPI, AND DQI COMPUTATIONS EXAMPLE

Table E-1 is an excerpt from the indexing system for one payment voucher cycle when design is in progress. The data was derived from an actual "footprint" bridge design. Scope, baseline budget, and scheduled finish data are transcribed from the planning model. The remaining data are developed during the indexing process. Full explanations of these data are provided in Chapter 5.

Table E-1: CPI, SPI, and DQI Computation

				Date:	30-Jun-95
				ACDP:	$ 29,240
Scope of Work (expressed as work product & deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	100%	$ 308	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	100%	$ 1,474	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	100%	$ 1,108	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	50%	$ 99	1/5/1995	$ 198
Bridge Sketch Plans	$1,721	75%	$ 1,290	2/27/1995	$ 1,721
Structural Analysis & Geometry	$4,998	50%	$ 2,499	5/3/1995	$ 4,998
Bridge Plans	$5,421	50%	$ 2,710	5/30/1995	$ 5,421
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ 506
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ -
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ -
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ -
Representative Cross Sections	$156	75%	$ 117	11/29/1994	$ 156
Functional Design Report	$356	75%	$ 267	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	75%	$ 215	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	100%	$ 263	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	100%	$ 323	5/16/1995	$ 323
Refined Plans & Profiles	$2,408	75%	$ 1,806	5/19/1995	$ 2,408
Special Provisions	$1,324	75%	$ 993	5/24/1995	$ 1,324
Detail Sheets	$1,455	75%	$ 1,091	5/29/1995	$ 1,455
Calculations Book & Quantity Estimates	$451	0%	$ -	5/29/1995	$ 451
Detailed Cost Estimates	$183	0%	$ -	5/29/1995	$ 183
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ 506
Public Hearing	$459	100%	$ 459	3/24/1995	$ 459
Preliminary Environmental Permits	$795	75%	$ 596	1/12/1995	$ 795
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ 355
Utilities Notifications	$352	0%	$ -	5/19/1995	$ 352
Preliminary ROW & Layout	$611	100%	$ 611	6/19/1995	$ 611
Final ROW & Layout Plans	$1,093	25%	$ 273	8/9/1995	$ 273
Total:	$35,731	60%	$ 21,457		$ 31,243
		CPI = Earned Value / ACDP:			**0.73**
		SPI = Earned Value / BCDS:			**0.69**
		DQI = 1.0<->avg variation CPI&SPI:			**0.71**

Appendix F

INDEXING SYSTEM

A full set of CPI, SPI, and DQI indexes for the design of an actual "footprint" bridge project is included in Appendix F. Each page (Tables F-2 to F-13) carries data from, and computes indexes for, one payment voucher cycle.
The indexing date (upper right corner) on each Table is the date that corresponds to the payment voucher date. Table F-1 is a summary of CPI, SPI, and DQI for the entire design project.

Table F-1: Index Summary

Pay Voucher Date	CPI	SPI	DQI
10/15/1994	1.22	0.52	0.65
11/19/1994	1.32	0.64	0.66
12/24/1994	1.10	0.71	0.81
1/21/1995	0.70	0.84	0.77
3/18/1995	0.69	0.89	0.79
4/15/1995	0.62	0.91	0.76
5/13/1995	0.68	0.83	0.75
6/30/1995	0.73	0.69	0.71
9/2/1995	0.71	0.63	0.67
9/30/1995	0.57	0.62	0.60
11/11/1995	0.84	0.93	0.88
3/30/1996	0.89	1.00	0.94
Avg CPI	0.84		
Avg SPI		0.77	
	Average DQI:		**0.75**

Table F-2: Indexing Computations for Payment Voucher 1

Scope of Work (expressed as deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
				Date:	15-Oct-94
				ACDP:	$ 893
Scope of Work	$595	75%	$ 446	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	0%	$ -	9/29/1994	$ 396
Notes/Data from Site Visit	$132	0%	$ -	9/30/1994	$ 132
Field Survey	$175	25%	$ 44	11/3/1994	$ 44
Base Plan	$337	0%	$ -	11/8/1994	$ -
Alternative Bridge & Roadway Designs	$750	25%	$ 187	11/14/1994	$ 187
Issues Evaluations	$198	0%	$ -	11/15/1994	$ -
Preliminary Cost Comparisons	$659	0%	$ -	11/22/1994	$ -
Bridge Type Study Report	$839	25%	$ 210	12/19/1994	$ 210
Hydrologic Computations	$308	0%	$ -	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	0%	$ -	12/19/1994	$ -
Proposed Subsurface Investigation Plan	$1,108	0%	$ -	11/18/1994	$ -
Geotechnical Report Submittal	$198	0%	$ -	1/5/1995	$ -
Bridge Sketch Plans	$1,721	0%	$ -	2/27/1995	$ -
Structural Analysis & Geometry	$4,998	0%	$ -	5/3/1995	$ -
Bridge Plans	$5,421	0%	$ -	5/30/1995	$ -
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ -
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ -
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ -
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ -
Representative Cross Sections	$156	0%	$ -	11/29/1994	$ -
Functional Design Report	$356	0%	$ -	12/2/1994	$ -
Preliminary Traffic Mgmt Plans	$287	0%	$ -	11/29/1994	$ -
Preliminary Plans & Profiles	$870	0%	$ -	12/15/1994	$ -
25% Highway Submittal	$263	0%	$ -	12/22/1994	$ -
MassHighway's 25% Project Approval	$323	0%	$ -	5/16/1995	$ -
Refined Plans & Profiles	$2,408	0%	$ -	5/19/1995	$ -
Special Provisions	$1,324	0%	$ -	5/24/1995	$ -
Detail Sheets	$1,455	0%	$ -	5/29/1995	$ -
Calculations Book & Quantity Estimates	$451	0%	$ -	5/29/1995	$ -
Detailed Cost Estimates	$183	0%	$ -	5/29/1995	$ -
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ -
Public Hearing	$459	0%	$ -	3/24/1995	$ -
Preliminary Environmental Permits	$795	25%	$ 199	1/12/1995	$ 199
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ -
Utilities Notifications	$352	0%	$ -	5/19/1995	$ -
Preliminary ROW & Layout	$611	0%	$ -	6/19/1995	$ -
Final ROW & Layout Plans	$1,093	0%	$ -	8/9/1995	$ -
Total:	$35,731	3%	$ 1,086		$ 2,070
		CPI = Earned Value / ACDP:			**1.22**
		SPI = Earned Value / BCDS:			**0.52**
		DQI = 1.0<->avg variation CPI&SPI:			**0.65**

Table F-3: Indexing Computations for Payment Voucher 2

Date: 19-Nov-94
ACDP: $ 2,651

Scope of Work (expressed as deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	50%	$ 375	11/14/1994	$ 750
Issues Evaluations	$198	0%	$ -	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	0%	$ -	11/22/1994	$ -
Bridge Type Study Report	$839	50%	$ 420	12/19/1994	$ 420
Hydrologic Computations	$308	0%	$ -	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	0%	$ -	12/19/1994	$ -
Proposed Subsurface Investigation Plan	$1,108	0%	$ -	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	0%	$ -	1/5/1995	$ -
Bridge Sketch Plans	$1,721	0%	$ -	2/27/1995	$ -
Structural Analysis & Geometry	$4,998	0%	$ -	5/3/1995	$ -
Bridge Plans	$5,421	0%	$ -	5/30/1995	$ -
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ -
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ -
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ -
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ -
Representative Cross Sections	$156	0%	$ -	11/29/1994	$ -
Functional Design Report	$356	0%	$ -	12/2/1994	$ -
Preliminary Traffic Mgmt Plans	$287	0%	$ -	11/29/1994	$ -
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	0%	$ -	12/22/1994	$ -
MassHighway's 25% Project Approval	$323	0%	$ -	5/16/1995	$ -
Refined Plans & Profiles	$2,408	0%	$ -	5/19/1995	$ -
Special Provisions	$1,324	0%	$ -	5/24/1995	$ -
Detail Sheets	$1,455	0%	$ -	5/29/1995	$ -
Calculations Book & Quantity Estimates	$451	0%	$ -	5/29/1995	$ -
Detailed Cost Estimates	$183	0%	$ -	5/29/1995	$ -
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ -
Public Hearing	$459	0%	$ -	3/24/1995	$ -
Preliminary Environmental Permits	$795	25%	$ 199	1/12/1995	$ 199
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ -
Utilities Notifications	$352	0%	$ -	5/19/1995	$ -
Preliminary ROW & Layout	$611	0%	$ -	6/19/1995	$ -
Final ROW & Layout Plans	$1,093	0%	$ -	8/9/1995	$ -
Total:	$35,731	10%	$ 3,498		$ 5,487

CPI = Earned Value / ACDP: **1.32**
SPI = Earned Value / BCDS: **0.64**
DQI = 1.0<->avg variation CPI&SPI: **0.66**

Table F-4: Indexing Computations for Payment Voucher 3

				Date:	24-Dec-94
				ACDP:	$ 6,461
Scope of Work (expressed as deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	25%	$ 77	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	0%	$ -	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	75%	$ 831	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	0%	$ -	1/5/1995	$ -
Bridge Sketch Plans	$1,721	25%	$ 430	2/27/1995	$ 430
Structural Analysis & Geometry	$4,998	0%	$ -	5/3/1995	$ -
Bridge Plans	$5,421	0%	$ -	5/30/1995	$ -
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ -
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ -
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ -
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ -
Representative Cross Sections	$156	25%	$ 39	11/29/1994	$ 156
Functional Design Report	$356	25%	$ 89	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	25%	$ 72	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	0%	$ -	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	0%	$ -	5/16/1995	$ -
Refined Plans & Profiles	$2,408	0%	$ -	5/19/1995	$ -
Special Provisions	$1,324	0%	$ -	5/24/1995	$ -
Detail Sheets	$1,455	0%	$ -	5/29/1995	$ -
Calculations Book & Quantity Estimates	$451	0%	$ -	5/29/1995	$ -
Detailed Cost Estimates	$183	0%	$ -	5/29/1995	$ -
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ -
Public Hearing	$459	0%	$ -	3/24/1995	$ -
Preliminary Environmental Permits	$795	75%	$ 596	1/12/1995	$ 596
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ -
Utilities Notifications	$352	0%	$ -	5/19/1995	$ -
Preliminary ROW & Layout	$611	0%	$ -	6/19/1995	$ -
Final ROW & Layout Plans	$1,093	0%	$ -	8/9/1995	$ -
Total:	$35,731	20%	$ 7,086		$ 9,930
		CPI = Earned Value / ACDP:			1.10
		SPI = Earned Value / BCDS:			0.71
		DQI = 1.0<->avg variation CPI&SPI:			0.81

Table F-5: Indexing Computations for Payment Voucher 4

				Date:	21-Jan-95
				ACDP:	$ 13,464
Scope of Work (expressed as work product & deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	75%	$ 231	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	75%	$ 1,106	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	75%	$ 831	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	0%	$ -	1/5/1995	$ 198
Bridge Sketch Plans	$1,721	50%	$ 860	2/27/1995	$ 860
Structural Analysis & Geometry	$4,998	0%	$ -	5/3/1995	$ -
Bridge Plans	$5,421	0%	$ -	5/30/1995	$ -
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ -
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ -
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ -
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ -
Representative Cross Sections	$156	75%	$ 117	11/29/1994	$ 156
Functional Design Report	$356	75%	$ 267	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	75%	$ 215	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	75%	$ 197	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	0%	$ -	5/16/1995	$ -
Refined Plans & Profiles	$2,408	0%	$ -	5/19/1995	$ -
Special Provisions	$1,324	0%	$ -	5/24/1995	$ -
Detail Sheets	$1,455	0%	$ -	5/29/1995	$ -
Calculations Book & Quantity Estimates	$451	0%	$ -	5/29/1995	$ -
Detailed Cost Estimates	$183	0%	$ -	5/29/1995	$ -
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ -
Public Hearing	$459	0%	$ -	3/24/1995	$ -
Preliminary Environmental Permits	$795	75%	$ 596	1/12/1995	$ 795
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ 355
Utilities Notifications	$352	0%	$ -	5/19/1995	$ -
Preliminary ROW & Layout	$611	0%	$ -	6/19/1995	$ -
Final ROW & Layout Plans	$1,093	0%	$ -	8/9/1995	$ -
Total:	$35,731	26%	$ 9,372		$ 11,112
		CPI = Earned Value / ACDP:			0.70
		SPI = Earned Value / BCDS:			0.84
		DQI = 1.0<->avg variation CPI&SPI:			0.77

