FINAL REPORT
DESIGN QUALITY RESEARCH
Management Practices Influence Design Quality

REPORT

BY

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FOR

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List of Abbreviations

ACEC/MA	American Council of Engineering Companies of Massachusetts
ACDP	Actual Cost of Deliverables Produced
ASCE	American Society of Civil Engineers
BCDP	Budgeted Cost-of-Deliverables Produced
BCDS	Budgeted Cost-of-Deliverables Scheduled
BP	Bid Price of Unit-Priced Item
BVI	Bid Variation Index
CDQI	Composite Design Quality Index
COC	Coefficient of Correlation
CPE	Consultant Performance Evaluation
CPEI	Consultant Performance Evaluation Index
CPI	Cost Performance Index
CQ	Constructed Quantity
DOT	Department of Transportation
DQR	Design Quality Ranking
DREWI	Design-Related Extra Work Index
EQ	Estimated Quantity
EWI	Extra Work Index
FPBs	Footprint bridges
ISO	International Organization of Standardization
MassHighway	Massachusetts Highway Department
MQI	Massachusetts Quality Initiative
PMBOK	Project Management Book of Knowledge
PMI	Project Management Institute
PMS	Project Management Software
QEI	Quantity Estimates Index
QV	Quantity Variation of Unit-Priced Item
SPI	Schedule Performance Index
Stdev TBP	Standard Deviation of Total Bid Prices

TAP	Total Awarded Bid Price
TCDREWO	Total Cost of Design-Related Extra Work Orders
TCEWO	Total Cost of Extra Work Orders
WBS	Work Breakdown Structure

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Concepts for the research evolved from partnering between the Massachusetts Highway Department (MassHighway) and the American Council of Engineering Companies of Massachusetts.

Project oversight was provided by a Steering Committee that was jointly staffed by representatives of MassHighway and ACEC/MA.

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EXECUTIVE SUMMARY

Concern over infrastructure quality led the Massachusetts Highway Department (MassHighway) to develop the Massachusetts Quality Initiative (MQI), under which MassHighway affirmed that design quality influences constructed projects. To promote future design quality, MassHighway engaged The Engineering Center to identify specific design management practices that influence the quality of highway and bridge construction. This research does that. It not only provides a model for measuring highway design quality, but also some telling findings: we were able to quantify the potential cost of poor design quality and unequivocally show which management practices positively (and negatively) affect design quality. With these results, state agencies and their consultants have a sound basis for making management decisions to effect higher quality infrastructure projects. Consequently, the public – users of our nation's roadways – will enjoy safer, more durable, and less costly highways and bridges. Moreover, we believe these findings also can be used to improve the design quality of all other types of constructed projects.

THE RESEARCH PROCESS

We conducted the research in two phases.

- In ***Phase I***, which culminated in the report "Design Quality Research," December 1999 (provided under separate cover), we defined quality, cited its benefits, theorized measurements that correspond to design quality, developed a metrics model based on those theorized measurements, and tested the model on actual highway/bridge projects.
- In ***Phase II***, the result of which is this report, we refined the metrics model, ranked the tested projects by design quality, determined the correlation of several management practices with design quality rankings, analyzed interrelationships among management practices having comparable design quality, and drew conclusions.

Following is a brief summary of each step in the research process. Full detail is provided in various sections of this report as indicated.

Design quality is everything prior to construction that bears on stakeholders' satisfaction.

Defining Quality

Because the term "quality" can mean different things to different people, we needed a definition that not only encompassed a broad spectrum of ideas, but was also reasonable in scope. Our research uncovered two definitions of quality that are particularly relevant to highway design – one from The International Organization for Standardization and the other from The American Society of Civil Engineers (see Chapter 2, "Definition of Design Quality"). Using these as a baseline and drawing upon our own research and knowledge of infrastructure projects, we recommend 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.

Quality designs induce better construction at predictable costs and lower risks – thereby benefiting sponsoring agencies like MassHighway, contractors, and the public.

Who Benefits?

Ultimately, the benefactors of this research – and of top quality highway designs – are highway users. However, society as a whole and agencies and contractors involved in building, operating, and maintaining roadways also benefit (see Chapter 3, "Benefits of Design Quality").

When a project is designed appropriately, with quality built into the process, the benefits are three-fold:

- More Economical: We found that quality designs are considerably less expensive to construct than designs with shortcomings. For the projects we tested, the potential cost savings in quality designs were 7.7% ($16.3 million) of the construction cost.
- More Useful: The public receives safer, more durable, and efficient roadways.
- Less Complicated to Construct, Easier to Maintain: Contractors won't have to rework a quality design and MassHighway (and other transportation agencies) won't spend as much time operating and maintaining a highway free of design defects.

Measuring and Testing Quality

Having developed a workable definition of design quality, we were then able to measure it using formulas theorized in Phase I and refined in Phase II (see Chapter 4, "Metrics of Design Quality"). We measured several factors likely to affect design quality:

- Construction bidders' satisfaction or variation among construction bidders' prices (expressed as Bid Variation Index or BVI).
- Stakeholders' satisfaction during construction (measured via extra work orders, design-related extra work orders, and quantity variations and expressed as EWI – Extra Work Index, DREWI – Design-Related Extra Work Index, and QEI – Quantity Estimates Index).
- Cost and schedule performance during design (expressed as Cost Performance Index, CPI, and Schedule Performance Index, SPI).

We were unable to measure MassHighway's Consultant Performance Evaluation (CPE) system as an indicator of design quality because the projects selected for testing preceded CPE's full implementation.

Correlation is Key

While quality is quantifiable, no single measure adequately represents design quality. In Phase I, using data from six MassHighway footprint bridge projects (FPBs), we tested the correlating strength and consistency of individual measurements in relation to other measurements. To further refine the model, in Phase II we tested seven more FPBs (see Chapter 5, "Testing and Ranking Projects by Design Quality Metrics").

We measured all 53 highway, bridge, and resurfacing projects together using this scale, which enables us to see how projects compare to each other in terms of design quality:

DQR = (BV+QE+EW+DREW)/4.

From the results of these tests, we decided on a model for measuring design quality individually and collectively. Design Quality Ranking (DQR), expressed mathematically as DQR = (BV+QE+EW+DREW)/4, is the formula we used to rank project quality and correlate management practices with design quality. We applied DQR to the FPBs, plus three major Massachusetts bridge projects, three major highway projects, and six resurfacing projects as well as 29 highway/bridge projects from seven other states.

Which Design Management Practices Influence Quality?

Originally, MassHighway wanted information regarding the effects of salary and overhead capping on design quality. Upon further consideration, the research scope was broadened to include several other management practices (see Chapter 6, "Management Practices Chosen"). We selected practices often used for managing civil engineering projects as well as those that affect project planning, organizing, leading, and control:

Scope Management	Human Resources Management
Quality Management	Cost and Procurement Management
Schedule (Time) Management	Communications-Risk-Integration Management

The Project Management Institute identified these practices as essential to project success. Table ES-1 lists each practice and elaborates on how we measured it.

Table ES-1. We measured management practices critical to project success by tasks common to civil engineering.

Management Practice	How Measured
Scope Management	Detailed scope of services, Work Breakdown Structure (WBS), Comparing deliverables to plan, Prompt changes to design scope
Cost and Procurement Management	Rationally developed design budgets, Capping of designer's compensation rates, Review of actual costs to budgeted costs, Routine checking of expended costs, Earned value analyses, DOT cost recovery policies
Schedule Management	Detailed schedules, Milestone dates, On-time deliverables, On-time DOT reviews, Monthly schedule reviews, Monthly design quality reviews
Human Resources Management	Detailed staffing plans, Skills and experience plan, Staff availability and workload balance, Appropriate and adequate staffing, Project manager's experience, Technical staff proficiency
Quality Management	Clearly stated design standards, Quality reviews by DOT, Constructability reviews, Value engineering
Communications-Risk-Integration Management	DOT partnering (design associations), DOT partnering (private design consultants), Project management software

WHAT WE FOUND

Correlating the selected management practices with DQR yielded interesting results – some of which are intuitive and some surprising (see Chapter 7, "Correlating Management Practices with DQR"). For example, most projects having "capped" salary and overhead rates have poorer design quality than projects without "caps." Additionally, as expected, design schedule management practices such as planned milestones, timely submissions, timely review of deliverables, and monthly quality and schedule reviews have a favorable impact on design quality: projects with those practices were of higher quality than those without them.

One might also expect that quality management practices such as constructability reviews and value engineering lead to higher design quality as well. However, this was not the case. Our testing revealed that the most effective quality management is "doing it right the first time:" projects subjected to *detailed* checking and revision had much *lower* design quality than those not subjected to such practices. We conclude that design quality is best assured by incorporating quality management – including constructability and value – as design *progresses*, not by rework.

We now have conclusive data that shows which management practices have positive and negative impacts on design quality. Chart ES-1 summarizes the practices normally found in higher DQR projects, and Chart ES-2 shows those practices normally present in lower-ranking projects.