Table F-6: Indexing Computations for Payment Voucher 5

				Date:	18-Mar-95
				ACDP:	$ 21,673
Scope of Work (expressed as deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	100%	$ 308	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	100%	$ 1,474	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	100%	$ 1,108	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	25%	$ 50	1/5/1995	$ 198
Bridge Sketch Plans	$1,721	50%	$ 860	2/27/1995	$ 1,721
Structural Analysis & Geometry	$4,998	50%	$ 2,499	5/3/1995	$ 2,499
Bridge Plans	$5,421	25%	$ 1,355	5/30/1995	$ 1,355
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ -
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ -
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ -
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ -
Representative Cross Sections	$156	75%	$ 117	11/29/1994	$ 156
Functional Design Report	$356	75%	$ 267	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	75%	$ 215	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	75%	$ 197	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	0%	$ -	5/16/1995	$ -
Refined Plans & Profiles	$2,408	0%	$ -	5/19/1995	$ -
Special Provisions	$1,324	0%	$ -	5/24/1995	$ -
Detail Sheets	$1,455	0%	$ -	5/29/1995	$ -
Calculations Book & Quantity Estimates	$451	0%	$ -	5/29/1995	$ -
Detailed Cost Estimates	$183	0%	$ -	5/29/1995	$ -
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ -
Public Hearing	$459	100%	$ 459	3/24/1995	$ 459
Preliminary Environmental Permits	$795	75%	$ 596	1/12/1995	$ 795
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ 355
Utilities Notifications	$352	0%	$ -	5/19/1995	$ -
Preliminary ROW & Layout	$611	75%	$ 458	6/19/1995	$ 458
Final ROW & Layout Plans	$1,093	0%	$ -	8/9/1995	$ -
Total:	$35,731	42%	$ 14,916		$ 16,744
		CPI = Earned Value / ACDP:			**0.69**
		SPI = Earned Value / BCDS:			**0.89**
		DQI = 1.0<->avg variation CPI&SPI:			**0.79**

Table F-7: Indexing Computations for Payment Voucher 6

Scope of Work (expressed as work product & deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
				Date:	**15-Apr-95**
				ACDP:	**$ 26,410**
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	100%	$ 308	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	75%	$ 1,106	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	100%	$ 1,108	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	50%	$ 99	1/5/1995	$ 198
Bridge Sketch Plans	$1,721	75%	$ 1,290	2/27/1995	$ 1,721
Structural Analysis & Geometry	$4,998	50%	$ 2,499	5/3/1995	$ 2,499
Bridge Plans	$5,421	50%	$ 2,710	5/30/1995	$ 2,710
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ -
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ -
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ -
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ -
Representative Cross Sections	$156	75%	$ 117	11/29/1994	$ 156
Functional Design Report	$356	75%	$ 267	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	75%	$ 215	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	75%	$ 197	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	0%	$ -	5/16/1995	$ -
Refined Plans & Profiles	$2,408	0%	$ -	5/19/1995	$ -
Special Provisions	$1,324	0%	$ -	5/24/1995	$ -
Detail Sheets	$1,455	0%	$ -	5/29/1995	$ -
Calculations Book & Quantity Estimates	$451	0%	$ -	5/29/1995	$ -
Detailed Cost Estimates	$183	0%	$ -	5/29/1995	$ -
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ -
Public Hearing	$459	100%	$ 459	3/24/1995	$ 459
Preliminary Environmental Permits	$795	75%	$ 596	1/12/1995	$ 795
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ 355
Utilities Notifications	$352	0%	$ -	5/19/1995	$ -
Preliminary ROW & Layout	$611	75%	$ 458	6/19/1995	$ 458
Final ROW & Layout Plans	$1,093	0%	$ -	8/9/1995	$ -
Total:	$35,731	46%	$ 16,382		$ 18,099
		CPI = Earned Value / ACDP:			**0.62**
		SPI = Earned Value / BCDS:			**0.91**
		DQI = 1.0<->avg variation CPI&SPI:			**0.76**

Table F-8: Indexing Computations for Payment Voucher 7

Scope of Work (expressed as deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
				Date:	13-May-95
				ACDP:	$ 27,882
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	100%	$ 308	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	100%	$ 1,474	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	100%	$ 1,108	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	50%	$ 99	1/5/1995	$ 198
Bridge Sketch Plans	$1,721	75%	$ 1,290	2/27/1995	$ 1,721
Structural Analysis & Geometry	$4,998	50%	$ 2,499	5/3/1995	$ 4,998
Bridge Plans	$5,421	50%	$ 2,710	5/30/1995	$ 2,710
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ -
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ -
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ -
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ -
Representative Cross Sections	$156	75%	$ 117	11/29/1994	$ 156
Functional Design Report	$356	75%	$ 267	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	75%	$ 215	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	100%	$ 263	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	100%	$ 323	5/16/1995	$ 323
Refined Plans & Profiles	$2,408	25%	$ 602	5/19/1995	$ 602
Special Provisions	$1,324	25%	$ 331	5/24/1995	$ 331
Detail Sheets	$1,455	25%	$ 364	5/29/1995	$ 364
Calculations Book & Quantity Estimates	$451	0%	$ -	5/29/1995	$ -
Detailed Cost Estimates	$183	0%	$ -	5/29/1995	$ -
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ -
Public Hearing	$459	100%	$ 459	3/24/1995	$ 459
Preliminary Environmental Permits	$795	75%	$ 596	1/12/1995	$ 795
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ 355
Utilities Notifications	$352	0%	$ -	5/19/1995	$ -
Preliminary ROW & Layout	$611	100%	$ 611	6/19/1995	$ 611
Final ROW & Layout Plans	$1,093	25%	$ 273	8/9/1995	$ 273
Total:	$35,731	53%	$ 18,863		$ 22,644
		CPI = Earned Value / ACDP:			0.68
		SPI = Earned Value / BCDS:			0.83
		DQI = 1.0<->avg variation CPI&SPI:			0.75

Table F-9: Indexing Computations for Payment Voucher 8

Scope of Work (expressed as work product & deliverables)	Baseline Budget	Percent Complete	Earned Value (BCWP)	Scheduled Finish	Baseline Schedule (BCWS)
				Date:	30-Jun-95
				ACWP:	$ 29,240
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	100%	$ 308	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	100%	$ 1,474	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	100%	$ 1,108	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	50%	$ 99	1/5/1995	$ 198
Bridge Sketch Plans	$1,721	75%	$ 1,290	2/27/1995	$ 1,721
Structural Analysis & Geometry	$4,998	50%	$ 2,499	5/3/1995	$ 4,998
Bridge Plans	$5,421	50%	$ 2,710	5/30/1995	$ 5,421
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ 506
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ -
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ -
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ -
Representative Cross Sections	$156	75%	$ 117	11/29/1994	$ 156
Functional Design Report	$356	75%	$ 267	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	75%	$ 215	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	100%	$ 263	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	100%	$ 323	5/16/1995	$ 323
Refined Plans & Profiles	$2,408	75%	$ 1,806	5/19/1995	$ 2,408
Special Provisions	$1,324	75%	$ 993	5/24/1995	$ 1,324
Detail Sheets	$1,455	75%	$ 1,091	5/29/1995	$ 1,455
Calculations Book & Quantity Estimates	$451	0%	$ -	5/29/1995	$ 451
Detailed Cost Estimates	$183	0%	$ -	5/29/1995	$ 183
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ 506
Public Hearing	$459	100%	$ 459	3/24/1995	$ 459
Preliminary Environmental Permits	$795	75%	$ 596	1/12/1995	$ 795
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ 355
Utilities Notifications	$352	0%	$ -	5/19/1995	$ 352
Preliminary ROW & Layout	$611	100%	$ 611	6/19/1995	$ 611
Final ROW & Layout Plans	$1,093	25%	$ 273	8/9/1995	$ 273
Total:	$35,731	60%	$ 21,457		$ 31,243
		CPI = Earned Value / ACWP:			0.73
		SPI = Earned Value / BCWS:			0.69
		DQI = 1.0<->avg variation CPI&SPI:			0.71

Table F-10: Indexing Computations for Payment Voucher 9

Scope of Work (expressed as deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
				Date:	2-Sep-95
				ACDP:	$ 31,663
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	100%	$ 308	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	100%	$ 1,474	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	100%	$ 1,108	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	100%	$ 198	1/5/1995	$ 198
Bridge Sketch Plans	$1,721	100%	$ 1,721	2/27/1995	$ 1,721
Structural Analysis & Geometry	$4,998	50%	$ 2,499	5/3/1995	$ 4,998
Bridge Plans	$5,421	50%	$ 2,710	5/30/1995	$ 5,421
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ 506
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ 2,300
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ 763
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ 604
Representative Cross Sections	$156	75%	$ 117	11/29/1994	$ 156
Functional Design Report	$356	75%	$ 267	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	75%	$ 215	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	100%	$ 263	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	100%	$ 323	5/16/1995	$ 323
Refined Plans & Profiles	$2,408	75%	$ 1,806	5/19/1995	$ 2,408
Special Provisions	$1,324	75%	$ 993	5/24/1995	$ 1,324
Detail Sheets	$1,455	75%	$ 1,091	5/29/1995	$ 1,455
Calculations Book & Quantity Estimates	$451	0%	$ -	5/29/1995	$ 451
Detailed Cost Estimates	$183	0%	$ -	5/29/1995	$ 183
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ 506
Public Hearing	$459	100%	$ 459	3/24/1995	$ 459
Preliminary Environmental Permits	$795	75%	$ 596	1/12/1995	$ 795
Final Environmental Permits	$355	25%	$ 89	1/16/1995	$ 355
Utilities Notifications	$352	0%	$ -	5/19/1995	$ 352
Preliminary ROW & Layout	$611	100%	$ 611	6/19/1995	$ 611
Final ROW & Layout Plans	$1,093	50%	$ 547	8/9/1995	$ 1,093
Total:	$35,731	63%	$ 22,348		$ 35,731
		CPI = Earned Value / ACDP:			0.71
		SPI = Earned Value / BCDS:			0.63
		DQI = 1.0<->avg variation CPI&SPI:			0.67

Table F-11: Indexing Computations for Payment Voucher 10

Scope of Work (expressed as work product & deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
				Date:	30-Sep-95
				ACDP:	$ 39,329
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	100%	$ 308	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	100%	$ 1,474	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	100%	$ 1,108	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	50%	$ 99	1/5/1995	$ 198
Bridge Sketch Plans	$1,721	100%	$ 1,721	2/27/1995	$ 1,721
Structural Analysis & Geometry	$4,998	50%	$ 2,499	5/3/1995	$ 4,998
Bridge Plans	$5,421	50%	$ 2,710	5/30/1995	$ 5,421
1st Structural Submittal	$506	0%	$ -	5/31/1995	$ 506
Bridge Special Provisions	$2,300	0%	$ -	7/5/1995	$ 2,300
Bridge Quantities & Estimates	$763	0%	$ -	7/5/1995	$ 763
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ 604
Representative Cross Sections	$156	75%	$ 117	11/29/1994	$ 156
Functional Design Report	$356	75%	$ 267	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	75%	$ 215	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	100%	$ 263	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	100%	$ 323	5/16/1995	$ 323
Refined Plans & Profiles	$2,408	75%	$ 1,806	5/19/1995	$ 2,408
Special Provisions	$1,324	75%	$ 993	5/24/1995	$ 1,324
Detail Sheets	$1,455	75%	$ 1,091	5/29/1995	$ 1,455
Calculations Book & Quantity Estimates	$451	25%	$ 113	5/29/1995	$ 451
Detailed Cost Estimates	$183	25%	$ 46	5/29/1995	$ 183
75/100% Highway Submittal	$506	0%	$ -	6/5/1995	$ 506
Public Hearing	$459	100%	$ 459	3/24/1995	$ 459
Preliminary Environmental Permits	$795	75%	$ 596	1/12/1995	$ 795
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ 355
Utilities Notifications	$352	0%	$ -	5/19/1995	$ 352
Preliminary ROW & Layout	$611	100%	$ 611	6/19/1995	$ 611
Final ROW & Layout Plans	$1,093	50%	$ 547	8/9/1995	$ 1,093
Total:	$35,731	62%	$ 22,318		$ 35,731
		CPI = Earned Value / ACDP:			**0.57**
		SPI = Earned Value / BCDS:			**0.62**
		DQI = 1.0<->avg variation CPI&SPI:			**0.60**

Table F-12: Indexing Computations for Payment Voucher 11

Scope of Work (expressed as deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
				Date:	11-Nov-95
				ACDP:	$ 39,555
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	100%	$ 308	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	100%	$ 1,474	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	100%	$ 1,108	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	50%	$ 99	1/5/1995	$ 198
Bridge Sketch Plans	$1,721	100%	$ 1,721	2/27/1995	$ 1,721
Structural Analysis & Geometry	$4,998	100%	$ 4,998	5/3/1995	$ 4,998
Bridge Plans	$5,421	100%	$ 5,421	5/30/1995	$ 5,421
1st Structural Submittal	$506	75%	$ 380	5/31/1995	$ 506
Bridge Special Provisions	$2,300	75%	$ 1,725	7/5/1995	$ 2,300
Bridge Quantities & Estimates	$763	75%	$ 573	7/5/1995	$ 763
2nd Bridge Submittal	$604	0%	$ -	7/7/1995	$ 604
Representative Cross Sections	$156	75%	$ 117	11/29/1994	$ 156
Functional Design Report	$356	75%	$ 267	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	75%	$ 215	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	100%	$ 263	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	100%	$ 323	5/16/1995	$ 323
Refined Plans & Profiles	$2,408	100%	$ 2,408	5/19/1995	$ 2,408
Special Provisions	$1,324	100%	$ 1,324	5/24/1995	$ 1,324
Detail Sheets	$1,455	100%	$ 1,455	5/29/1995	$ 1,455
Calculations Book & Quantity Estimates	$451	100%	$ 451	5/29/1995	$ 451
Detailed Cost Estimates	$183	100%	$ 183	5/29/1995	$ 183
75/100% Highway Submittal	$506	75%	$ 379	6/5/1995	$ 506
Public Hearing	$459	100%	$ 459	3/24/1995	$ 459
Preliminary Environmental Permits	$795	75%	$ 596	1/12/1995	$ 795
Final Environmental Permits	$355	0%	$ -	1/16/1995	$ 355
Utilities Notifications	$352	75%	$ 264	5/19/1995	$ 352
Preliminary ROW & Layout	$611	100%	$ 611	6/19/1995	$ 611
Final ROW & Layout Plans	$1,093	100%	$ 1,093	8/9/1995	$ 1,093
Total:	$35,731	93%	$ 33,167		$ 35,731
		CPI = Earned Value / ACDP:			**0.84**
		SPI = Earned Value / BCDS:			**0.93**
		DQI = 1.0<->avg variation CPI&SPI:			**0.88**

Table F-13: Indexing Computations for Payment Voucher 12

				Date:	30-Mar-96
				ACDP:	$ 40,184
Scope of Work (expressed as work product & deliverables)	Baseline Budget	Percent Complete	Earned Value (BCDP)	Scheduled Finish	Baseline Schedule (BCDS)
Scope of Work	$595	100%	$ 595	9/27/1994	$ 595
Project Design Parameters & Site Visit	$396	100%	$ 396	9/29/1994	$ 396
Notes/Data from Site Visit	$132	100%	$ 132	9/30/1994	$ 132
Field Survey	$175	100%	$ 175	11/3/1994	$ 175
Base Plan	$337	100%	$ 337	11/8/1994	$ 337
Alternative Bridge & Roadway Designs	$750	100%	$ 750	11/14/1994	$ 750
Issues Evaluations	$198	100%	$ 198	11/15/1994	$ 198
Preliminary Cost Comparisons	$659	100%	$ 659	11/22/1994	$ 659
Bridge Type Study Report	$839	100%	$ 839	12/19/1994	$ 839
Hydrologic Computations	$308	100%	$ 308	10/3/1994	$ 308
Hydraulics Report Submittal	$1,474	100%	$ 1,474	12/19/1994	$ 1,474
Proposed Subsurface Investigation Plan	$1,108	100%	$ 1,108	11/18/1994	$ 1,108
Geotechnical Report Submittal	$198	100%	$ 198	1/5/1995	$ 198
Bridge Sketch Plans	$1,721	100%	$ 1,721	2/27/1995	$ 1,721
Structural Analysis & Geometry	$4,998	100%	$ 4,998	5/3/1995	$ 4,998
Bridge Plans	$5,421	100%	$ 5,421	5/30/1995	$ 5,421
1st Structural Submittal	$506	100%	$ 506	5/31/1995	$ 506
Bridge Special Provisions	$2,300	100%	$ 2,300	7/5/1995	$ 2,300
Bridge Quantities & Estimates	$763	100%	$ 763	7/5/1995	$ 763
2nd Bridge Submittal	$604	100%	$ 604	7/7/1995	$ 604
Representative Cross Sections	$156	100%	$ 156	11/29/1994	$ 156
Functional Design Report	$356	100%	$ 356	12/2/1994	$ 356
Preliminary Traffic Mgmt Plans	$287	100%	$ 287	11/29/1994	$ 287
Preliminary Plans & Profiles	$870	100%	$ 870	12/15/1994	$ 870
25% Highway Submittal	$263	100%	$ 263	12/22/1994	$ 263
MassHighway's 25% Project Approval	$323	100%	$ 323	5/16/1995	$ 323
Refined Plans & Profiles	$2,408	100%	$ 2,408	5/19/1995	$ 2,408
Special Provisions	$1,324	100%	$ 1,324	5/24/1995	$ 1,324
Detail Sheets	$1,455	100%	$ 1,455	5/29/1995	$ 1,455
Calculations Book & Quantity Estimates	$451	100%	$ 451	5/29/1995	$ 451
Detailed Cost Estimates	$183	100%	$ 183	5/29/1995	$ 183
75/100% Highway Submittal	$506	100%	$ 506	6/5/1995	$ 506
Public Hearing	$459	100%	$ 459	3/24/1995	$ 459
Preliminary Environmental Permits	$795	100%	$ 795	1/12/1995	$ 795
Final Environmental Permits	$355	100%	$ 355	1/16/1995	$ 355
Utilities Notifications	$352	100%	$ 352	5/19/1995	$ 352
Preliminary ROW & Layout	$611	100%	$ 611	6/19/1995	$ 611
Final ROW & Layout Plans	$1,093	100%	$ 1,093	8/9/1995	$ 1,093
Total:	$35,731	100%	$ 35,731		$ 35,731
		CPI = Earned Value / ACDP:			0.89
		SPI = Earned Value / BCDS:			1.00
		DQI = 1.0<->avg variation CPI&SPI:			0.94

APPENDIX G

MASSHIGHWAY'S CONSULTANT PERFORMANCE EVALUATION SYSTEM

MassHighway's existing system for measuring design quality, the *Consultant Performance Evaluation* system, was implemented in March 1998 through a formal policy directive from the Chief Engineer. The system is based on studies by a task force of representatives of MassHighway and ACEC/NE and described in their report entitled *Evaluating the Quality of Consultant Designs: A Plan for Improving the Highway Department's Current Evaluation System.* A copy of the Report and the Engineering Directive are included in this appendix.

MASS HIGHWAY

Number: E-98-001

Date: 03/13/98

ENGINEERING DIRECTIVE

Thomas F. Broderick
CHIEF ENGINEER

CONSULTANT PERFORMANCE EVALUATION

General

The purpose of this Policy Directive is to document and implement an improved Consultant Performance Evaluation System on a Department-wide basis.

MHD personnel, with the cooperation and assistance of the consultant community, developed an improved Performance Evaluation system. The system allows input from all engineers and managers who review and direct consultant work on engineering projects. This activity documents performance during the project allowing for corrective action to be taken prior to project completion. Feedback may be provided to consultants on an interim basis to provide opportunities for improvements or corrections as necessary during the course of a project.

Performance evaluation is improved since it allows input from the several disciplines involved in a project rather than critiques of the administrative aspects alone. Information thus captured may then be reflected in future selections for contracts, emphasizing specific areas of expertise. It also allows for more objective evaluation by decentralizing review to several individuals and disciplines rather than depending solely on the Project Manager's perspective.

A detailed Final Report which explains development of the system and specific components is included with this Directive (see Attachment 6). This Report provides more detailed and in-depth information than the Directive alone.

Procedure

When a consultant contract is initiated, the Project Manager (PM) will set up a Consultant Evaluation Summary Sheet (see Attachment 5) to record project identification information and any review evaluations that are submitted at certain stages throughout the project. Reviewers will transmit interim performance scores (and

Distribution: B   Please post: ______   Do not post X comments as appropriate) with the normal review transmittals. A record of the scores and comments will be kept with the summary sheet and sent to the consultant via the PM's Supervisor and the Division Head.

At the conclusion of design, (project advertised for construction bids) information is forwarded to the Secretary of the Architects and Engineers Review Board for incorporation into a data base, and to the consultant for information. Specific information will be made available as needed to assist those participating in the consultant selection process and to the A&E Board for reference as necessary.

Details

Attachments are included to illustrate detailed procedures to be followed:

Attachment 1 - Transmittal memos which request review of consultant submittals shall also include a request for evaluation of the quality of the consultant's design

Attachment 2 - The return transmittal memo shall contain the score (on a basis of 0 to 10) and comments as appropriate.

Attachment 3 - The Environmental Division has a more complex format for evaluation. These reviews and evaluations are expected to be performed within the Division. The final overall environmental score and comments, however, will satisfy the overall Performance Evaluation System; details will be useful to the Environmental Division.

Attachment 4 - This is the Project Manager's Evaluation Form which is the basis for review of administrative aspects of the project such as schedules, budgets, cooperation, etc. It is used by the Project Manager for each project assigned to the consultant.

Attachment 5 - The Summary Form is the direct basis of the Final Evaluation. All other evaluations are compiled into this report and combined to yield a weighted score for the project and weighted scores for the individual disciplines listed.

Specific Instructions for the Summary Form:

- Roadway Reviews: Scores will be weighted 30% - 70% for the Project Manager and District respectively. Equal weights will be given for the various stages (i.e."25%"- "75/100%"- "Specs&Est" stages will be 1/3 each).

- Bridge Reviews: Weights will be as indicated for various stages of design.

- Traffic Reviews: Traffic components will be equally weighted, 100% being distributed to those activities contained in the subject project.(e.g.. if there were no "signals and lighting, the 100% would be distributed to the remaining three categories)

- Environmental Reviews- Handled in the same manner as Traffic.

- Other: These are discreet categories which will have greater or lesser degrees of importance, depending on the project. As such, they will be weighted based on the relative number of work-hours allotted in the negotiated estimate. The PM will assign these weights.

Work contracted by Cities and Towns will be given a standard set of weights depending on the type of project being designed (e.g. Safety Improvements, Signalization, Drainage Improvements, etc.)

Implementation

Converting to the new system and replacing current evaluation information will require a transition period. Existing evaluations in the A&E Board's files will be pro-rated to the new scale. New evaluations will be more detailed and graded on the 10-scale. Total conversion will be made by continually replacing evaluations which are four or more years old. In four years, all information will be based on the new system.

At present, reviewers who have attended a workshop/presentation are evaluating submittals and returning information to project managers. The next step is to extend the system to all those responsible for reviewing consultants' work.

Effective immediately, all those who are responsible for managing consultant contracts or reviewing consultants' work shall provide evaluations according to the referenced Performance Evaluation System.

Attachment 1

THE COMMONWEALTH OF MASSACHUSETTS

MASSACHUSETTS HIGHWAY DEPARTMENT

INTEROFFICE MEMORANDUM

TO: Sherman Eidelman, P.E., District 4 Highway Director

FROM: Paul A. Patneaude, P.E., Acting Manager/Engineering Expediting

DATE: February 6, 1995

SUBJECT: Billerica - Boston Road @ Pollard and Floyd Streets Safety Improvement

---

Attachment(s) :
(a) 2 set(s) of 75 % Highway Plans
(b) ______ copy/copies of the Traffic Control Agreement
(c) 2 " " of the Draft Special Provisions
(d) 2 " " of the Estimates
(e) 1 set of marked-up plans from the 25% review

We request your early review of these contract (project) documents.

The closing dates for review comments are as follows: (25%) - 30 calendar days : and (75%) - 21 calendar days: (100%) Submission Approval - 14 calendar days; all from receipt date.

NOTE; No additional comments should be needed after the 75% review. 100% Review is to insure that 75% comments were addressed.

Engineering Work Order #091-005-700(1) .
Record Key #006821 .
Project Manager: Bruce Sylvia ,Tel. #973-7732

Along with your review comments, please provide this Office with the District's evaluation of the consultant's 75% design, using the scoring range (0-10) shown below. Provide comments where appropriate. Your evaluation score and comments will be used by the A&E Review Board in determining the amount and complexity of future design work assigned to this consultant.

CONSULTANT EVALUATION SCORING:

0 1 2 3 4 5 6 7 8 9 10

Unacceptable *Below Average* *Average* *Above Average* *Exceptional*

BJS/bjs

Attachment 2

THE COMMONWEALTH OF MASSACHUSETTS

MASSACHUSETTS HIGHWAY DEPARTMENT

INTEROFFICE MEMORANDUM

TO: Paul A. Patneaude, P.E. Acting Manager/ Engineering Expediting

FROM: Sherman Eidelman, P.E., District Highway Director

DATE: February 20, 1995

SUBJECT: BILLERICA - Boston Road @ Pollard & Floyd Streets
75% Review Comments
EWO # 091-005-700(1)
Record Key # 006821

The District review of the 75% highway design submission for the subject project has been completed. Review comments are attached.

Please include a written response to all review comments with subsequent submissions. If you have any questions, please contact Mr. James Alexander at 617-648-6100, extension 465.

CONSULTANT EVALUATION:

75% Roadway Design Score: 6

General Comments:

1. Very good job addressing 25% comments, on plans and in writing.
2. Consultant seems to lack knowledge regarding MHD Special Provisions.
3. TMP barely acceptable - needs work.