Chart ES-1. Average DQR Position of Management Practices Normally Found in Higher Ranking Projects

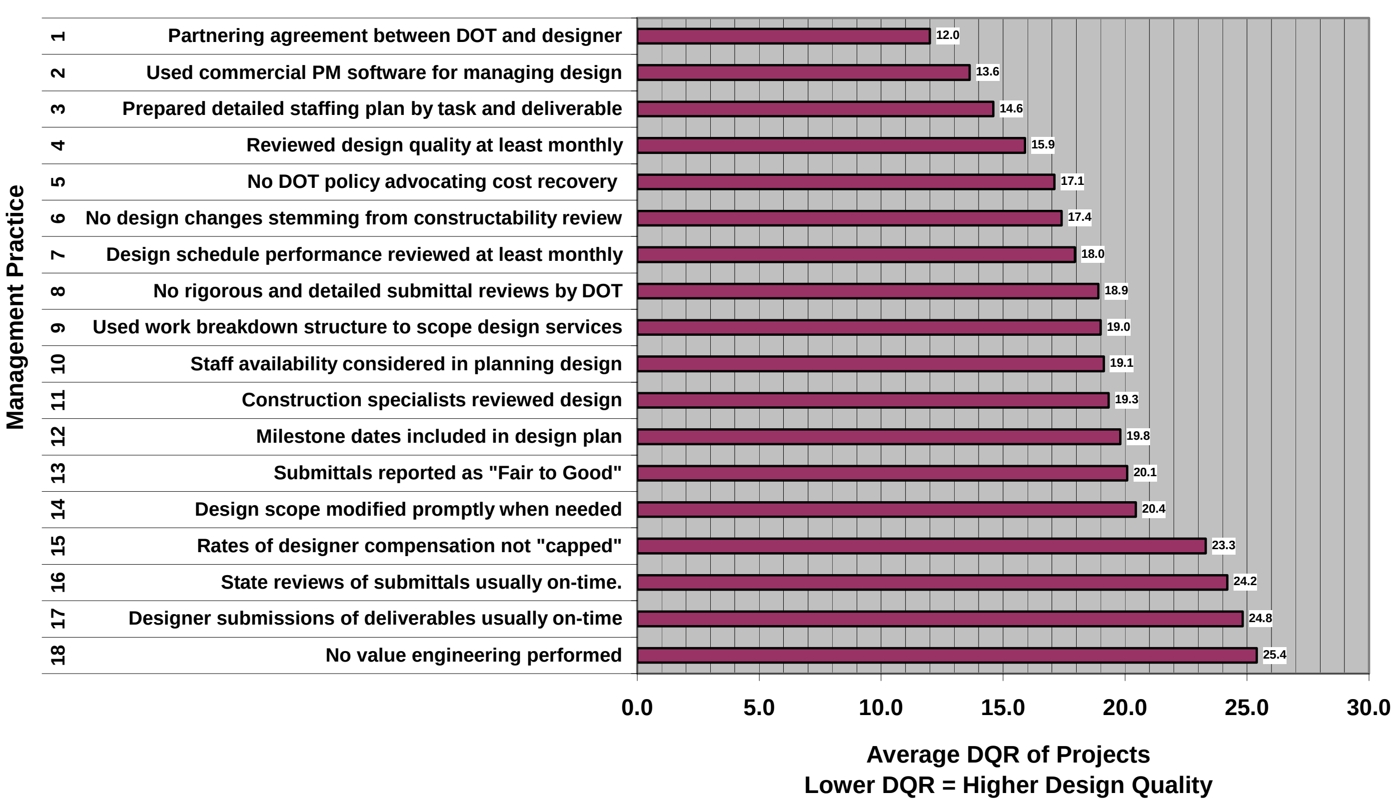
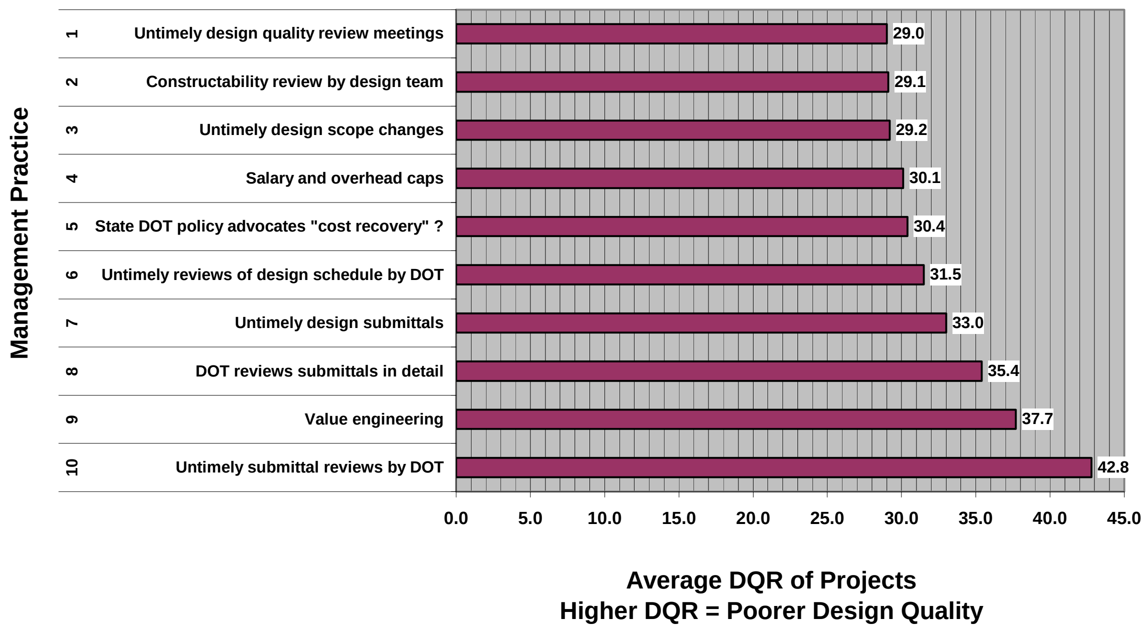


Chart ES-2. Average DQR Position of Management Practices Normally Found in Lower Ranking Projects



SPI: A Valuable Tool for Controlling Risk

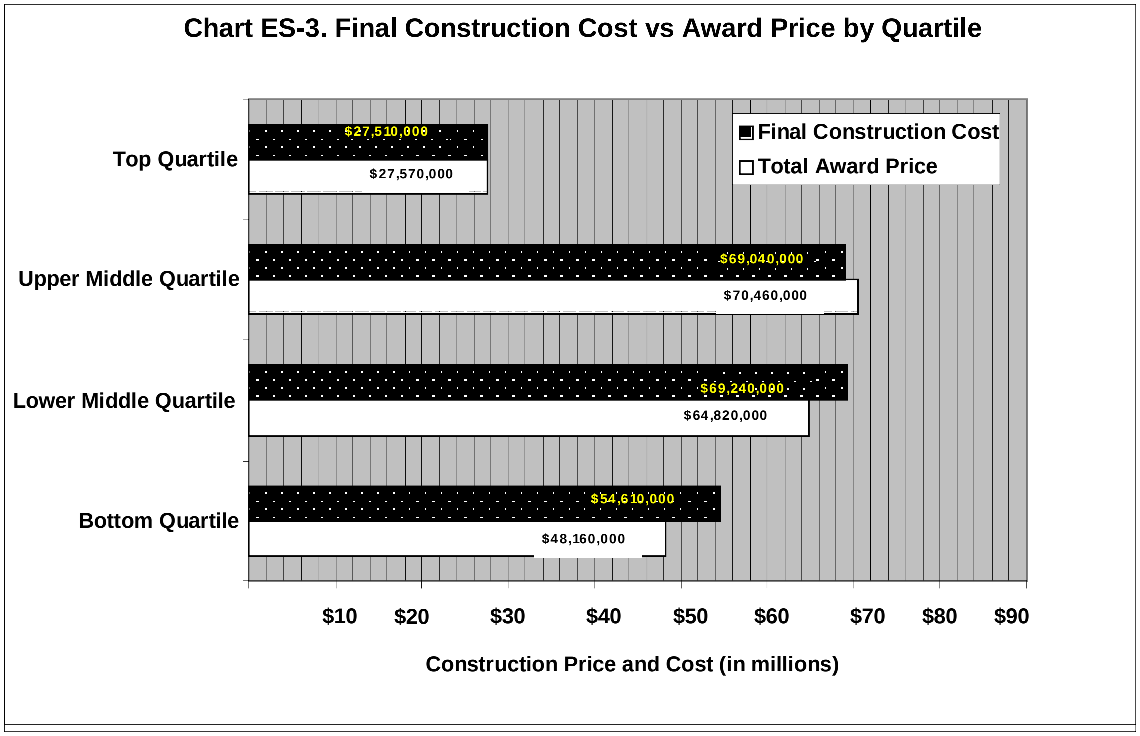
Perhaps one of the more useful findings of this research is the direct correlation of design-schedule performance (or schedule performance index, SPI) to design quality. SPI provides a simple metric (see the box) for continuously measuring design schedule progress and quality. Our testing revealed that SPI measurements on the dates when design services are scheduled to be 25%, 50%, and 75% complete provide the most reliable predictors of design quality. Measurements at 25% complete are especially valuable because enough time remains to “do it right once” (see Chapter 8, “Forecasting Design Quality and Controlling Projects in Progress”).

> ***SPI, expressed mathematically:***
>
> SPI = BCDP / BCDS
>
> *Where*:
>
> BCDP = Budgeted Cost-of-Deliverables Produced
>
> BCDS = Budgeted Cost-of-Deliverables Scheduled

Measurements at 25% complete are especially valuable because enough time remains to “do it right once.”