Attach.
JRA/jra
cc: GRM, DRA, CFN

Attachment 3

MHD ENVIRONMENTAL DIVISION
DESIGN CONSULTANT EVALUATION FORM

PROJECT INFORMATION:

Consultant: | *Design Contract #:*

Project Description: | *Record Key #:*

Design Project Manager: | *Envir. Eval. Date:*

ENVIRONMENTAL REVIEWER EVALUATION:

	Technical Expertise & Knowledge	Clearness, Accuracy & Completeness of Plans Permits & Reports	Responsiveness and Cooperation	Design Ingenuity	Performance at Meetings & Hearings	Overall Score
MEPA/NEPA						
ENF						
EIR						
CE Checklist						
4(f)						
EA/EIS						

Env. Reviewer: *Subconsultant: None* *Overall, MEPA/NEPA:*

Comments:

WETLANDS/WATER QUALITY						
WPA						
404						
401						
CZM						
Ch. 91						
U.S. CG						

Env. Reviewer: *Subconsultant* *Overall, Wetlands/Water Quality:*

Comments:

CULTURAL RESOURCES						
HABS/HAER						
Section 106						
Chapter 254						
Archeology						

Env. Reviewer: *Subconsultant: None* *Overall, Cultural Resources:*

Comments:

*HAZARDOUS MATERIALS **						
Overall						

Env. Reviewer: *Subconsultant: None* *Overall, Hazardous Materials:*

Comments:

ENVIRONMENTAL DESIGN REVIEW						
25% / 75%						

Env. Reviewer: *Subconsultant: None* *Overall, Envir. Design Review:*

Comments:

OTHER:						

OVERALL QUALITY OF DESIGN WORK: *Overall Environmental Score:*

CONSULTANT EVALUATION SCORING:

0	1	2	3	4	5	6	7	8	9	10

Unacceptable *Below Average* *Average* *Above Averag* *Exceptional*

PERFORMANCE EVALUATION ARCHITECT–ENGINEER PROFESSIONAL SERVICES CONSULTANT	P/E EVALUATION

Name & Address of Consultant	Location & Description of Project
Type of Services	Complexity of Project

CONTRACT DATA

Contract No.	Date of Contract	Notice to Proceed	Estimated Completion Date
Method of Payment	Amount of Fee		Maximum Obligation
Description and Costs of Sub–Contracts (if any)			
Amount of Direct Costs	Percent of Work Completed		Percent of Fee Billed

PERFORMANCE:

Overall P/E Evaluation

0* 1* 2* 3* 4 5 6 7 8 9 10

Unacceptable | Below Average | Average | Above Average | Exceptional

Responsiveness and Cooperation		Efficient Use of Manhours	
Involvement of Key Personnel in Engineering Services		Ability to Work Within Budget Amount or Fee	
Manner in which Work was Organized and Accomplished		Promptness in Submission of Data and Plans	
Clearness & Completeness of Presentation		Local Office Staffing and Equipment	
Evidence of Ingenuity and Experience in Design		Capability for Doing More Complex Work	
Performance at Public Hearings and Other Meetings		Preparation of Invoices and Other Billing Material	

Reasons for Delays (if any)

REMARKS:

Division or Section Managing Work:

Submitted by: ______________ Title: ______________________ Date: ________

Approved by: ______________ Title: ______________________ Date: ________

This form to be submitted by Project Manager to Secretary of the Architects & Engineers Review Board annually and at completion of work (not including construction stage) or at any other time when such a report may be pertinent.

* Give further explanation under remarks or on attached sheet.

Attachment 5

QUALITY OF DESIGN
CONSULTANT EVALUATION SUMMARY FORM

PROJECT INFORMATION:

Consultant: ______________________ Design Contract #: _______
Project Description: ______________________ Project File #: _______
Project Manager: ______________________ Design Eval. Date: _______

ROADWAY REVIEWS:

	Plans: 25%	Plans: 75%/100%	Specs & Estimate
District (Projects/Construction)			
Project Manager			
	70%/30%	70%/30%	50%/50%

Roadway: ____

BRIDGE REVIEWS: Bridge: ____

Type Study/Sketch Plan	35%	
Final Design	35%	
Specs & Est.	30%	

ENVIRONMENTAL REVIEWS: Envir.: ____

MEPA/NEPA	
Wetlands/Water Quality	
Cultural Resources	
Hazardous Materials	
Design Plans	
Other:	

TRAFFIC REVIEWS:
(At 75/100% Review) Traffic: ____

Signs/Pavement Markings	
Signals & Lighting	
Operations/Safety Management	

OTHER REVIEWS: Other: ____

Geotechnical	
Hydraulics	
Landscape	
Right of Way	

PROJECT MANAGER: Proj. Mgr.: ____ (See Project Manager Evaluation Form)

OVERALL QUALITY OF DESIGN:

	Rdwy	Bridge	Envir.	Traffic	Other	Proj. Mgr.
Evaluation:						
Weight:						0.20 Fixed
Wt. Score:						

Weighted Score: ____

CONSULTANT EVALUATION SCORING:

0 1 2 3 4 5 6 7 8 9 10

Unacceptable | Below Average | Average | Above Average | Exceptional

EVALUATING THE QUALITY OF CONSULTANT DESIGNS

A PLAN FOR IMPROVING THE HIGHWAY DEPARTMENT'S CURRENT CONSULTANT EVALUATION SYSTEM

FINAL REPORT

Prepared By The
Massachusetts Highway Department
Architects & Engineers Review Board

Reviewed and Revised By The
MHD/ACEC Partnership
Performance Evaluation Task Force

May 1997

EVALUATING THE QUALITY OF CONSULTANT DESIGNS
PLAN FOR IMPROVING CURRENT SYSTEM

INTRODUCTION

This report presents a plan for improving the Massachusetts Highway Department's current system for evaluating the quality of consultant designs. These recommendations are a compilation of ideas and suggestions brought forth in a number of committees and workshops, including the following:

- The MHD/ACEC Compensation/Value Task Force - when discussing how to quantify the value of a consultant design. "Value" is determined by how much time and effort MHD personnel must put into reviewing and correcting design submissions as well as the design's ultimate constructibility in the field (i.e. the number of EWOs, claims, time extensions, etc.).

- The MHD/ACEC Cost Recovery Task Force - when discussing the need for better communication between MHD personnel and the consultant regarding the Department's opinion of their work. Consultants want to know how they are doing in the eyes of their client as well as how they "rank" among others. By letting them know their individual strengths and weaknesses, they can take internal steps (e.g. recruiting, training) to improve their designs. Also, as the Department moves toward the direction of cost recovery, much better documentation is needed regarding the quality of the design. This system will help to provide that documentation.

- The MHD Extra Work Order Task Force - when discussing recommendations as to how to decrease the number of EWOs, claims, overruns, time extensions, etc. currently being realized in the field. Besides increasing the cost of construction projects, poor quality designs also have strong cash flow and spending cap implications.

- The Project Development/Highway Engineering Partnering Workshop - with Project Managers from the Environmental Division stating their concern over being left out of the consultant evaluation process. With the number of projects that expeditors must now manage, it is not possible to closely review plans, drawings and other documents. Although the District, Traffic, ROW, Environmental and others are relied on to perform the design reviews, none play a significant role in the design evaluation.

- The A&E Review Board - the Board has also discussed the need for improving the consultant evaluation process, in order to more efficiently identify consultants who have excelled in various fields and to obtain better documentation on which to support the Board's consultant selection decisions.

Although each of these groups examined the issues of quality and consultant evaluations from very different perspectives, they all reached the same general conclusion - that improving the current process would result in considerable benefits to the Department as well as to the design community. Based on input from these groups and others throughout the Department, the A&E Review Board developed a "prototype" for an improved consultant evaluation system. In order to secure input from the design community, MHD management suggested that the MHD/ACEC Partnership create a task force to review the recommendations and comment on them. This final report is the product of that task force.

PROBLEM STATEMENT

In order to make designers more accountable for the quality of their work, the first step is to do a better job defining what the Department means by quality, and then developing an evaluation system that will fairly "grade" their performance based on this criteria. In general, there are two types of costs to the Department associated with poor designs. First, a poor design takes more time to review and correct. Second, a poor design results in more extra work orders and cost overruns in the field. Both of these "quality" issues have been addressed as part of the evaluation system.

A major weakness of the Department's current consultant evaluation process is that the Project Manager essentially has the only voice in the matter, through the consultant "Performance Evaluation" form prepared at the end of the job and submitted to the A&E Review Board. This may have worked well in the past, when expeditors' smaller workload gave them the opportunity to thoroughly review all aspects of the design. Over the past few years, however, nearly all of the review responsibility has shifted outside of the Expediting Section. It is essential that the evaluation process be revised to reflect this, by giving the actual reviewers (the ones wielding the red pencils) the opportunity to evaluate the designer. For instance, the Environmental Division reviews dozens of ENFs each year. These reviewers can tell a quality work product from a poor one immediately, and they know through experience which consultants are able to prepare one correctly. The Department should take full advantage of this experience and give <u>them</u> the opportunity to evaluate the consultant in terms of environmental permitting. With similar input from other Department reviewers (e.g. District, Traffic, Bridge, Geotechnical, ROW), the evaluation could help to point out the stronger and weaker firms (in terms of an overall quality work product), as well as the relative strengths and weaknesses of individual firms (e.g. strong in bridge design, but weak in terms of environmental permitting).

Another shortcoming of the existing process is that evaluations are rarely shared with the designer - unless there is a significant problem. Since there is no formal evaluation performed until after the project is completed, consultants cannot determine how well the Department feels they are doing along the way. By including performance ratings at various stages of the design (e.g. 25%, 75%) and after various tasks are completed (e.g. ENF, Hydraulics Report), the Department's Project Manager will be able to share the evaluations with the consultant on a continuous basis. Final evaluations will also be made available to designers, through the A&E Review Board. By sharing this information with the designers, as appropriate, they will know where they stand in the eyes of their client and can take steps to improve the quality of their work.

It is generally thought that the 80/20 rule applies to consultant designs: that 20% of the consultants are causing 80% of the design problems (both for reviewers and in the field). The Department must do a better job of finding out which consultants fall into that 20% category, and then take steps to make them accountable for their work (including any additional costs to the Department caused by their design errors and omissions). On the other hand, the majority of the designers who consistently provide a high quality work product should be rewarded with future design contracts. An improved consultant evaluation process will help to ensure that this happens.

OBJECTIVE

The short term objective of this system is to improve the quality of designer evaluations by giving all stakeholders in the process an opportunity to be involved in it. With an improved system in place, both the A&E Review Board and individual RFP selection committees will be able to make better decisions in terms of selecting the best qualified designers for specific types of work. By hiring the best qualified designers and making them more accountable for their performance, the quality of designs should improve which will, in the long term, result in less review time and fewer constructibility problems (i.e. extra work orders).

SYSTEM DESIGN CRITERIA

Two criteria were considered when developing this evaluation system - simplicity and usefulness:

1. Simplicity - the system must be easily understood and cannot create an administrative burden. Wherever possible, existing evaluation forms have been revised and not replaced. Vague qualitative scores such as fair and poor have been avoided as much as possible.

2. Usefulness - the output must be both reliable and meaningful in terms of making better selection decisions. All stakeholders involved in the process must feel that the system provides them with a benefit that is worth their extra effort. These stakeholders include:

   - Reviewers - all MHD design reviewers will have the opportunity to take part in the consultant evaluation process. They are the experts in each field and review the same aspects of a design day in and day out. They know the difference between a high quality design and a shoddy one thrown together by a firm's "rookies." Their opinions will help to ensure better designs in the future, which will eventually make their jobs as reviewers much easier. This will also help to get everyone in the Department to "think quality."

   - Project Manager - still plays the primary role in coordinating the evaluation process and preparing the evaluation form at the end of the project. Whereas the actual reviewers will evaluate the specific design elements, the Project Manager will focus on issues such as responsiveness, cooperation, timeliness and budget. Under this proposal, Project Managers from other units (e.g. Environmental, Traffic) would also have the opportunity to provide the A&E Review Board with consultant evaluations for internal (e.g. open ended) contracts.

   - Consulting Firm - will, for the first time, be able to determine what their strengths and weaknesses are, in the eye of their client - the Department - as well as how they compare to the industry as a whole. Once principals understand that future work is dependent on today's evaluations, they should start to take this process very seriously. By pointing out specific weaknesses this evaluation will also help them in their recruiting and training practices, which will eventually result in better MHD designs. Since a designer's final score will actually be a compilation of evaluations from a number of MHD reviewers, there is also less of a chance that one Project Manager may base an evaluation on previous personal experiences with the firm.

- A&E Review Board - will have access to much improved data on the quality of consultant's past work. For example, with a laptop at each meeting the Board could find out which firms have "scored" the best for complex bridge designs during the past three years, or who is best suited for an environmentally sensitive project. The system will also give the Board better information to back up their selection decisions, should they ever be disputed.

- RFP Selection Committees - would also have access to design evaluations for competing consultants in terms of past Department work, typically an important criteria for selection.

PROCESS AND ADMINISTRATION

The evaluation system would work in much the same way as it currently does; a two-part process in which the Project Manager is ultimately responsible for the design performance evaluation and the Resident Engineer is responsible for the constructibility evaluation. There are only five basic changes made to the current system:

1. All Department personnel who are responsible for reviewing a design are given the opportunity to provide input into the designer's evaluation. By evaluating a design specifically for roadway, bridge, traffic, environmental and other categories of work, the Department will be able to determine the specific strengths and weaknesses of individual design firms.

2. Vague qualitative terms such as good, fair, and poor have been replaced with more quantitative numeric scores. These scores will allow the Department to rank consultants. By basing the scores on a "5 = average" benchmark, managers will also be able to ensure that various units are evaluating designers fairly.

3. Evaluation criteria have either been expanded upon or clarified, to ensure that all aspects of the designer's performance are evaluated by the appropriate person.

4. The A&E Review Board will have access to a more complete data base which includes data on type of work, size of job, complexity of design, and performance rating. By including all of these criteria, and consolidating the design and constructibility reviews, the Board will have a meaningful overall index, or score, to assist them in making selection decisions.

5. By enhancing the lines of communication regarding quality issues (both informal on a continuous basis and formal at the end of the job), this system will serve as a partnering tool for all MHD projects - even when a more formal design partnering relationship may not be warranted.

The attached forms and memos show how the system might work. A brief description of each follows, along with a discussion of how the system might be administered in practice.

<u>Attachment 1</u>: The Project Manager's form letter (as sent to the District and Traffic) has been modified to include a request for evaluation by the reviewer - shown at the bottom of the memo. It explains that the reviewer's input <u>will</u> be used by the A&E Review Board in determining the amount and complexity of future design work assigned to this consultant. Once reviewers realize that their input makes a difference, they will

be more willing to actively participate in the review. The evaluation is based on a score of 1-10, with 5 being "average." One problem with existing evaluations is that everyone perceives terms such as "fair," "good" or "excellent" differently. Basing evaluations on "average" is much more meaningful, while enabling the Board to monitor consistency in scoring in each category over time, based on a bell curve distribution.

Attachment 2: When the design review is completed, the reviewer (in Traffic or the District) would simply include the evaluation score and any comments on the return memo. Other units, such as Geotechnical or Hydraulics, could include comments in a similar way, on their transmittal letters.

Attachment 3: For the Environmental Division the process will be slightly different, because often times a document (such as a CE Checklist or ENF) may need to undergo multiple iterations before it is satisfactorily completed. In this case, the appropriate Environmental Project Manager may wish to evaluate the consultant after the permits are approved, instead of for each submission. Attachment 3 has been developed by the Environmental Division as a means to evaluate performance once the permitting stage is complete. By evaluating each environmentally-related task separately, it helps to differentiate between minor and major permitting work based upon its complexity; for instance, preparation of an ENF versus an EIR under the MEPA/NEPA category. A firm which is very adept at preparing an ENF may not necessarily have the ability to prepare a more complex EIR. Although only the overall scores would be included in the evaluation "Summary Form," both the A&E Board and the Environmental Division would have access to the detailed evaluations - either on a case-by-case basis or to "rank" consultants for a specific task (e.g. EIR preparation). For open ended and other contracts within the Environmental Division, the Project Manager would submit a single form to the A&E Board, which would resemble Attachment 4.

Attachment 4: The only modifications to the existing Project Manager Evaluation Form are the 1-10 rating (rather than poor-excellent) and the addition of two criteria related to performance at public meetings and invoice preparation. The numerical scoring will ensure consistency with the rest of the evaluation rankings and the additional criteria cover areas not specifically noted on the current form. With this form, the Project Manager will have the same input as always regarding issues such as consultant responsiveness, cooperation, ingenuity, promptness, efficiency and ability to work within budget. These are the issues that the Project Manager is most concerned with, as opposed to more technical design issues generally addressed by others. For open ended and other contracts managed by other MHD units (e.g. Environmental, Traffic), the appropriate Project Manager would fill out an evaluation form similar to this.

Attachment 5: Once all reviews (and evaluations) are in, the Project Manager will be responsible for consolidating them, completing the "Evaluation Summary Form," and submitting it to the A&E Review Board as the final evaluation. Although it looks tedious, it is only a matter of filling in numbers (from each of the reviews) onto a spreadsheet, such as Lotus or Excel. The computer program will perform any necessary calculations. The only subjective matter is applying weighted scores to each category of work, depending upon the type of project. Obviously, a bridge project should be weighted higher for bridge scores, whereas a resurfacing job would be weighted higher for roadway scores. The Department initially plans to use two general approaches to weighting a project's scores:

- For MHD negotiated designs - basing weights on the number of manhours negotiated in each category of work (e.g. roadway, bridge, environmental), as presented in the final scope and manhour estimate. This should approximate the relative "importance" of each category as part of the total design effort and is the most quantitative approach.

- For designs not negotiated by MHD - setting up a number of standard weighting categories based upon the type of work involved, and determining which category a project best fits. For instance, a basic bridge job may be weighted 40% bridge, 20% project management, 20% roadway, 20% other. For work that does not fit into a "general" category, the Department may determine weights on a case-by-case basis, either before work begins or after it has been completed.

Attachment 6: The Record of Design (ROD) has also been modified to include more useful data, to categorize the criteria into more meaningful groupings, and to require more written explanations. The ROD will be filled out as part of the finals process, as is done today. The A&E Review Board will still be responsible for giving the designer a final numeric score, based on the Resident Engineer's input. It will need to be stressed within Construction that these RODs are a vital tool in ensuring that poor quality designs do not make their way out to the field in the future. As part of this process, Resident Engineers will have to clearly differentiate between EWOs required as a result of design error or omission, as opposed to EWOs beyond the control of the designer - to make certain that designers are not rated poorly due to EWOs for which they were not responsible. To that end, it is suggested that all EWOs be classified into three general categories, based on their cause, at the time that the Resident Engineer fills out the initial CSD-683 form: (1) design error or omission; (2) unforeseeable condition; or (3) change in scope requested by the Department. It would be helpful if major overruns/underruns and time extensions were classified in a similar way. (Note: The ROD form has not yet been finalized by the Construction Division.)

Attachment 7: This is a sample printout from an improved A&E Review Board data base, based on the evaluation system described above. The Board could use these evaluations to assist them in selecting the most qualified firms for a particular type of work. For instance, if looking for a consultant to design a complex bridge job, the A&E Review Board could query the consultant data base for the firm(s) with the highest bridge quality ratings. As in the case of Attachment 7, the Board could also query the data base for all evaluations for a specific consultant, to determine how the firm rates in various technical areas. It shows how well the consultant compares to all other prequalified A/E firms in terms of roadway, bridge, environmental and other work, and includes data on the constructibility of the firm's designs as well. (For instance, this sample shows that Designer Corp. performs very well for bridge work, but quite poorly in terms of environmental work.) It also shows trends in designer performance; such as a steady improvement over time (especially important in evaluating less experienced firms). Although "quality" ratings are just one of the measures used by the A&E Review Board, this type of information will lead to better selections, which will lead to better quality designs which, in turn, will lead to less review time and fewer cost overruns in the field.

Attachment 8: This bar chart shows Attachment 7 data in graphical form; that is, how a specific consulting firm (Designer Corp.) compares with the industry as a whole. Although this chart does not show anything new, it is sometimes easier to visualize strengths and weaknesses (compared to the industry average) in this format. A chart such as this may also be useful to send to the principals of consulting firms, at the discretion of the A&E Review Board and Chief Engineer, so that they can see for themselves the quality of work that their staff is providing to the Department. By identifying their weaknesses, they will be able to take steps through recruiting, training and better managing to improve in these areas.

DEVELOPMENT AND IMPLEMENTATION

Although the framework for this evaluation system was initially prepared by the A&E Review Board, it has been developed and improved based on considerable input from ACEC and others. Several meetings were held with ACEC members, through the MHD/ACEC Partnership, between March 1996 and April 1997. Once the Task Force reached consensus on the plan, it was discussed with MHD managers to ensure that it met their divisional needs. Finally, the system was presented to MHD staff involved in the review process through two workshops, one for Project Managers and another for reviewers. Their comments were incorporated into the final system design.

The Department is now in the process of putting the new evaluation system into place. Project managers are using the revised forms and the A&E Review Board has developed a new data base for collecting and analyzing the information. Consultant evaluations recently submitted in the "old" (i.e. poor to excellent) format are being prorated into the "1 to 10 scale" scoring basis by the A&E Review Board. Over the course of the next couple of months, implementation should be completed.

It needs to be recognized up front that the real benefits of this system are long term, once there are enough designers and projects in the data base to make true comparisons and useful queries. In the short term, all reviewers will feel that their input does make a difference, the A&E Review Board will have more complete data to assist them in making selection decisions, and designers will have better feedback regarding the quality of their work. It is important that all those involved have realistic expectations so that they will not become discouraged, which could eventually lead to apathy and poor input.

Finally, this is just one piece of the puzzle in terms of improving the quality of consultant designs. Other ideas such as "quality assurance" reviews, random "quality audits," constructibility reviews and cost recovery have all been discussed in various forums, and all should eventually be considered together as part of a comprehensive long term solution for improving quality at all levels.

APPENDIX H

MASSHIGHWAY'S FORM 683

MassHighway analyzes each construction extra work order (EWO) to determine its cause. This analysis has two basic purposes:

1. Categorize the cause of the extra work order:
- Design error or omission,
- Unforeseen condition, or
- MassHighway request for out of scope work.
2. Obtain official approvals for changing the project requirements:
- MassHighway's Approval
- Federal Highway Administration Approval

The results of the EWO analysis are recorded on MassHighway's Form 683 (copy on next page of this appendix). Every extra work order recorded on a Form 683 is included in the total count and cost of EWO's. Each EWO that is classified as *#1. Design Error or #2. Item Omission* is included in the quality measurements as *design-related extra work orders* having the index acronym *D-REWI.*

THE COMMONWEALTH OF MASSACHUSETTS
MASSACHUSETTS HIGHWAY DEPARTMENT
RESIDENT ENGINEER'S REPORT OF CHANGES IN DESIGN, SPECIFICATIONS OR PRELIMINARY ESTIMATE FEATURES

City or Town:
Route No. or Location:
Contract No.:
Contractor:

Federal Aid No.:

Project Report No.:

Project File No.:

Describe fully by stations, offsets, depths or whatever is necessary to provide a complete record of what the change is from plan, specification or what was anticipated. The changes could ultimately result in underrun, overrun, extra work or alteration.

Comments or contacts made with a Federal Highway Administration Representative, including dates involved, leading up to Federal Highway Administration Representative's approval of change.

Environmental Review Required:
Yes____ No____

_______________________ *Resident Engineer (Signature)* ________ *Date*

________ A.S. (Initial) ________ A.D.C.E. (Initial)

ACTION BY- _______________________ *FHWA Representative (Signature) Retain Copy* ________ *Date*

1. APPROVED
2. RECOMMEND FOR APPROVAL
3. CONCUR IN DEPARTMENT ACTION
4. OTHER ACTION

APPROVED BY- _______________________ *District Construction Engineer (Signature)* ________ *Date*

COPIES TO-
Construction Engineer (2)
District Highway Director
FHWA
file

CAUSE OF EWO
Circle appropriate Number

1 2 3 4 5 6 7 8 9

A. Design Error or Omission
   1. Design Error
   2. Item Omission

B. Unforeseen Condition
   3. Subsurface or latent field condition
   4. Changed field condition

C. Department request for Out-of-Scope Work
   5. Request by city/town
   6. Safety/accident related
   7. Repairs/other work requested while under contract
   8. Handling contaminated materials
   9. Other Department request (specify)

APPENDIX I

TEST DATA

Summary test results from each of the "footprint" bridge projects are included in this appendix, as follows:

Project	Table
Alpha	I-1
Beta	I-2
Epsilon	I-3
Lambda	I-4
Omega	I-5
Sigma	I-6

Table I-1: Project Alpha Summary of Measurements of Design Quality

Project and Measurements Report Identification

		MHD Contract No.	#####
Project Name / Description	**ALPHA**	Payment Voucher (PV) No.	#####
Project Location (city or town)	*(name of city/town)*	PV Closing Date	*mm/dd/yy*
MHD Project Manager	*(name of MHD expediter)*	Measuring Date	*mm/dd/yy*
Consulting Firm	*(name of consulting firm)*	Design Month No.	*##*
Consulting Firm's Project Mgr	*(name of project manager in consulting firm)*	Design % Complete	*100%*
		Construction % Complete	*100%*

Measurements Taken During Design

Earned Value Indexes					Consultant Performance Evaluation			
Percent Complete	**Report Date**	**CPI**	**SPI**	**DQI**	**Discipline / Deliverable**	**Raw Score**	**Weighted Score**	**Percent "Perfect"**
					Project Mgmt Evaluation	5.2	1.04	52%
8%	22-Jan-93	0.41	0.34	0.37	Roadway	0.0	0.00	0%
31%	19-Feb-93	0.80	0.84	0.82	25% Submittal	0.0		0%
44%	26-Mar-93	0.74	0.78	0.76	75/100% Submittal	0.0		0%
53%	30-Apr-93	0.75	0.77	0.76	Specs & Estimate	0.0		0%
62%	28-May-93	0.81	0.77	0.79	Bridge	0.0	0.00	0%
68%	30-Jun-93	0.85	0.80	0.82	Type/Sketch	0.0		0%
71%	23-Jul-93	0.82	0.80	0.81	Final Design	0.0		0%
77%	3-Sep-93	0.79	0.77	0.78	Specs & Estimate	0.0		0%
96%	1-Oct-93	0.89	0.96	0.92	Traffic	0.0	0.00	0%
99%	29-Oct-93	0.92	0.99	0.96	Signs/Pavement	0.0		0%
100%	26-Nov-93	0.93	1.00	0.97	Signals & Lighting	0.0		0%
					Operations/Safety	0.0		0%
					Environmental	0.0	0.00	0%
					MEPA/NEPA	0.0		0%
					Wetlands/Water Quality	0.0		0%
					Cultural Resources	0.0		0%
					Hazardous Materials	0.0		0%
					Design Plans	0.0		0%
					Other	0.0		0%
					Other Disciplines	0.0	0.00	0%
					Geotechnical	0.0		0%
					Hydraulics	0.0		0%
Median		**0.81**	**0.80**	**0.81**	Landscape	0.0		0%
Average		**0.79**	**0.80**	**0.80**	Right-of-Way	0.0		0%
					Composite Evaluation		1.04	10%