POOR DESIGN QUALITY HAS A HIGH COST

Construction changes, necessary because of design shortcomings, cost money – extra money not budgeted for early in the process. Our research reveals that projects with top quality designs will probably be constructed without significant cost overruns (see Chapter 9, “Cost of Poor Design Quality”). In fact, as Chart ES-3 shows, projects ranking in the top DQR quartile were constructed for .2% ***less*** than the awarded price ($60,000), whereas projects ranking in the bottom DQR quartile overran the award price by more than 13% ($6.35 million).



Misestimated Quantities and Bid Unbalancing

"Bid unbalancing," where construction bidders quote above-market unit-prices for underestimated items and below-market prices for overestimated items, is more likely to occur when construction quantities in the bid sheets are significantly misestimated. Higher quality estimates, characteristic of high quality designs, preclude the opportunity to unbalance bids.

We estimate that the total actual cost of all 53 projects researched was 7.7% ($16.3 million) greater than market prices because of bid unbalancing. For projects in the bottom DQR quartile (low-quality designs), bid unbalancing prompted by poor quantity estimates cost an extra $5 million or 10.4% of the total award price as compared to $1 million or 3.7% for all projects ranking in the top DQR quartile (high-quality designs). We further estimate that the prices of low-ranking projects are more than 110% of market prices.

The *increased* cost of lower-ranking projects was nearly *three times* that of higher-ranking projects.

CONCLUSIONS

The goal of this research was to determine whether certain common civil engineering management practices influence design quality. Using data from MassHighway and other states' highway, bridge, and resurfacing projects, we devised a practical and reliable metric for quantifying design quality – Design Quality Ranking or DQR. With this tool, we were able to evaluate the impact of commonly used management practices on design quality.

Our analyses yielded interesting results. We now know which management practices help in producing high quality infrastructure designs and which hinder such development. We also know that *built-in* quality – *quality from the start, at the design phase* – has a significant impact on actual project cost: in our research, we estimate that the added cost of poor design quality is $16.3 million or 7.7% of the total award price.

Top-notch design quality requires alignment of stakeholders' efforts, especially those of sponsoring agencies and design teams. Moving forward, we believe this research will be useful to MassHighway and their consultants in designing economical highway, bridge, and resurfacing projects – the first time, without incurring costs to remedy design shortcomings.

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 evaluate the influences of certain design management practices on highway design quality. Findings in this report were developed from sources in the fields of transportation at-large, highways, design, construction, management-at-large, quality management, and project management.

STEERING COMMITTEE

A Steering Committee, comprised of the following members, was formed at the project's outset to provide guidance:

- Thomas Broderick, MassHighway
- Robert Caton, ACEC/MA (Phase II)
- Domanic D'Eramo, ACEC/MA
- Ross Dindio, MassHighway
- Thomas DiPaolo, MassHighway
- Anthony Lionetta, ACEC/MA (Phase II)
- Judith Nitsch, ACEC/MA
- William Rizzo, ACEC/MA (Phase I)

Project Purpose:

To determine which design management practices most influence the quality of highway and bridge designs.

SUCCESS FACTORS

Success of this research project should be gauged by several criteria:

- Acceptance of findings by the Steering Committee, MassHighway, ACEC/MA, and the engineering, transportation, and construction communities at-large.
- Universal and practical usefulness of results for improving quality of designs of highways and bridges in particular, and all construction projects in general.
- Clarity of this report's text and illustrations.
- Objectivity of design quality measurements.
- Integrity of data, findings, and conclusions.
- Completion within scheduled time and budget.

RESEARCH PROCESS

Several steps were taken to conduct this research:

1. Define design quality.
2. Cite the benefits of design quality.
3. Theorize measurements that correspond to design quality.
4. Develop a metrics model for measuring design quality using theorized measurements.
5. Test theoretical metrics model on actual highway projects.
6. Refine metrics model based upon tests of actual highway projects.
7. Adopt design quality metrics model.
8. Rank researched projects by design quality metrics.
9. Test correlation of each management practice with design quality rankings.
10. Analyze interrelationships among management practices having comparable design quality rankings.
11. Conclude influences of management practices on design quality.

Steps 1 through 5 were included in the first phase report “Design Quality Research,” December 1999 (provided under separate cover). Steps 6 through 11 are included in this Phase II report.

For ease in following and understanding the complete research process, pertinent highlights from Phase I are incorporated in Chapters 2, 3, and 4 herein; Phase II results are discussed in Chapters 5 through 9.

Chapter 2

DEFINITION OF DESIGN QUALITY

The term *quality* is not defined 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, a definition of design quality is needed here to set a benchmark and foster clarity in this process, its evaluations, and findings.

Two definitions of quality 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."[1]

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." [2]

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

In short, design quality is *everything* prior to construction that bears on stakeholders' satisfaction.

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, all stakeholders' needs 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. *Everything* bearing on satisfaction is quality.

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

[2] *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.*

Chapter 3

BENEFITS OF DESIGN QUALITY

Our Phase I findings are summarized below, in an excerpt from our Phase I report, “Design Quality Research,” December 1999, pages xiv -xv. (Footnotes from this excerpt are not included here; refer to original document provided under separate cover.)

> 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 (NQI) 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.”
>
> 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….” 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 and by MassHighway, 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, 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.

In Phase II, we found that high quality designs are significantly less expensive than those of low quality. Chapter 9 is devoted to the potential cost-savings benefits of high quality design.

Chapter 4

METRICS OF DESIGN QUALITY

PHASE I MODEL FOR MEASURING STAKEHOLDERS' SATISFACTION

If design quality is "*everything* prior to construction that bears on stakeholders' satisfaction," then measurements of stakeholders' satisfaction (or dissatisfaction) indicate the presence (or absence) of design quality.

At the outset, the Steering Committee established "objectivity of measurements" as a critical success factor for the research. For practical purposes, we also concluded that the measurements' data needs to be commonly available in project files.

Based on tests of six projects in Phase I, we theorized that the comprehensive metric model for measuring design quality ought to be the formula below.

Composite Design Quality Index, expressed mathematically:

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

Where:

- CDQI means Composite Design Quality Index.
- BVI means Bid Variation Index. BVI measures variations of total construction bid prices.
- DREWI means Design-Related Extra Work Index. DREWI measures the cost of those construction change orders for work stemming from design errors or omissions.
- CPEI means Consultant Performance Evaluation Index. CPEI measures MassHighway's satisfaction with the designer's deliverables and services.
- SPI means Schedule Performance Index. SPI measures adherence to the pre-construction schedule.
- QEI means Quantities Estimate Index. QEI measures deviations of constructed quantities from estimated quantities of unit-priced items.

Note: The weighted percentages applied to each term in the CDQI formula were adopted based upon the Steering Committee's judgment of how each factor influences design quality.

PHASE II METRICS OF STAKEHOLDERS' SATISFACTION

In Phase II, we reexamined and, when appropriate, modified our reasoning for selecting each of the model's measurement terms. We also named the measurement's model of design quality *"metrics of design quality for highway and bridge projects."* We adopted the term *metrics* because governments and industry commonly use it to refer to measurements used in controlling planned processes.

Quality is a Relative Concept

Quality is relative to stakeholders' expectations. In 1980, an IBM Selectric typewriter was considered the best means of processing words to paper. By the 1990s, word processing software on desktop computers had banished the Selectric to antiquity. Metrics of design quality need to be expressed in relative terms.

Measuring Construction Bidders' Satisfaction

Competitive bids for construction projects are influenced by several factors:

- Each bidder's interpretation of the work represented by the plans, specifications, and contract documents.
- Each bidder's speculation of the extent that the actual work to be done will depart from the work represented by the plans, specifications, and contract documents.
- Each bidder's estimates of costs associated with doing the actual work.
- Pricing for business considerations that are unrelated to the project being bid, such as the bidder's current work backlog.

In Phase I, we reasoned that design quality plays an important role in acquiring competitive construction bids. Following is an excerpt from our Phase I report, "Design Quality Research," December 1999, page 39 (provided under separate cover).

> Construction contractors, subcontractors, suppliers, vendors and subcontractors, are key stakeholders in highway and bridge projects. The quality of the construction plans, specifications, contract documents and quantity estimates significantly affect their perception of risks associated with bidding and constructing the project. '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 their 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.
>
> 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.

Upon reexamination and as proposed in Phase I, we believe that the ratio of the standard deviation of total prices of all bidders to the total awarded low-bid price is a rational measure of departure from design quality. If "perfect" quality is numerically represented as 1.00, then 1.00 minus "departure from quality" represents the balance of remaining design quality. We named this measurement Bid Variation Index or BVI.

Bid Variation Index, expressed mathematically:

$$BVI = 1.00 - \left(StdevTBP \div TAP\right)$$

Where:

BVI	= Bid Variation Index
Stdev TBP	= Standard Deviation of Total Bid Prices
TAP	= Total Awarded Bid Price (usually the lowest bid price)

Measuring Stakeholders' Satisfaction During Construction

Construction Extra Work Orders

In Phase I, we reasoned that construction extra work orders are a reasonable measure of design quality when the cause for the change is design error or omission. Here is an excerpt from the Phase I report, "Design Quality Research," December 1999, pages 40 - 42. (Footnotes and appendices from this excerpt are not included here; refer to original document provided under separate cover.)

> 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.'
>
> 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:

Categorize the cause of the extra work order:

- Design error or omission,
- Unforeseen condition, or
- MassHighway request for out of scope of work.