Measurements Taken During Construction

Measurement	Index	$ Amount	Index	% Low Bid
Lowest Bid Price		$342,930		100.0%
MHD Office Estimated Construction Cost	**OEI**	$351,041	**0.976**	102.4%
Average of Bid Prices		$385,303		112.4%
STDEV in Bid Prices	**BVI**	$40,002	**0.883**	11.7%
Highest Bid		$443,627		129.4%
Final Total Construction Cost		$379,886		110.8%
Net Cost of Overruns / Underruns		$16,760		4.9%
Cost of Quantity Overruns		$29,243		8.5%
Cost of Quantity Underruns	**QEI**	$12,483	**0.879**	3.6%
Total Cost of Construction Extra Work Orders	**EWI**	$20,196	**0.941**	5.9%
Design Related Construction Extra Work Orders	**D-REWI**	$1,868	**0.995**	0.5%

Direct Labor Cost of Design		$36,458		10.6%

Table I-2: Project Beta Summary of Measurements of Design Quality

Project and Measurements Report Identification

		MHD Contract No.	#####
Project Name / Description	**BETA**	Paymnt Voucher (PV) No.	#####
Project Location (city or town)	*(name of city/town)*	PV Closing Date	*mm/dd/yy*
MHD Project Manager	*(name of MHD expediter)*	Measuring Date	*mm/dd/yy*
Consulting Firm	*(name of consulting firm)*	Design Month No.	*##*
Consulting Firm's Project Mgr	*(name of project manager in consulting firm)*	Design % Complete	%
		Construction % Complete	%

Measurements Taken During Design

Earned Value Indexes					Consultant Performance Evaluation			
Percent Complete	**Report Date**	**CPI**	**SPI**	**DQI**	**Discipline / Deliverable**	**Raw Score**	**Weighted Score**	**Percent Perfect**
					Project Mgmt Evaluation	8.0	1.60	80%
19%	1-Aug-92	0.75	0.50	0.63	Roadway	0.0	0.00	0%
57%	26-Sep-92	0.85	0.65	0.75	25% Submittal	0.0		0%
70%	24-Oct-92	0.89	0.70	0.80	75/100% Submittal	0.0		0%
87%	28-Nov-92	0.93	0.87	0.90	Specs & Estimate	0.0		0%
96%	26-Dec-92	0.86	0.96	0.91	Bridge	0.0	0.00	0%
98%	27-Mar-93	0.78	0.98	0.88	Type/Sketch	0.0		0%
					Final Design	0.0		0%
					Specs & Estimate	0.0		0%
					Traffic	0.0	0.00	0%
					Signs/Pavement	0.0		0%
					Signals & Lighting	0.0		0%
					Operations/Safety	0.0		0%
					Environmental	0.0	0.00	0%
					MEPA/NEPA	0.0		0%
					Wetlands/Water Quality	0.0		0%
					Cultural Resources	0.0		0%
					Hazardous Materials	0.0		0%
					Design Plans	0.0		0%
					Other	0.0		0%
					Other Disciplines	0.0	0.00	0%
					Geotechnical	0.0		0%
					Hydraulics	0.0		0%
Average		**0.85**	**0.78**	**0.81**	Landscape	0.0		0%
Median		**0.86**	**0.79**	**0.81**	Right-of-Way	0.0	-	0%
					Composite Evaluation		1.60	16%

Measurements Taken During Construction

Measurement	Index	$ Amount	Index	% Low Bid
Lowest Bid Price		$307,554		100.0%
MHD Office Estimated Construction Cost	**OEI**	$338,452	**0.900**	110.0%
Average of Bid Prices		$353,689		115.0%
STDEV in Bid Prices	**BVI**	$52,635	**0.829**	17.1%
Highest Bid Price		$407,165		132.4%
Final Total Construction Cost		$317,364		103.2%
Net Cost of Overruns / Underruns		($188)		-0.1%
Cost of Quantity Overruns		$13,171		4.3%
Cost of Quantity Underruns	**QEI**	$13,359	**0.914**	4.3%

Total Cost of Construction Extra Work Orders	**EWI**	$9,998	**0.967**	3.3%
Design Related Construction Extra Work Orders	**D-REWI**	$9,998	**0.967**	3.3%
Direct Labor Cost of Design		$35,320		11.5%

Table I-3: Project Epsilon Summary of Measurements of Design Quality

Project and Measurements Report Identification

		MHD Contract No.	*#####*
Project Name / Description	**EPSILON**	Payment Voucher (PV) No.	*#####*
Project Location (city or town)	*(name of city/town)*	PV Closing Date	*mm/dd/yy*
MHD Project Manager	*(name of MHD expediter)*	Measuring Date	*mm/dd/yy*
Consulting Firm	*(name of consulting firm)*	Design Month No.	*##*
Consulting Firm's Project Mgr	*(name of project manager in consulting firm)*	Design % Complete	*%*
		Construction % Complete	*%*

Measurements Taken During Design

Earned Value Indexes					Consultant Performance Evaluation			
Percent Complete	**Report Date**	**CPI**	**SPI**	**DQI**	**Discipline / Deliverable**	**Raw Score**	**Weighted Score**	**Percent "Perfect"**
					Project Mgmt Evaluation	8.0	1.60	80%
9%	28-Feb-94	1.02	1.00	0.99	Roadway	0.0	0.00	0%
10%	31-Mar-94	0.79	1.00	0.90	25% Submittal	0.0		0%
23%	30-Jun-94	0.84	0.75	0.80	75/100% Submittal	0.0		0%
28%	31-Jul-94	0.78	0.74	0.76	Specs & Estimate	0.0		0%
31%	31-Aug-94	0.67	0.38	0.52	Bridge	0.0	0.00	0%
47%	30-Sep-94	0.99	0.53	0.76	Type/Sketch	0.0		0%
75%	31-Oct-94	1.16	0.75	0.79	Final Design	0.0		0%
82%	26-Nov-94	1.01	0.82	0.90	Specs & Estimate	0.0		0%
93%	31-Dec-94	1.05	0.93	0.94	Traffic	0.0	0.00	0%
94%	28-Jan-95	1.06	0.94	0.94	Signs/Pavement	0.0		0%
96%	25-Feb-95	1.07	0.96	0.95	Signals & Lighting	0.0		0%
97%	31-Mar-95	1.07	0.97	0.95	Operations/Safety	0.0		0%
97%	29-Apr-95	1.05	0.97	0.96	Environmental	0.0	0.00	0%
98%	27-May-95	1.04	0.98	0.97	MEPA/NEPA	0.0		0%
98%	24-Jun-95	0.94	0.98	0.96	Wetlands/Water Quality	0.0		0%
98%	1-Feb-97	0.92	0.98	0.95	Cultural Resources	0.0		0%
					Hazardous Materials	0.0		0%
					Design Plans	0.0		0%
					Other	0.0		0%
					Other Disciplines	0.0	0.00	0%
					Geotechnical	0.0		0%
					Hydraulics	0.0		0%
Median		**1.02**	**0.95**	**0.94**	Landscape	0.0		0%
Average		**0.97**	**0.86**	**0.88**	Right-of-Way	0.0		0%
					Composite Evaluation		1.60	16%

Measurements Taken During Construction

Measurement	Index	$ Amount	Index	% Low Bid
Lowest Bid Price		$717,756		100.0%
MHD Office Estimated Construction Cost	**OEI**	$767,585	**0.931**	106.9%
Average of Bid Prices		$771,209		107.4%
STDEV in Bid Prices	**BVI**	$58,968	**0.918**	8.2%
Highest Bid Price		$854,943		119.1%
Final Total Construction Cost		$742,776		103.5%
Net Cost of Quantity Overruns / Underruns		$9,834		1.4%
Cost of Quantity Overruns		$28,839		4.0%

Cost of Quantity Underruns	**QEI**	$19,005	**0.935**	2.5%
Total Cost of Construction Extra Work Orders	**EWI**	$15,186	**0.979**	2.1%
Design Related Construction Extra Work Orders	**D-REWI**	$0	**1.000**	0.0%
Direct Labor Cost of Design		$39,522		5.5%

Table I-4: Project Lambda Summary of Measurements of Design Quality

Project and Measurements Report Identification									
							MHD Contract No.		*#####*
Project Name / Description			**LAMBDA**				Paymnt Voucher (PV) No.		*#####*
Project Location (city or town)			*(name city / town)*				PV Closing Date		*mm/dd/yy*
MHD Project Manager			*(name of MHD project expediter)*				Report Date		*mm/dd/yy*
Consulting Firm			*(name of consulting firm)*				Design Month No.		*##*
Consulting Firm's Project Mgr			*(name of project manager in consulting firm)*				Design % Complete		*%*
							Construction % Complete		*%*
Measurements Taken During Design									
Earned Value Indexes					**Consultant Performance Evaluation**				
Percent Complete	**Report Date**	**CPI**	**SPI**	**DQI**	**Discipline / Deliverable**		**Raw Score**	**Weight Score**	**Percent "Perfect"**
					Project Mgmt Evaluation		8.0	1.60	80%
3%	15-Oct-94	1.22	0.76	0.77	Roadway		7.1	1.92	71%
10%	19-Nov-94	1.32	0.87	0.78		25% Submittal	6.7		67%
20%	24-Dec-94	1.10	0.80	0.85		75/100% Submittal	8.1		81%
26%	21-Jan-95	0.70	0.91	0.81		Specs & Estimate	6.5		65%
42%	18-Mar-95	0.69	1.25	0.72	Bridge		7.7	3.54	77%
45%	15-Apr-95	0.62	1.32	0.65		Type/Sketch	9.0		90%
53%	13-May-95	0.68	1.08	0.80		Final Design	6.0		60%
60%	30-Jun-95	0.73	0.71	0.72		Specs & Estimate	8.0		80%
63%	2-Sep-95	0.71	0.63	0.67	Traffic		7.1	0.10	71%
62%	30-Sep-95	0.57	0.62	0.60		Signs/Pavement	8.0		80%
93%	11-Nov-95	0.84	0.93	0.88		Signals & Lighting	8.0		80%
100%	30-Mar-96	0.89	1.00	0.94		Operations/Safety	5.0		50%
					Environmental		7.6	0.17	76%
						MEPA/NEPA	8.0		80%
						Wetlands/Water Quality	5.0		50%
						Cultural Resources	9.0		90%
						Hazardous Materials	8.0		80%
						Design Plans	9.0		90%
						Other	7.5		75%
					Other Disciplines		7.5	0.23	75%
						Geotechnical	8.0		80%
						Hydraulics	5.0		50%
Average		**0.84**	**0.91**	**0.77**		Landscape	9.0		90%
Median		**0.72**	**0.87**	**0.77**		Right-of-Way	8.0		80%
					Composite Evaluation			7.56	76%
Measurements Taken During Construction									
Measurement						**Index**	**$ Amount**	**Index**	**% Low Bid**
Lowest Bid Price							$761,096		100.0%
MHD Office Estimated Construction Cost						**OEI**	$646,604	**0.850**	85.0%
Average of Bid Prices							$881,161		115.8%
STDEV in Bid Prices						**BVI**	$77,693	**0.898**	10.2%
Highest Bid							$0		38.4%
Final Total Construction Cost							$756,434		99.4%
Net Cost of Quantity Overruns / Underruns							$ (18,278)		-2.4%
Cost of Quantity Overruns							$ 21,367		2.8%

Cost Of Quantity Underruns	**QEI**	$ (39,644)	**1.052**	-5.2%
Total Cost of Construction Extra Work Orders	**EWI**	$13,616	**0.982**	1.8%
Design Related Construction Extra Work Orders	**D-REWI**	$0	**1.000**	0.0%
Direct Labor Cost of Design		$40,184		5.3%

Table I-5: Project Omega Summary of Measurements of Design Quality

Project and Measurements Report Identification			
		MHD Contract No.	#######
Project Name / Description	**OMEGA**	Payment Voucher (PV) No.	#####
Project Location (city or town)	*(name of city/town)*	PV Closing Date	*mm/dd/yy*
MHD Project Manager	*(name of MHD expediter)*	Measuring Date	*mm/dd/yy*
Consulting Firm	*(name of consulting firm)*	Design Month No.	*##*
Consulting Firm's Project Mgr	*(name of project manager in consulting firm)*	Design % Complete	*%*
		Construction % Complete	*%*