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.

The metric model postulated in Phase I included only those extra work orders deemed to be "design-related." Upon reexamination, in Phase II we concluded that *all* construction changes are indicators of design shortcomings – irrespective of the causes for change.

The model used in Phase II calibrations included two measurements for construction changes: one for design-related extra work and one for all extra work. Therefore, every construction change is a departure from design quality and design-related changes are foreseeable during design. The concept is not meant to assess blame, culpability, or accountability, but to measure deviations from design quality, especially those that can be prevented during design.

The Leaning Tower of Pisa resulted from design shortcomings, in part, because designers did not have knowledge of soils mechanics. Those designers should not have been accountable because such knowledge was not available in the 12th century. Nonetheless, the foundation soils settled irregularly, the bell tower leaned, and the project fell short of satisfying stakeholders' needs, in part, because of design shortcomings.

We propose that the measure of departure from design quality caused by construction changes be the ratio of the total cost of all extra work authorized during construction to the total awarded bid price (normally the low-bid price). If "perfect" quality is numerically represented as 1.00, then 1.00 minus "departure from quality" represents "remaining design quality." We named this measurement Extra Work Index or EWI (see the equation at the left).

Extra Work Index, expressed mathematically:

$$EWI = 1.00 - (TCEWO \div TAP)$$

Where:

EWI	= Extra Work Index
TCEWO	= Total Cost of Extra Work Orders
TAP	= Total Award Price

Design-Related Construction Extra Work Orders

We further propose that a measure for "design-related" construction changes be included in design quality metrics. This measurement represents construction changes attributable to designs that fall short of the prevailing level-of-care in the opinion of the person(s) measuring. We named this measurement Design-Related Extra Work Index or DREWI (see the equation at the right).

Design-Related Extra Work Index, expressed mathematically:

$$DREWI = 1.00 - (TCDREWO \div TAP)$$

Where:

DREWI	= Design-Related Extra Work Index
TCDREWO	= Total Cost of Design-Related Extra Work Orders
TAP	= Total Award Price

Quantity Variations

In Phase I, we reasoned that variations in constructed quantities from estimated quantities are valid measures of stakeholders' satisfaction (or dissatisfaction) with design quality (see the Phase I report, "Design Quality Research," December 1999, p. 42, provided under separate cover).

Compensation to construction contractors is typically based, in part, on the quantities of items that the contractor furnishes and/or installs. 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.

On reexamination, Phase I conclusions, while affirmed, were revised to measure *the ratio of the absolute sum of the cost variations for unit-priced items to the sum of extended low-bid price of **unit-priced items***. In Phase I, the denominator in the ratio is the total low-bid price. We revised it by excluding fixed-price or lump sum items and including only unit-priced construction items. This modification more accurately represents stakeholders' satisfaction by more sensitively measuring quantity variances.

Quantity Estimates Index, expressed mathematically:

$$\text{QEI} = 1.00 - \left[\left|\sum(BP \times QV)\right| \div \sum(BP \times EQ)\right]$$

Where:

QEI	= Quantity Estimates Index
BP	= Bid Price of Unit-Priced Item
QV	= Quantity Variation of Unit-Priced Item
	QV = CQ – EQ
EQ	= Estimated Quantity
CQ	= Constructed Quantity

Measuring Design Quality During Design

In Phase I, we learned that Project Management Institute (PMI) and other project management experts evaluate project performance, in part, by measuring variations in cost and time from budgeted costs and planned time. PMI advises that cost variance (CV) is the difference between budgeted costs and actual costs expended in carrying out a specified scope of work and schedule variance (SV) is the difference between budgeted costs-of-work performed and budgeted costs-of-work scheduled to have been performed as of a specific date.

Cost and Schedule Performance During Design

Cost Performance Index (CPI) is the ratio of budgeted cost-of-work performed to the actual cost-of-work performed. CPI represents the extent that actual cost varies from budgeted cost. When CPI equals 1.00, actual costs are exactly on budget. When CPI exceeds 1.00, actual costs are below budget, and when CPI is less than 1.00, actual costs exceed the budget.

Cost Performance Index and Schedule Performance Index, expressed mathematically:

$$\text{CPI} = \text{BCDP} \div \text{ACDP}$$

$$\text{SPI} = \text{BCDP} \div \text{BCDS}$$

Where:

CPI	= Cost Performance Index
SPI	= Schedule Performance Index
BCDP	= Budgeted Cost of Deliverables Produced
ACDP	= Actual Cost of Deliverables Produced
BCDS	= Budgeted Cost of Deliverables Scheduled

Schedule Performance Index (SPI) is the ratio of budgeted cost-of-work performed to budgeted cost-of-work scheduled as of a specified date. SPI relates the work completed to the work planned as of a specified date. When SPI equals 1.00, the work is on schedule. When SPI is greater than 1.00, the work is ahead of schedule, and when SPI is less than 1.00, the work is lagging behind.

For this research, we measured "deliverables budgeted" and "deliverables produced" in lieu of "work budgeted" and "work performed." Deliverables are finite and more tangible than work and, therefore, can be measured more objectively and accurately. We believe that budgets, schedules, costs, and time durations expressed in terms of specific discreet deliverables provide more finite measures of performance than those expressed in terms of work or tasks. Progress in producing physical deliverables can be more tangibly, objectively, and accurately measured than progress in completing tasks. We have measured CPI as the ratio of the Budgeted Cost of Deliverables Produced to the Actual Cost of Deliverables Produced and SPI as the Budgeted Cost of Deliverables Produced to the Budgeted Cost of Deliverables Scheduled.

Owners' Performance Reviews

Most owners, either directly or through their sponsoring agents, review and evaluate project performance as the pre-construction activities proceed. Many state transportation agencies have formal performance evaluation processes, especially reviews of services and deliverables provided by private consultants.

MassHighway's Consultant Performance Evaluation (CPE) system is a process designed to measure the quality of the services provided by private consultants on highway and bridge projects (see the Phase I report, "Design Quality Research," December 1999, pp. 99 – 115, provided under separate cover). The system is multi-lateral in that it is designed to integrate the evaluations of reviewers representing those engineers and scientists on MassHighway's professional staff who reviewed the project designers' submittals. MassHighway's system was implemented in March 1998 as a replacement for a much less robust system used previously.

Performance evaluation systems are founded on the premise that stakeholders' satisfaction is a measure of quality and that professionals, when reviewing the performance of submittals and services, represent the stakeholders at-large. In Phase I, we tentatively adopted MassHighway's CPE scoring as a measure of design quality subject to testing; but then we learned that the projects preceded CPE's full implementation. Unfortunately, the projects selected for testing in Phase II also preceded full CPE implementation, and we were unable to determine the value of the system in measuring design quality.

We believe that, in time, performance evaluation systems scored by professionals representing project sponsors and stakeholders will be worthy measures in the metrics of design quality. Currently, not enough data is available to test the hypothesis that CPEs are reliable measures of design quality. We suggest that when sufficient test data is available, a CPE index be reconsidered for inclusion in the metrics of design quality for highways and bridges.

Chapter 5

TESTING AND RANKING PROJECTS BY DESIGN QUALITY METRICS

In Chapter 4, we discussed the metrics model developed in Phase I. In this Chapter, we discuss the method and results of the tests used to refine and validate the model and the resulting rankings of those projects tested.

In Phase I, we used data from six Massachusetts footprint bridge projects to develop the hypothetical model. In Phase II, we used data from seven additional MassHighway footprint bridge projects, plus three major bridge projects, three major highway projects, and six resurfacing projects to further calibrate and refine the model. Our objectives were to increase the numbers and diversity of projects tested.

In addition to testing the model produced in Phase I, we retested two other metrics, CPI and EWI, that had been previously set aside because of inconclusive correlations found in Phase I.

Design quality hinges on successfully managing many variables.

TESTING OBJECTIVES

The objective of the testing process was to determine the correlating strength of several metrics with one another. From the research and our own experiences in managing projects, we have found that no individual metric comprehensively represents design quality. Design quality hinges on successfully managing many variables. No single measurement can represent the quality of so many variables. Our objective was to test the correlating strength and consistency of individual metrics in relation to others. For example, are those projects with small variations in construction bids (BVI is near 1.00) also likely to have small deviations between estimated and constructed quantities (QEI is near 1.00) and few, if any, extra work orders (EWI is near 1.00)? The principle in testing for correlations among metrics is that design quality begets good rankings by many or all measures of stakeholder satisfaction.

CONSULTANT PERFORMANCE EVALUATIONS INDEX (CPEI)

We believe that CPEI can become a worthy metric of design quality. Professionals who review design submittals on behalf of stakeholders have hands-on information for assessing quality as designs progress. They have the technical training, experience, and project-specific knowledge to appropriately judge the quality of design deliverables. Unfortunately, completed projects with final data needed for QEI, EWI, and DREWI calculations did not have data needed for CPE computations. All MassHighway projects tested were designed before the CPE process was fully instituted. CPEI is not included in the refined model because we were unable to test its validity.

TESTING METRICS MODELS ON FOOTPRINT BRIDGE (FPB) PROJECTS

MassHighway's FPB program was a valuable source of data for testing and refining the metrics model. The purpose of this program is to replace existing bridges and appurtenant facilities within their existing "footprints," thus limiting environmental and abutting property impacts. In general, these projects cost under $2 million and have much in common with one another. FPB projects are representative of highway-related projects as a whole for they involve most risks and challenges and virtually all engineering and science disciplines, management skills, construction trades, and materials found in highway transportation projects. MassHighway's FBP files are replete with data, correspondence, design status reports, and other pertinent documentation needed to reliably measure project plans and results.