Measurements Taken During Design

Earned Value Indexes					Consultant Performance Evaluation			
Percent Complete	**Report Date**	**CPI**	**SPI**	**DQI**	**Discipline / Deliverable**	**Raw Score**	**Weighted Score**	**Percent "Perfect"**
					Project Mgmt Evaluation	5.8	1.60	58%
4%	1-Jan-93	1.55	2.97	-0.26	Roadway	0.0	0.00	0%
5%	29-Jan-93	1.11	2.99	-0.05	25% Submittal	0.0		0%
8%	26-Feb-93	0.90	0.41	0.65	75/100% Submittal	0.0		0%
8%	26-Mar-93	0.75	0.28	0.52	Specs & Estimate	0.0		0%
10%	30-Apr-93	0.79	0.32	0.55	Bridge	0.0	0.00	0%
10%	28-May-93	0.65	0.13	0.39	Type/Sketch	0.0		0%
17%	25-Jun-93	0.82	0.17	0.50	Final Design	0.0		0%
22%	30-Jul-93	0.75	0.22	0.49	Specs & Estimate	0.0		0%
24%	27-Aug-93	0.79	0.24	0.52	Traffic	0.0	0.00	0%
25%	24-Sep-93	0.73	0.25	0.49	Signs/Pavement	0.0		0%
40%	26-Nov-93	0.79	0.40	0.59	Signals & Lighting	0.0		0%
79%	31-Dec-93	1.05	0.79	0.87	Operations/Safety	0.0		0%
79%	28-Jan-94	1.04	0.79	0.87	Environmental	0.0	0.00	0%
79%	25-Mar-94	1.03	0.79	0.88	MEPA/NEPA	0.0		0%
79%	27-May-94	1.03	0.79	0.88	Wetlands/Water Quality	0.0		0%
94%	30-Jun-94	1.07	0.94	0.94	Cultural Resources	0.0		0%
94%	22-Jul-94	1.04	0.94	0.95	Hazardous Materials	0.0		0%
100%	26-Aug-94	1.10	1.00	0.95	Design Plans	0.0		0%
					Other	0.0		0%
					Other Disciplines	0.0	0.00	0%
					Geotechnical	0.0		0%
Average		**0.94**	**0.80**	**0.60**	Hydraulics	0.0		0%
Median		**0.96**	**0.60**	**0.57**	Landscape	0.0		0%
					Right-of-Way	0.0		0%
					Composite Evaluation		1.60	16%

Measurements Taken During Construction

Measurement	Index	$ Amount	Index	% Low Bid
Lowest Bid Price		$510,039		100.0%
MHD Office Estimated Construction Cost	**OEI**	$507,235	**0.995**	99.5%
Average of Bid Prices		$684,506		134.2%
STDEV in Bid Prices	**BVI**	$168,022	**0.671**	32.9%
Highest Bid Price		$871,283		170.8%
Final Total Construction Cost		$722,083		141.6%
Net Cost of Quantity Overruns / Underruns		$7,026		1.4%
Cost of Quantity Overruns		$16,860		3.3%
Cost of Quantity Underruns	**QEI**	($9,833)	**0.948**	-1.9%
Total Cost of Construction Extra Work Orders	**EWI**	$205,018	**0.598**	40.2%
Design Related Construction Extra Work Orders	**D-REWI**	$63,185	**0.876**	12.4%

Direct Labor Cost of Design		$41,374		8.1%

Table I-6: Project Sigma Summary of Measurements of Design Quality

Project and Measurements Report Identification

		MHD Contract No.	*#####*
Project Name / Description	**SIGMA**	Payment Voucher (PV) No.	*#####*
Project Location (city or town)	*(name of city/town)*	PV Closing Date	*mm/dd/yy*
MHD Project Manager	*(name of MHD expediter)*	Measuring Date	*mm/dd/yy*
Consulting Firm	*(name of consulting firm)*	Design Month No.	*##*
Consulting Firm's Project Mgr	*(name of project manager in consulting firm)*	Design % Complete	*%*
		Construction % Complete	*%*

Measurements Taken During Design

Earned Value Indexes					Consultant Performance Evaluation			
Percent Complete	**Report Date**	**CPI**	**SPI**	**DQI**	**Discipline / Deliverable**	**Raw Score**	**Weighted Score**	**Percent Perfect**
					Project Mgmt Evaluation	8.1	1.62	81%
19%	30-Apr-93	1.39	0.81	0.71	Roadway	0.0	0.00	0%
24%	31-May-93	0.99	0.66	0.82	25% Submittal	0.0		0%
37%	30-Jun-93	1.12	0.86	0.87	75/100% Submittal	0.0		0%
52%	31-Jul-93	1.16	0.95	0.90	Specs & Estimate	0.0		0%
61%	31-Aug-93	0.94	0.62	0.78	Bridge	0.0	0.00	0%
76%	30-Sep-93	0.94	0.76	0.85	Type / Sketch	0.0		0%
96%	31-Oct-93	0.85	0.96	0.91	Final Design	0.0		0%
100%	30-Nov-93	0.80	1.00	0.90	Specs & Estimate	0.0		0%
					Traffic	0.0	0.00	0%
					Signs/Pavement	0.0		0%
					Signals & Lighting	0.0		0%
					Operations/Safety	0.0		0%
					Environmental	0.0	0.00	0%
					MEPA/NEPA	0.0		0%
					Wetlands/Water Quality	0.0		0%
					Cultural Resources	0.0		0%
					Hazardous Materials	0.0		0%
					Design Plans	0.0		0%
					Other	0.0		0%
					Other Disciplines	0.0	0.00	0%
					Geotechnical	0.0		0%
					Hydraulics	0.0		0%
Average		**1.02**	**0.83**	**0.84**	Landscape	0.0		0%
Median		**0.96**	**0.84**	**0.86**	Right-of-Way	0.0		0%
					Composite Evaluation		1.62	16%

Measurements Taken During Construction

Measurement	**Index**	**$ Amount**	**Index**	**% Low Bid**
Lowest Bid Price		$244,582		100.0%
MHD Office Estimated Construction Cost	**OEI**	$238,938		97.7%
Average of Bid Prices		$286,406		117.1%
STDEV in Bid Prices	**BVI**	$32,688	**0.866**	13.4%
Highest Bid		$340,711		139.3%
Final Total Construction Cost		$267,699		109.5%
Net Cost of Quantity Overruns / Underruns		$5,072		2.1%
Cost of Quantity Overruns		$11,415	**0.927**	4.7%
Cost of Quantity Underruns	**QEI**	($6,344)		-2.6%
Total Cost of Construction Extra Work Orders	**EWI**	$18,717		7.7%
Design Related Construction Extra Work Orders	**D-REWI**	$18,717	**0.923**	7.7%

Direct Labor Cost of Design		$46,618		19.1%

NOTES

[1] International Organization for Standardization (ISO) (1992). *ISO 9000 International Standards for Quality Management* (2nd ed.). Geneva: ISO, p. 16.

[1] American Society of Civil Engineers (ASCE). (1988). *Quality in the Constructed Project—A Guideline for Owners, Designers, and Constructors.* New York: American Society of Civil Engineers, p. 17.

[1] National Quality Initiative (NQI) Steering Committee. (November 13, 1997). National Policy on the Quality of Highways [Online]. Available: http://www.nqi.org/policy.html [January 24, 1998], p. 1.

[1] Ibid.

[1] National Quality Initiative (NQI) Steering Committee. (November 13, 1997). National Policy on the Quality of Highways [Online]. Available: http://www.nqi.org/policy.html [January 24, 1998], p. 13-14.

[1] Karakaya, F. and Mogawer, W. S. (1997). *Evaluation of the Road System in Massachusetts*. Amherst, MA: University of Massachusetts Transportation Center, p. viii.

[1] Project Management Institute Standards Committee. (1996). *A Guide to the Project Management Body of Knowledge.* Upper Darby, PA: Project Management Institute, p. 167.

[1] Ibid.

[1] Ibid.

[1] Ireland, L. R. (1991). *Quality Management for Projects and Programs*. Upper Darby, PA: Project Management Institute, p. i.

[1] Deming, W. E. (1982, 1986). *Out of the Crisis*. Cambridge, MA: Massachusetts Institute of Technology, Center for Advanced Engineering Study, p. 169.

[1] Crosby, P. B. (1984). *Quality Without Tears: The Art of Hassle-Free Management*. New York: McGraw-Hill, p. 59.

[1] Ibid.

[1] Juran, J. M., & Gryna, F. M. (Eds.). (1988). T*he Quality Control Handbook* (4th ed.). New York: McGraw-Hill.

[1] International Organization for Standardization (ISO) (1992). *ISO 9000 International Standards for Quality Management* (2nd ed.). Geneva: ISO, p. 16.

[1] Ibid., p. 17.

[1] Ibid.

[1] Project Management Institute Standards Committee. (1996). *A Guide to the Project Management Body of Knowledge*. Upper Darby, PA: Project Management Institute, p. 84.

[1] American Society of Civil Engineers (ASCE). (1988). *Quality in the Constructed Project—A Guideline for Owners, Designers, and Constructors.* New York: American Society of Civil Engineers, p. 17.

[1] National Quality Initiative (NQI) Steering Committee. (November 13, 1997). National Policy on the Quality of Highways [Online]. Available: http://www.nqi.org/policy.html [January 24, 1998], p. 1.

[1] Ibid.

[1] Ibid., p. 13-14.

[1] Karakaya, F. and Mogawer, W. S. (1997). *Evaluation of the Road System in Massachusetts*. Amherst, MA: University of Massachusetts Transportation Center, p. viii.

[1] American Society of Civil Engineers (ASCE). (1988). *Quality in the Constructed Project—A Guideline for Owners, Designers, and Constructors.* New York: American Society of Civil Engineers, p. 19.

[1] Project Management Institute Standards Committee. (1996). *A Guide to the Project Management Body of Knowledge.* Upper Darby, PA: Project Management Institute, p. 108.

[1] American Society of Civil Engineers (ASCE). (1988). *Quality in the Constructed Project—A Guideline for Owners, Designers, and Constructors.* New York: American Society of Civil Engineers, p. 182.

BIBLIOGRAPHY

AASHTO (1991). *AASHTO Guidelines for Preconstruction Engineering Management*. Washington, DC: American Association of State Highway and Transportation Officials (AASHTO).

AASHTO (1995). *A Policy on Geometric Design of Highways and Streets 1994*. Washington, DC: American Association of State Highway and Transportation Officials (AASHTO).

AASHTO Task Force on Preconstruction Engineering Management (1996*). Guide for Contracting, Selecting, and Managing Consultants in Preconstruction*. Washington, DC: American Association of State Highway and Transportation Officials (AASHTO).

Ahmed, S. M. (September 1994). An Integrated Total Quality Management (TQM) Model for the Construction Process. *Quality Management Journal*. 2(1), 6.

American Productivity & Quality Center. Current Productivity and Quality Resources [Online]. Available: http://www.apqc.org/b5/b5.htm [November 3, 1997].

American Society for Quality. Cost of Quality [Online]. Available: http://www.asq.org/abtquality/govt/cost.html [November 3, 1997].

American Society for Quality. Government Quality [Online]. Available: http://www.asq.org/abtquality/govt/gquality.html [November 3, 1997].

American Society for Quality. Total Quality Management [Online]. Available: http://www.asq.org/abtquality/govt/total.html [November 3, 1997].

American Society of Civil Engineers (1988). *Quality in the Constructed Project*. New York: American Society of Civil Engineers.

Arditi, D. and Gunaydin, H. M. (May/June 1998). Factors That Affect Process Quality in the Life Cycle of Building Projects. *Journal of Construction Engineering and Management*. 124(3), 194-203.

Arizona Department of Transportation. Value Engineering Reports (How Other States Do It) [Online]. Available: http://www.dot.state.az.us/ABOUT/va/reports.html [November 12, 1997].

Beheiry, M. F. The Cost of Quality [Online]. Available: http://www.dbainc.com/dba2/library/cost.html [November 3, 1997].

Braithwaite, J. J. (May 1990). Highway Design and Quality: A Local Authority Viewpoint. *Highways and Transportation*. 37(5), 19-21.

Butler, D. A Comprehensive Survey On How Companies Improve Performance Through Quality Efforts: Common Features Contributing to Improved Performance [Online]. Available: http://www.dbainc.com/dba2/library.survey/section4.html [November 3, 1997].

Butler, D. The Benefits of The David Butler Total Quality Management Process [Online]. Available: http://www.dbainc.com/dba2/library/benefits.html [November 5, 1997].

Butler, D. The Price of Non-Quality Elements [Online]. Available: http://www.dbainc.com/dba2/library/price.html [November 3, 1997].

Butler, D. The Total Quality Management Glossary of Terms [Online]. Available: http://www.dbainc.com/dba2/library/glossary.html [November 5, 1997].

Code FT Program/Project Management Librarian, NASA Headquarters Library. Doing More With Less [Online]. Available: http://www.hq.nasa.gov/office/hqlibrary/ppm/ppm19.htm [October 7, 1997].

Code FT Program/Project Management Librarian, NASA Headquarters Library. Index to PPM Resource Lists [Online]. Available: http://www.hq.nasa.gov/office/hqlibrary/ppm/ppmbib.htm [October 7, 1998].

Code FT Program/Project Management Librarian, NASA Headquarters Library. ISO 9000 Program/Project Management Resource List #45 [Online]. Available: http://www.hq.nasa.gov/office/hqlibrary/ppm/ppm45.htm [October 7, 1997].

Code FT Program/Project Management Librarian, NASA Headquarters Library. Joseph M. Juran: A Reading List [Online]. Available: http://www.hq.nasa.gov/office/hqlibrary/ppm/ppm20.htm [October 7, 1997].