Design quality can be quantified and measured, but no single metric is adequate.

Quantifying Quality – How We Chose the Model "DQR"

Table 1 shows how we quantified quality. Here are the test results of 31 metrics' combinations for 13 FPB projects. Cells B2 through G14 list the calculated index values for each project identified in column A. The ranking of each project by index value is listed in cells H2 through M14. For example, Project "NASH" (cell A2) has a BVI of 0.898 (cell B2) and ranks 4th (cell H2) when compared with all 13 BVI values (cells B2 to B14). The ranking scale is 1 to 13. Rank 1 is highest; rank 13 is lowest.

When metrics are combined, the various combinations correlate and one begins to see patterns.

In Table 1, the high-ranking quartiles are shaded black, the lowest quartiles are shaded gray, and the middle two quartiles are white. Note that quartile rankings of each project are often comparable from index to index. For instance, project NASH ranks in the highest quartile in four of the six metrics; project MILL ranks in the lowest quartile for all metrics; and project CRYS ranks low in four of the six metrics. Table 1 graphically displays correlations among indices. Table 1 also illustrates that projects have comparable rankings for many index combinations. Projects ranking high by one combination usually rank high by many other combinations. Most combinations of metrics have moderate to strong correlations to most others, especially in the high and low quartiles.

Correlations among combinations can be further validated by statistical analyses. Coefficient of Correlation (COC) is a standard statistical measure of the correlating strength between two sets of values. COC values can range from +1 to –1. Positive values demonstrate a direct correlation between two sets of values. Negative values demonstrate an inverse correlation. When COC is zero there is no correlation. The nearer COC is to +1 or to –1, the stronger the direct or inverse correlation. Rows 17 through 27 of Table 1 list COCs of combinations listed in cells A17 to A27 versus those listed in each column. For example, the COC of the rankings of BVI, QEI, EWI, DREWI versus the rankings of SPI is 0.418 (see cell L17). Every COC listed in Table 1 is greater than zero indicating that the rankings of every metric tested correlate directly with the rankings of every other metric.

The combination having the strongest correlation is BVI, QEI, EWI, DREWI, and SPI. This combination has an average correlation of 0.865 (see cell C19). However, this combination was impractical to use in measuring design quality of projects submitted by other states because the data needed to compute SPI would have been impractical to research. Based on the FPB model tests, we tentatively chose BVI, QEI, EWI, DREWI as the metric model to test on other types of projects. This model includes four of the five terms included in the best model; it has an average COC of 0.790 and data required to compute this metric is usually available and readily accessible in project files.

Table 1. Test Results and Alternative Metrics for Measuring Design Quality in Footprint Bridge Projects

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Project**	**BVI**	**QEI**	**EWI**	**D-REWI**	**SPI**	**CPI**	**BVI Rank**	**QEI Rank**	**EWI Rank**	**DREWI Rank**	**SPI Rank**	**CPI Rank**
2	NASH	0.898	0.779	0.9910	1.0000	0.862	0.700	4	3	2	1	1	9
3	ABER	0.942	0.738	0.9041	1.0000	0.790	0.952	1	5	11	1	2	5
4	HUBB	0.918	0.901	0.9796	1.0000	0.677	0.756	2	1	4	1	6	7
5	SHAW	0.866	0.846	0.9235	0.9235	0.790	1.184	9	2	10	11	2	3
6	RIPP	0.885	0.754	0.9878	0.9878	0.705	1.215	6	4	3	8	5	2
7	POWW	0.883	0.528	0.9411	0.9946	0.750	0.669	7	12	9	6	4	11
8	WHIT	0.868	0.529	1.0000	1.0000	0.602	0.676	8	11	1	1	9	10
9	ONOT	0.905	0.598	0.9443	0.9443	0.656	1.173	3	9	8	10	7	4
10	FORG	0.897	0.583	0.9790	0.9944	0.585	1.376	5	10	5	7	10	1
11	FALL	0.829	0.738	0.9589	0.9718	0.640	0.869	10	5	6	9	8	6
12	NODD	0.805	0.683	0.9475	1.0000	0.548	0.395	11	8	7	1	11	12
13	CRYS	0.671	0.710	0.5980	0.8772	0.497	0.734	13	7	12	12	13	8
14	MILL	0.754	0.424	0.5901	0.5901	0.548	0.319	12	13	13	13	11	13
15													
16	**Coefficient of Correlation**		Average	stdev									
17	vs BVI, QEI, EWI, DREWI		0.790	0.171				0.721	0.530	0.748	0.828	0.418	0.251
18	vs BVI,QEI,EWI,DREWI,SPI,CPI		0.855	0.133				0.802	0.714	0.566	0.547	0.753	0.511
19	vsBVI,QEI,EWI,DREWI,SPI		0.865	0.134				0.813	0.644	0.657	0.689	0.729	0.383
20	vsBVI,QEI,EWI,DREWI,CPI		0.852	0.134				0.841	0.620	0.663	0.619	0.577	0.502
21	vsBVI,QEI,EWI		0.835	0.134				0.840	0.583	0.720	0.579	0.537	0.518
22	vs BVI,QEI,EWI,SPI,CPI		0.831	0.141				0.798	0.748	0.546	0.402	0.743	0.610
23	vs QEI, EWI,DREWI,SPI,CPI		0.847	0.129				0.698	0.758	0.654	0.570	0.698	0.462
24	vs QEI, EWI,DREWI,SPI		0.785	0.158				0.588	0.703	0.615	0.766	0.693	0.148
25	vs QEI, EWI,DREWI		0.727	0.196				0.517	0.555	0.838	0.833	0.407	0.071
26	vs EWI, DREWI, SPI, CPI		0.851	0.130				0.763	0.638	0.725	0.577	0.654	0.476
27	vs SPI, CPI		0.643	0.210				0.660	0.623	0.213	0.086	0.777	0.810
28	Notes												
29	BVI: Bid Variation Index								High Rank		1 to 3		
30	QEI: Quantity Estimate Index								Above Avg Rank		4 to 7		
31	EWI: Extra Work Index								Below Avg Rank		5 to 10		
32	DREWI: Design-Related Extra Work Index								Low Rank		11 to 13		
33	SPI: Schedule Performance Index												
34	CPI: Cost Performance Index												

Table 1. Test Results and Alternative Metrics for Measuring Design Quality in Footprint Bridge Projects

	A	O	Q	S	U	W	Y	AA	AC	AE	AG	AI	AK	AM
1	**Project**	**BVI, QEI, EWI, DREWI,SPI, CPI**	**BVI, QEI, EWI, DREWI,SPI,cpi**	**BVI, QEI, EWI, DREWI,**spi, cpi	**BVI, QEI, EWI,** drewi, spi, cpi	**BVI, QEI,** ewi, drewi, spi, cpi	bvi,**QEI, EWI, DREWI,SPI, CPI**	bvi,**QEI, EWI, DREWI,SPI,** cpi	bvi,**QEI, EWI, DREWI,**spi, cpi	bvi, qei, **EWI, DREWI,SPI, CPI**	bvi, qei, ewi, **DREWI,SPI , CPI**	bvi, qei, ewi, drewi,**SPI, CPI**	**BVI,** qei, **EWI, DREWI,SPI, CPI**	**BVI,** qei, **EWI, DREWI,SPI,** cpi
2	NASH	1	1	2	2	3	1	1	1	1	2	4	1	1
3	ABER	3	3	3	4	2	4	3	6	4	1	2	2	3
4	HUBB	2	2	1	1	1	2	2	1	2	3	7	2	2
5	SHAW	5	6	10	8	5	5	6	9	7	5	1	8	10
6	RIPP	4	4	4	3	4	3	4	4	2	4	2	4	5
7	POWW	10	9	11	11	9	11	9	10	10	8	9	9	6
8	WHIT	7	5	4	5	9	6	5	3	5	7	10	6	4
9	ONOT	8	7	8	5	6	9	11	10	8	8	5	7	8
10	FORG	6	7	6	5	7	7	10	8	6	6	5	5	7
11	FALL	9	9	8	8	7	8	8	7	8	10	8	10	11
12	NODD	11	9	6	10	9	10	7	5	11	11	12	11	9
13	CRYS	12	12	12	12	12	12	12	12	12	12	11	12	13
14	MILL	13	13	13	13	13	13	13	13	13	13	13	13	12
15														
16	**Coefficient of Correlation**													
17	vs BVI, QEI, EWI, DREWI	0.830	0.901	1.000	0.911	0.797	0.863	0.868	0.938	0.885	0.781	0.437	0.878	0.868
18	vs BVI,QEI,EWI,DREWI,SPI,CPI	1.000	0.970	0.830	0.922	0.935	0.978	0.868	0.756	0.963	0.970	0.794	0.960	0.830
19	vsBVI,QEI,EWI,DREWI,SPI	0.970	1.000	0.901	0.939	0.914	0.964	0.918	0.848	0.963	0.947	0.701	0.963	0.906
20	vsBVI,QEI,EWI,DREWI,CPI	0.955	0.956	0.926	0.983	0.905	0.944	0.831	0.816	0.971	0.913	0.684	0.974	0.863
21	vsBVI,QEI,EWI	0.922	0.939	0.911	1.000	0.881	0.916	0.780	0.806	0.958	0.862	0.663	0.946	0.834
22	vs BVI,QEI,EWI,SPI,CPI	0.964	0.919	0.769	0.916	0.948	0.942	0.787	0.687	0.937	0.917	0.844	0.914	0.744
23	vs QEI, EWI,DREWI,SPI,CPI	0.978	0.964	0.863	0.916	0.906	1.000	0.918	0.838	0.974	0.920	0.735	0.917	0.802
24	vs QEI, EWI,DREWI,SPI	0.868	0.918	0.868	0.780	0.825	0.918	1.000	0.908	0.871	0.842	0.533	0.821	0.835
25	vs QEI, EWI,DREWI	0.756	0.848	0.938	0.806	0.698	0.838	0.908	1.000	0.834	0.674	0.304	0.759	0.816
26	vs EWI, DREWI, SPI, CPI	0.963	0.963	0.885	0.958	0.878	0.974	0.871	0.834	1.000	0.916	0.706	0.955	0.860
27	vs SPI, CPI	0.794	0.701	0.437	0.663	0.796	0.735	0.533	0.304	0.706	0.821	1.000	0.706	0.453
28	Notes													
29	BVI: Bid Variation Index													
30	QEI: Quantity Estimate Index													
31	EWI: Extra Work Index													
32	DREWI: Design-Related Extra W													
33	SPI: Schedule Performance Inde													
34	CPI: Cost Performance Index													

High Rank	1 to 3
Above Avg Rank	4 to 7
Below Avg Rank	5 to 10
Low Rank	11 to 13

Table 1. Test Results and Alternative Metrics for Measuring Design Quality in Footprint Bridge Projects

	A	AO	AQ	AS	AU	AW	AY	BA	BC	BE	BG	BI	BK
1	**Project**	**BVI,** qei, **EWI, DREWI,** spi, cpi	**BVI,** qei, **EWI,** drewi, spi, cpi	**BVI, QEI,** ewi, **DREWI,SPI, CPI**	**BVI, QEI,** ewi, **DREWI,SPI,** cpi	**BVI, QEI,** ewi, **DREWI,** spi, cpi	**BVI, QEI,** ewi, drewi, spi, cpi	**BVI, QEI, EWI,** drewi, **SPI, CPI**	**BVI, QEI, EWI,** drewi, **SPI,** cpi	**BVI, QEI,** ewi, drewi, spi, cpi	**BVI, QEI, EWI, DREWI,** spi, **CPI**	BVI, QEI**, EWI, DREWI,SPI, CPI**	bvi, qei, ewi, drewi**, SPI, CPI**
2	NASH	1	1	3	1	3	3	1	1	3	2	1	4
3	ABER	4	7	1	1	2	2	4	4	2	3	4	2
4	HUBB	1	1	2	3	1	1	2	2	1	1	2	7
5	SHAW	11	11	5	5	7	5	5	5	5	8	7	1
6	RIPP	5	3	4	4	4	4	2	3	4	3	2	2
7	POWW	9	8	10	6	11	9	10	10	9	11	10	9
8	WHIT	3	3	9	6	5	9	9	7	9	6	5	10
9	ONOT	8	6	6	6	7	6	6	6	6	7	8	5
10	FORG	5	5	6	10	7	7	6	9	7	5	6	5
11	FALL	10	8	8	10	10	7	8	7	7	9	8	8
12	NODD	7	10	11	9	5	9	11	11	9	10	11	12
13	CRYS	12	12	12	12	12	12	12	12	12	12	12	11
14	MILL	13	12	13	13	13	13	13	13	13	13	13	13
15													
16	**Coefficient of Correlation**												
17	vs BVI, QEI, EWI, DREWI	0.961	0.862	0.767	0.741	0.948	0.797	0.769	0.787	0.797	0.926	0.885	0.437
18	vs BVI,QEI,EWI,DREWI,SPI,CPI	0.805	0.780	0.954	0.877	0.854	0.935	0.964	0.948	0.935	0.955	0.963	0.794
19	vsBVI,QEI,EWI,DREWI,SPI	0.887	0.841	0.908	0.925	0.919	0.914	0.919	0.942	0.914	0.956	0.963	0.701
20	vsBVI,QEI,EWI,DREWI,CPI	0.899	0.876	0.919	0.811	0.907	0.905	0.929	0.903	0.905	1.000	0.971	0.684
21	vsBVI,QEI,EWI	0.886	0.908	0.890	0.781	0.879	0.881	0.916	0.906	0.881	0.983	0.958	0.663
22	vs BVI,QEI,EWI,SPI,CPI	0.721	0.762	0.955	0.835	0.796	0.948	1.000	0.960	0.948	0.929	0.937	0.844
23	vs QEI, EWI,DREWI,SPI,CPI	0.811	0.791	0.904	0.845	0.870	0.906	0.942	0.953	0.906	0.944	0.974	0.735
24	vs QEI, EWI,DREWI,SPI	0.816	0.709	0.773	0.872	0.881	0.825	0.787	0.860	0.825	0.831	0.871	0.533
25	vs QEI, EWI,DREWI	0.906	0.833	0.623	0.692	0.869	0.698	0.687	0.752	0.698	0.816	0.834	0.304
26	vs EWI, DREWI, SPI, CPI	0.865	0.888	0.890	0.833	0.848	0.878	0.937	0.938	0.878	0.971	1.000	0.706
27	vs SPI, CPI	0.368	0.398	0.860	0.709	0.550	0.796	0.844	0.774	0.796	0.684	0.706	1.000
28	Notes												
29	BVI: Bid Variation Index					High Rank		1 to 3					
30	QEI: Quantity Estimate Index					Above Avg Rank		4 to 7					
31	EWI: Extra Work Index					Below Avg Rank		5 to 10					
32	DREWI: Design-Related Extra W					Low Rank		11 to 13					
33	SPI: Schedule Performance Inde												
34	CPI: Cost Performance Index												

The model proposed in Phase I was CDQI = 40%BVI+25%DREWI+15%CPEI+15%SPI+5%QEI. That model was replaced by DQR = (BVI + QEI + EWI + DREWI) ÷ 4, where DQR means "Design Quality Ranking." The percentage weighting factors were discarded because they were found to distort correlations among the individual metrics. These factors had been subjectively selected. The CPEI and SPI terms were eliminated because data for these metrics is not commonly available in project files. The EWI term was introduced in Phase II to represent design changes during construction.

CDQI and the terms in the Phase I model were expressed as absolute index values. DQR and the terms in the Phase II model are expressed as relative ranking values among projects compared.

Design Quality Ranking, expressed mathematically:

DQR = (BV+QE+EW+DREW) ÷ 4.

TESTING METRICS MODELS AND RANKING ALL RESEARCH PROJECTS

Using the model that we chose from the FPB tests as a benchmark, we tested its applicability to major bridges, highways, and resurfacing, individuality and collectively. In this test, we also included 29 projects from seven other states. All 53 projects are listed in Table 2. Projects are listed in order of their ranking by the chosen model [i.e., (BV+QE+EW+DREW) ÷ 4] with the highest ranking projects in the top quartile shaded black and the lowest ranking projects in the bottom quartile shaded gray (see column O). Table 2 also lists rankings by individual metrics and combinations of metrics (see other columns). As found with rankings for FPB projects, project quartile rankings for the other three types of projects are generally consistent across the various combinations of metrics.

Based on the findings as shown in Tables 1 and 2, we conclude that Design Quality Ranking (DQR), as computed in Table 2, is a rational and reliable metric indicator of design quality for highway and bridge projects.

DQR by Project Type

		DQR		
Project Type	**Count**	**Avg**	**Range**	**Stdev**
Footprint Bridges	20	25.6	1 to 54	17.0
Major Bridges	4	35.3	26 to 48	9.2
Major Highways	20	27.9	2 to 51	16.6
Resurfacing	9	23.2	9 to 50	11.5
All Projects	53	26.8	1 to 53	15.5
w/o Footprint Bridge	33	27.5	2 to 51	14.7
w/o Major Bridges	49	26.1	1 to 53	15.7
w/o Major Highways	33	26.1	1 to 53	15.0
w/o Resurfacing	44	27.5	1 to 53	16.2

We theorized that inherent characteristics of each project type may affect DQR in relation to the DQR of other types of projects. Projects requiring below-ground construction, like bridge foundations, have more uncertainties than above-grade construction, such as resurfacing pavements. For example, contaminated soils or buried obstructions may be undetected by subsurface explorations during design, but require removal during construction via construction change orders. Such inherent uncertainties increase the probability of undetected latent conditions, increase the likelihood of change orders, and decrease DQR.