Code FT Program/Project Management Librarian, NASA Headquarters Library. Partnering [Online]. Available: http://www.hq.nasa.gov/office/hqlibrary/ppm/ppm47.htm [October 7, 1997]. Code FT Program/Project Management Librarian, NASA Headquarters Library. Quality Metrics and Measurements [Online]. Available: http://www.hq.nasa.gov/office/hqlibrary/ppm/ppm7.htm [October 7, 1997].

Code FT Program/Project Management Librarian, NASA Headquarters Library. Selected Articales on TQM in the Public Sector [Online]. Available: http://www.hq.nasa.gov/office/hqlibrary/ppm/ppm4.htm [October 7, 1997].

Code FT Program/Project Management Librarian, NASA Headquarters Library. Taguchi Methods for Quality Control [Online]. Available: http://www.hq.nasa.gov/office/hqlibrary/ppm/ppm32.htm [October 7, 1997].

Code FT Program/Project Management Librarian, NASA Headquarters Library. The Cost of Quality [Online]. Available: http://www.hq.nasa.gov/office/hqlibrary/ppm/ppm35.htm [October 7, 1997].

Code FT Program/Project Management Librarian, NASA Headquarters Library. The Deming Management Method [Online]. Available: http://www.hq.nasa.gov/office/hqlibrary/ppm/ppm6.htm [October 7, 1997].

Code FT Program/Project Management Librarian, NASA Headquarters Library. TQM Case Studies [Online]. Available: http://www.hq.nasa.gov/office/hqlicrary/ppm/ppm37.htm [October 7, 1997].

Construction Industry Institute (1989). *Costs of Quality Deviations in Design and Construction*. Austin, TX: Construction Industry Institute, University of Texas.

Construction Industry Institute (1989). *Measuring the Cost of Quality in Design and Construction*. Austin, TX: Construction Industry Institute, University of Texas.

Construction Industry Institute. Quality Management Catalog [Online]. Available: http://construction-institute.org/services/catalog/products/quality.htm [November 6, 1997].

Crosby, P. B. (1972, 1981). *The Art of Getting Your Own Sweet Way*. New York: McGraw-Hill.

Crosby, P. B. (1979). *Quality Is Free: The Art of Making Quality Certain*. New York: McGraw-Hill.

Crosby, P. B. (1984). *Quality Without Tears: The Art of Hassle-Free Management*. New York: McGraw-Hill.

Crosby, P. B. (1986). *Running Things: The Art of Making Things Happen*. New York: McGraw-Hill.

Crosby, P. B. (1988). *The Eternally Successful Organization: The Art of Corporate Wellness*. New York: McGraw-Hill.

Crosby, P. B. (1989). *Let's Talk Quality: 96 Questions You Always Wanted to Ask Phil Crosby*. New York: McGraw-Hill.

Crosby, P. B. (1990). *Leading: The Art of Becoming an Executive*. New York: McGraw-Hill.

Crosby, P. B. (1996). *Phil Crosby's Reflections on Quality*. New York: McGraw-Hill.

Crosby, P. B. (1996). *Quality Is Still Free: Making Quality Certain in Uncertain Times*. New York: McGraw-Hill.

Dean, E. B. Design for Quality Bibliography [Online]. Available: http://akao.larc.nasa.gov/dfc/biblio/dfqualB.html [October 9, 1997].

Dean, E. B. Design for Quality from the Perspective of Competitive Advantage [Online]. Available: http://garcia1.larc.nasa.gov/dfca/dfc/dfqual.html [October 9, 1997].

Dean, E. B. Taguchi Methods Bibliography [Online]. Available: http://mijuno.larc.nasa.gov/dfc/biblio/tmBiblio.html [October 9, 1997].

Dean, E. B. Total Quality Management Bibliography [Online]. Available: http://mijuno.larc.nasa.gov/dfc/biblio/tqmB.html [October 30, 1997].

Deming Electronic Network. Deming Bibliographies [Online]. Available: http://deming.ces.clemson.edu/pub/den/deming_biblio.htm [October 21, 1997].

Deming Electronic Network. Information about Dr. Deming [Online]. Available: http://deming.ces.clemson.edu/pub/den/deming_info.htm [October 21, 1997].

Deming, W. E. (1943 & 1964). *Statistical Adjustment of Data*. New York: John Wiley and Sons.

Deming, W. E. (1950). *Theory of Sampling*. New York: John Wiley and Sons.

Deming, W. E. (1960). *Sample Design In Business Research*. New York: John Wiley and Sons.

Deming, W. E. (1982). *Quality, Productivity, and Competitive Position*. Cambridge, MA: Massachusetts Institute of Technology, Center for Advanced Engineering Study.

Deming, W. E. (1982, 1986). *Out of the Crisis*. Cambridge, MA: Massachusetts Institute of Technology, Center for Advanced Engineering Study.

Deming, W. E. (1994). *The New Economics for Industry, Government, Education* (2nd ed.). Cambridge, MA: Massachusetts Institute of Technology, Center for Advanced Engineering Study.

Duttenhoeffer, R. (April 1992). Cost and Quality Management. *Journal of Management in Engineering*. 8(2), 167-175.

Erickson, J. (April 1989). Meeting the Quality Management Issue on Highway Construction. *Journal of Professional Issues in Engineering*. 115(2), 162-167.

Extra Work Order Task Force (1995). MHD Construction Project: Cost Comparisons. Unpublished data.

Federle, M. O. and Chase, G. W. (October 1993). Applying Total Quality Management to Design and Construction. *Journal of Management in Engineering*. 9(4), 357-364.

Fergusson, K. J. and Teicholz, P. M. (April 1994). Facility Quality Measurement as the Engine of Continuous Product and Process Improvement in the AEC/EPC Industry. *Quality Management Journal*. 1(3), 43-56.

Fleming, Q. W. and Koppelman, J. M. (1996). *Earned Value Project Management*. Newtown Square, PA: Project Management Institute.

Gerald, S. J. Three Experts on Quality Management: Philip B. Crosby, W. Edwards Deming, Joseph M. Juran [Online]. Available: http://deming.eng.clemson.edu/pub/psci/files/3expert.txt [October 8, 1997].

Hardaker, M. and Ward, B. K. (November-December 1987). Getting Things Done: How To Make a Team Work. *Harvard Business Review*. 65(6), 112-117.

Hodges, J. TQM Philosophers Matrix [Online]. Available: http://deming.ces.clemson.edu/pub/den/deming_papers.htm [October 21, 1997].

Hunicke, W. J. Getting the Most from Your Training [Online]. Available: http://www.dbainc.com/dba2/library/train.html [November 5, 1997].

Hunicke, W. J. How to Implement a TQM Process [Online]. Available: http://www.dbainc.com/dba2/library/meswork.html [November 5, 1997].

International Organization for Standardization (ISO) (1992). *ISO 9000 International Standards for Quality Management* (2nd ed.). Geneva: International Organization for Standardization.

Ireland, L. R. (1991). *Quality Management for Projects and Programs*. Drexel Hill, PA: Project Management Institute.

Juran, J. M. (1944). *Bureaucracy: A Challenge to Better Management*. New York: Harper and Brothers.

Juran, J. M. (1945). *Management of Inspection and Quality Control*. New York: Harper and Brothers.

Juran, J. M. (1955). *Case Studies in Industrial Management*. New York: McGraw-Hill.

Juran, J. M. (1964). *Managerial Breakthrough*. New York: McGraw-Hill.

Juran, J. M. (1988). *Juran on Planning for Quality*. New York: Free Press.

Juran, J. M. (1989). *Juran on Leadership for Quality*. New York: Free Press.

Juran, J. M. (August 1986). The Quality Trilogy: A Universal Approach to Managing for Quality. *Quality Progress*. 19(8), 19-24.

Juran, J. M. (July/August 1993). Why Quality Initiatives Fail. *Journal of Business Strategy*. 14(4), 35-38.

Juran, J. M., & Gryna, F. M. (1970, 1980, 1993). *Quality Planning and Analysis: From Product Development Through Use*. New York: McGraw-Hill.

Juran, J. M., & Gryna, F. M. (Eds.) (1988). *The Quality Control Handbook* (4th ed.). New York: McGraw-Hill.

Karakaya, F. and Mogawer, W. S. (1997). *Evaluation of the Road System in Massachusetts*. Amherst, MA: University of Massachusetts Transportation Center.

Lutz, J. D., Hancher, D. E. and East, E. W. (July 1990). Framework for Design-Quality-Review Data Base System. *Journal of Management in Engineering*. 6(3), 296-312.

Massachusetts Highway Department (1997). *Highway Design Manual*. Boston: Massachusetts Highway Department.

Massachusetts Highway Department Architects & Engineers Review Board (1997). *Evaluating the Quality of Consultant Designs: A Plan for Improving the Highway Department's Current Consultant Evaluation System*. Boston: Massachusetts Highway Department.

Massachusetts Quality Initiative. Construction Partnering [Online]. Available: http://www.state.ma.us/mhd/mqi/constr.htm [November 10, 1997].

Massachusetts Quality Initiative. Design Partnering [Online]. Available: http://www.state.ma.us/mhd/mqi/design.htm [October 9, 1997].

Massachusetts Quality Initiative. Massachusetts Bridge Quality Partnership [Online]. Available: http://www.state.ma.us/mhd/mqi/mbqp.htm [November 1, 1997].

Massachusetts Quality Initiative. Massachusetts Pavement Quality Partnership [Online]. Available: http://www.state.ma.us/mhd/mqi/mpqp.htm [November 10, 1997].

National Quality Initiative (NQI). National Policy on the Quality of Highways [Online]. Available: http://www.nqi.org/policy.html [February 20, 1998].

National Quality Initiative (NQI) Steering Committee. NQI Background [Online]. Available: http://www.nqi.org/nqibkgrd.html [October 24, 1997].

National Quality Initiative (NQI) Steering Committee. NQI Long-Range Plan [Online]. Available: http://www.nqi.org/longplan.html [November 11, 1997].

National Quality Initiative (NQI) Steering Committee. National Highway User Survey [Online]. Available: http://www.nqi.org [May 21, 1998].

Poister, T. H. and Harris, R. H. (July-August 1997). Public Administration Review. *Public Administration Review*. 57(4), 294 (9).

Project Management Institute Standards Committee (1996). *A Guide to the Project Management Body of Knowledge*. Upper Darby, PA: Project Management Institute.

PSMJ Resources, Inc. (1997). *Design Services Fee Survey* (12th ed.). Newton, MA: PSMJ Resources, Inc.

PSMJ Resources, Inc. (1997). *Survey & Report on Financial Performance in Design Firms* (17th ed.). Newton, MA: PSMJ Resources, Inc.

PSMJ Resources, Inc. 1996 Design Services Fee Survey Executive Summary [Online]. Available: http://www.psmj.com/fee.htm [January 27, 1998].

PSMJ Resources, Inc. 1996 Financial Statistics Survey Executive Summary [Online]. Available: http://www.psmj.com/finstat.htm [January 27, 1998].

Rothery, B. (1993). *ISO 9000* (2nd ed.). Brookfield, VT: Gower Press.

Russel, J. S., Swiggum, K. E., Shapiro, J. M. and Alaydrus, A.F. (February 1994). Constructability Related To TQM, Value Engineering, and Cost Benefits. *Journal of Performance of Constructed Facilities*. 8(1), 31-45.

Stevens, T. (January 17, 1994). Dr. Deming: 'Management Today Does Not Know What Its Job Is.'. *Industry Week*. 243(2), 21-28.

Teets, M. K. (Ed.) (1996). *Highway Statistics 1995*. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Teets, M. K. (Ed.) (1997). *Highway Statistics Summary to 1995*. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Texas Department of Transportation. 1997 Texas Quality Initiative [Online]. Available: http://www.dot.state.tx.us/tdotnews/tqi/tqiele.htm [November 11, 1997].

Tufte, E. R. (1990). *Envisioning Information*. Cheshire, CT: Graphics Press.

University of Washington Libraries. Guide to Engineering Salary Surveys [Online]. Available: http://www.lib.washington.edu/libinfo/libunits/sciences/engineering/career/salsurv.html [January 27, 1998].

US Army Corps of Engineers, Construction Engineering Research Laboratories. Fact Sheet: Total Quality Management at CERL [Online]. Available: http://www.cecer.army.mil/facts/sheets/GI12.html [October 21, 1997].

Washington Quality Initiative. Washington Quality Initiative [Online]. Available: http://www.wsdot.wa.gov/wqi/benefit.htm [October 30, 1997].

Washington Quality Initiative. WQI Successes [Online]. Available: http://www.wsdot.wa.gov/wqi/success.htm [October 21, 1997].

Wisconsin Department of Transportation. Highway Structures [Online]. Available: http://www.dot.state.wi.us/dtid/index.html [October 28, 1997].

Zweig White & Associates, Inc. Finance & Accounting Survey [Online]. Available: http://www.zwa.com/SURVEYS/finacc.htm [January 27, 1998].

Zweig White & Associates, Inc. Management Surveys [Online]. Available: http://www.zwa.com/SURVEYS/Surveys.htm [January 27, 1998].

Zweig White & Associates, Inc. The State DOT Market for Engineering [Online]. Available: http://www.zwa.com/MARKETS/Dot.htm [January 27, 1998