Each project tested, together with its type, index measurement, index ranking, and DQR, is listed in Table 2. Each project is again listed by its type in Tables 2A and 2B and summarized in the insert above.
TABLE 2 HERE

Table 2. Design Quality Metric (DQM) of All Projects Researched

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	BVI	BVI Rank	QEI	QEI Rank	EWI	EWI Rank	DREWI	DREWI Rank	Avg BVI QEI EWI DREWI Rank	DQR
2	LUTE	X				0.920	15	0.918	7	1.000	1	1.000	1	6.00	**1**
3	AMNO			X		0.964	3	0.942	5	0.985	17	1.000	1	6.50	**2**
4	TAME			X		0.906	23	0.876	12	0.999	9	1.000	1	11.25	**3**
5	HUBB	X				0.918	16	0.901	9	0.980	20	1.000	1	11.50	**4**
6	BEAR			X		0.913	19	0.870	14	0.990	15	1.000	1	12.25	**5**
7	BOMO			X		0.935	10	0.948	4	0.997	10	0.997	26	12.50	**6**
8	JMNO	X				0.893	30	0.805	26	1.000	1	1.000	1	14.50	**7**
9	BUIA	X				0.971	2	0.860	16	0.934	39	1.000	1	14.50	**7**
10	MAME			X		0.934	11	0.819	24	0.977	23	1.000	1	14.75	**9**
11	FAME	X				0.909	22	0.837	23	0.991	13	1.000	1	14.75	**9**
12	SANT				X	0.854	42	0.867	15	1.000	1	1.000	1	14.75	**9**
13	PAME	X				0.944	8	0.803	28	0.973	26	1.000	1	15.75	**12**
14	RAME	X				0.705	51	0.882	11	1.000	1	1.000	1	16.00	**13**
15	SAME	X				0.693	52	0.949	3	0.993	11	1.000	1	16.75	**14**
16	LOMO			X		0.933	13	0.950	1	0.981	19	0.981	34	16.75	**14**
17	IPSW				X	0.802	49	0.860	17	1.000	1	1.000	1	17.00	**16**
18	NASH	X				0.898	27	0.779	30	0.991	14	1.000	1	18.00	**17**
19	KOMO			X		0.989	1	0.896	10	0.973	25	0.973	37	18.25	**18**
20	PERR				X	0.863	38	0.743	34	1.000	1	1.000	1	18.50	**19**
21	SANY				X	0.862	39	0.711	39	1.000	1	1.000	1	20.00	**20**
22	DUIA				X	0.944	7	0.915	8	0.937	37	0.991	31	20.75	**21**
23	THAY				X	0.946	6	0.841	21	0.980	21	0.980	35	20.75	**21**
24	KUIA				X	0.848	44	0.933	6	0.942	35	1.000	1	21.50	**23**
25	WHIT	X				0.868	36	0.529	49	1.000	1	1.000	1	21.75	**24**
26	ABER	X				0.942	9	0.738	36	0.904	46	1.000	1	23.00	**25**
27	GROV		X			0.896	29	0.803	27	0.992	12	0.998	25	23.25	**26**
28	WAME			X		0.906	23	0.769	31	0.927	41	1.000	1	24.00	**27**
29	CAME			X		0.912	20	0.781	29	0.985	18	0.988	32	24.75	**28**
30	MOMO			X		0.930	14	0.950	2	0.935	38	0.935	45	24.75	**28**
31	KENO				X	0.934	12	0.841	21	0.896	47	0.998	24	26.00	**30**
32	LEAR			X		0.912	21	0.851	18	0.953	31	0.957	41	27.75	**31**
33	RIPP	X				0.885	31	0.754	33	0.988	16	0.988	33	28.25	**32**
34	TANY		X			0.874	35	0.875	13	0.863	49	0.999	23	30.00	**33**
35	BRAC		X			0.953	4	0.504	51	0.966	27	0.960	40	30.50	**34**
36	NODD	X				0.805	48	0.683	42	0.948	33	1.000	1	31.00	**35**
37	FORG	X				0.897	28	0.583	47	0.979	22	0.994	30	31.75	**36**
38	NOMO			X		0.861	41	0.848	19	0.962	28	0.962	39	31.75	**36**
39	POMO			X		0.950	5	0.741	35	0.929	40	0.929	47	31.75	**36**
40	SEAR			X		0.916	18	0.637	43	0.921	43	0.995	28	33.00	**39**
41	MUTE			X		0.918	17	0.818	25	0.904	45	0.932	46	33.25	**40**
42	ONOT	X				0.905	25	0.598	44	0.944	34	0.944	43	36.50	**41**
43	POWW	X				0.883	32	0.528	50	0.941	36	0.995	29	36.75	**42**
44	SHAW	X				0.866	37	0.846	20	0.924	42	0.923	48	36.75	**42**
45	QUIN			X		0.853	43	0.595	45	0.976	24	0.978	36	37.00	**44**
46	MEAR			X		0.901	26	0.565	48	0.949	32	0.949	42	37.00	**44**
47	FALL	X				0.829	46	0.738	36	0.959	29	0.972	38	37.25	**46**
48	PAST			X		0.881	33	0.592	46	0.916	44	0.995	27	37.50	**47**
49	CONN		X			0.832	45	0.442	52	0.954	30	0.940	44	42.75	**48**
50	WOMO			X		0.875	34	0.716	38	0.835	50	0.835	51	43.25	**49**
51	KUTE				X	0.862	40	0.759	32	0.564	53	0.564	53	44.50	**50**
52	PONT			X		0.818	47	0.685	41	0.868	48	0.872	50	46.50	**51**
53	CRYS	X				0.671	53	0.710	40	0.598	51	0.877	49	48.25	**52**
54	MILL	X				0.754	50	0.424	53	0.590	52	0.590	52	51.75	**53**

Table 2. Design Quality Metric (DQM) of All Projects Researched

	A	B	C	D	E	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	Avg BVI QEI EWI	Rank Avg BVI QEI EWI	Avg BVI QEI	Rank Avg BVI QEI	Avg QEI EWI DREWI	Rank Avg QEI EWI DREWI	Avg QEI EWI	Rank Avg QEI EWI	Avg QEI DREWI	Rank Avg QEI DREWI	Avg EWI DREWI	Rank Avg EWI DREWI
2	LUTE	X				7.67	1	11.00	8	3.00	1	4.00	1	4.00	4	1.00	1
3	AMNO			X		8.33	3	4.00	1	7.67	7	11.00	9	3.00	2	0.99	16
4	TAME			X		14.67	6	17.50	13	7.33	6	10.50	8	6.50	7	1.00	9
5	HUBB	X				15.00	7	12.50	9	10.00	9	14.50	11	5.00	5	0.99	17
6	BEAR			X		16.00	8	16.50	11	10.00	9	14.50	11	7.50	8	0.99	15
7	BOMO			X		8.00	2	7.00	3	13.33	13	7.00	3	15.00	16	1.00	10
8	JMNO	X				19.00	12	28.00	27	9.33	8	13.50	10	13.50	14	1.00	1
9	BUIA	X				19.00	12	9.00	7	18.67	21	27.50	30	8.50	10	0.97	30
10	MAME			X		19.33	14	17.50	13	16.00	17	23.50	23	12.50	13	0.99	18
11	FAME	X				19.33	14	22.50	19	12.33	12	18.00	15	12.00	12	1.00	12
12	SANT				X	19.33	14	28.50	29	5.67	4	8.00	5	8.00	9	1.00	1
13	PAME	X				20.67	17	18.00	15	18.33	20	27.00	29	14.50	15	0.99	22
14	RAME	X				21.00	18	31.00	34	4.33	2	6.00	2	6.00	6	1.00	1
15	SAME	X				22.00	19	27.50	25	5.00	3	7.00	3	2.00	1	1.00	11
16	LOMO			X		11.00	4	7.00	3	18.00	19	10.00	7	17.50	19	0.98	23
17	IPSW				X	22.33	20	33.00	36	6.33	5	9.00	6	9.00	11	1.00	1
18	NASH	X				23.67	24	28.50	29	15.00	16	22.00	21	15.50	17	1.00	13
19	KOMO			X		12.00	5	5.50	2	24.00	23	17.50	13	23.50	27	0.97	27
20	PERR				X	24.33	25	36.00	38	12.00	11	17.50	13	17.50	19	1.00	1
21	SANY				X	26.33	26	39.00	43	13.67	14	20.00	17	20.00	24	1.00	1
22	DUIA				X	17.33	10	7.50	5	25.33	25	22.50	22	19.50	23	0.96	32
23	THAY				X	16.00	8	13.50	10	25.67	27	21.00	20	28.00	31	0.98	24
24	KUIA				X	28.33	31	25.00	23	14.00	15	20.50	19	3.50	3	0.97	28
25	WHIT	X				28.67	32	42.50	47	17.00	18	25.00	28	25.00	29	1.00	1
26	ABER	X				30.33	35	22.50	19	27.67	30	41.00	44	18.50	22	0.95	39
27	GROV		X			22.67	22	28.00	27	21.33	22	19.50	16	26.00	30	1.00	14
28	WAME			X		31.67	36	27.00	24	24.33	24	36.00	38	16.00	18	0.96	33
29	CAME			X		22.33	20	24.50	22	26.33	28	23.50	23	30.50	34	0.99	21
30	MOMO			X		18.00	11	8.00	6	28.33	31	20.00	17	23.50	27	0.93	44
31	KENO				X	26.67	27	16.50	11	30.67	35	34.00	34	22.50	26	0.95	42
32	LEAR			X		23.33	23	19.50	16	30.00	34	24.50	26	29.50	33	0.96	38
33	RIPP	X				26.67	27	32.00	35	27.33	29	24.50	26	33.00	35	0.99	19
34	TANY		X			32.33	37	24.00	21	28.33	31	31.00	31	18.00	21	0.93	45
35	BRAC		X			27.33	30	27.50	25	39.33	44	39.00	41	45.50	50	0.96	34
36	NODD	X				41.00	47	45.00	50	25.33	25	37.50	39	21.50	25	0.97	26
37	FORG	X				32.33	37	37.50	42	33.00	36	34.50	35	38.50	41	0.99	20
38	NOMO			X		29.33	34	30.00	32	28.67	33	23.50	23	29.00	32	0.96	35
39	POMO			X		26.67	27	20.00	17	40.67	46	37.50	39	41.00	44	0.93	46
40	SEAR			X		34.67	41	30.50	33	38.00	40	43.00	47	35.50	37	0.96	36
41	MUTE			X		29.00	33	21.00	18	38.67	42	35.00	37	35.50	37	0.92	48
42	ONOT	X				34.33	40	34.50	37	40.33	45	39.00	41	43.50	46	0.94	43
43	POWW	X				39.33	45	41.00	45	38.33	41	43.00	47	39.50	42	0.97	29
44	SHAW	X				33.00	39	28.50	29	36.67	39	31.00	31	34.00	36	0.92	47
45	QUIN			X		37.33	44	44.00	48	35.00	38	34.50	35	40.50	43	0.98	25
46	MEAR			X		35.33	42	37.00	41	40.67	46	40.00	43	45.00	49	0.95	40
47	FALL	X				37.00	43	41.00	45	34.33	37	32.50	33	37.00	40	0.97	31
48	PAST			X		41.00	47	39.50	44	39.00	43	45.00	51	36.50	39	0.96	37
49	CONN		X			42.33	50	48.50	52	42.00	48	41.00	44	48.00	52	0.95	41
50	WOMO			X		40.67	46	36.00	38	46.33	50	44.00	49	44.50	47	0.84	50
51	KUTE				X	41.67	49	36.00	38	46.00	49	42.50	46	42.50	45	0.56	53
52	PONT			X		45.33	51	44.00	48	46.33	50	44.50	50	45.50	50	0.87	49
53	CRYS	X				48.00	52	46.50	51	46.67	52	45.50	52	44.50	47	0.74	51
54	MILL	X				51.67	53	51.50	53	52.33	53	52.50	53	52.50	53	0.59	52

Table 2A. Design Quality Rank (DQR)
Footprint Bridge Projects

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Project Acronym**	**Footprint Bridge**	**Major Bridge**	**Major Highway**	**Resurface**	**BVI**	**BVI Rank**	**QEI**	**QEI Rank**	**EWI**	**EWI Rank**	**DREWI**	**DREWI Rank**	**Avg BVI QEI EWI DREWI Rank**	**DQR**
2	**Footprint Bridges**														
3	LUTE	X				0.920	15	0.918	7	1.000	1	1.000	1	6.00	1
4	HUBB	X				0.918	16	0.901	9	0.980	20	1.000	1	11.50	4
5	JMNO	X				0.893	30	0.805	26	1.000	1	1.000	1	14.50	7
6	BUIA	X				0.971	2	0.860	16	0.934	39	1.000	1	14.50	7
7	FAME	X				0.909	22	0.837	23	0.991	13	1.000	1	14.75	9
8	PAME	X				0.944	8	0.803	28	0.973	26	1.000	1	15.75	12
9	RAME	X				0.705	51	0.882	11	1.000	1	1.000	1	16.00	13
10	SAME	X				0.693	52	0.949	3	0.993	11	1.000	1	16.75	14
11	NASH	X				0.898	27	0.779	30	0.991	14	1.000	1	18.00	17
12	WHIT	X				0.868	36	0.529	49	1.000	1	1.000	1	21.75	24
13	ABER	X				0.942	9	0.738	36	0.904	46	1.000	1	23.00	25
14	RIPP	X				0.885	31	0.754	33	0.988	16	0.988	33	28.25	32
15	NODD	X				0.805	48	0.683	42	0.948	33	1.000	1	31.00	35
16	FORG	X				0.897	28	0.583	47	0.979	22	0.994	30	31.75	36
17	ONOT	X				0.905	25	0.598	44	0.944	34	0.944	43	36.50	41
18	POWW	X				0.883	32	0.528	50	0.941	36	0.995	29	36.75	42
19	SHAW	X				0.866	37	0.846	20	0.924	42	0.923	48	36.75	42
20	FALL	X				0.829	46	0.738	36	0.959	29	0.972	38	37.25	46
21	CRYS	X				0.671	53	0.710	40	0.598	51	0.877	49	48.25	52
22	MILL	X				0.754	50	0.424	53	0.590	52	0.590	52	51.75	53
23	Average	X				0.858	30.90	0.743	30.15	0.932	24.40	0.964	16.70	25.54	25.60
24	Stdev	X				0.087	15.79	0.146	15.43	0.119	16.99	0.094	20.48	12.71	16.97

Table 2B. Design Quality Rank (DQR)
Major Bridge, Major Highway and Resurfacing Projects

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	BVI	Rank BVI	QEI	Rank QEI	EWI	Rank EWI	DREWI	Rank DREWI	Avg BVI QEI EWI DREWI Rank	Design Quality Rank (DQR)
2	**Major Bridges**														
3	GROV		X			0.896	29	0.803	27	0.992	12	0.998	25	23.25	**26**
4	TANY		X			0.874	35	0.875	13	0.863	49	0.999	23	30.00	**33**
5	BRAC		X			0.953	4	0.504	51	0.966	27	0.960	40	30.50	**34**
6	CONN		X			0.832	45	0.442	52	0.954	30	0.940	44	42.75	**48**
7	Average		x			0.889	28.3	0.656	35.8	0.944	29.5	0.974	33.0	31.625	35.3
8	Stdev		x			0.050	17.5	0.215	19.1	0.056	15.2	0.029	10.6	8.120	9.2
9	**Major Highways**														
10	AMNO			X		0.964	3	0.942	5	0.985	17	1.000	1	6.50	**2**
11	TAME			X		0.906	23	0.876	12	0.999	9	1.000	1	11.25	**3**
12	BEAR			X		0.913	19	0.870	14	0.990	15	1.000	1	12.25	**5**
13	BOMO			X		0.935	10	0.948	4	0.997	10	0.997	26	12.50	**6**
14	MAME			X		0.934	11	0.819	24	0.977	23	1.000	1	14.75	**9**
15	LOMO			X		0.933	13	0.950	1	0.981	19	0.981	34	16.75	**14**
16	KOMO			X		0.989	1	0.896	10	0.973	25	0.973	37	18.25	**18**
17	WAME			X		0.906	23	0.769	31	0.927	41	1.000	1	24.00	**27**
18	CAME			X		0.912	20	0.781	29	0.985	18	0.988	32	24.75	**28**
19	MOMO			X		0.930	14	0.950	2	0.935	38	0.935	45	24.75	**28**
20	LEAR			X		0.912	21	0.851	18	0.953	31	0.957	41	27.75	**31**
21	NOMO			X		0.861	41	0.848	19	0.962	28	0.962	39	31.75	**36**
22	POMO			X		0.950	5	0.741	35	0.929	40	0.929	47	31.75	**36**
23	SEAR			X		0.916	18	0.637	43	0.921	43	0.995	28	33.00	**39**
24	MUTE			X		0.918	17	0.818	25	0.904	45	0.932	46	33.25	**40**
25	QUIN			X		0.853	43	0.595	45	0.976	24	0.978	36	37.00	**44**
26	MEAR			X		0.901	26	0.565	48	0.949	32	0.949	42	37.00	**44**
27	PAST			X		0.881	33	0.592	46	0.916	44	0.995	27	37.50	**47**
28	WOMO			X		0.875	34	0.716	38	0.835	50	0.835	51	43.25	**49**
29	PONT			X		0.818	47	0.685	41	0.868	48	0.872	50	46.50	**51**
30	Average			X		0.910	21.1	0.792	24.5	0.948	30.0	0.964	29.3	26.225	27.9
31	Stdev			X		0.039	13.1	0.126	15.9	0.044	13.0	0.045	18.2	11.494	16.6
32	**Resurfacing**														
33	SANT				X	0.854	42	0.867	15	1.000	1	1.000	1	14.75	**9**
34	IPSW				X	0.802	49	0.860	17	1.000	1	1.000	1	17.00	**16**
35	PERR				X	0.863	38	0.743	34	1.000	1	1.000	1	18.50	**19**
36	SANY				X	0.862	39	0.711	39	1.000	1	1.000	1	20.00	**20**
37	DUIA				X	0.944	7	0.915	8	0.937	37	0.991	31	20.75	**21**
38	THAY				X	0.946	6	0.841	21	0.980	21	0.980	35	20.75	**21**
39	KUIA				X	0.848	44	0.933	6	0.942	35	1.000	1	21.50	**23**
40	KENO				X	0.934	12	0.841	21	0.896	47	0.998	24	26.00	**30**
41	KUTE				X	0.862	40	0.759	32	0.564	53	0.564	53	44.50	**50**
42	Average				x	0.879	30.8	0.830	21.4	0.924	21.9	0.948	16.4	22.639	23.2
43	Stdev				x	0.050	17.2	0.077	11.5	0.140	21.6	0.144	19.8	8.773	11.5

Contrary to our theory, the DQR average of resurfacing projects is only 2.4 DQR positions above the DQR average for FPBs, 3.6 DQR positions above that of all projects, and has a DQR range of 9 to 51 and a DQR stdev of 11.5. Also, the DQR ranges of both FPBs and major highways span the range of resurfacing projects. One would expect that resurfacing projects having low levels of design risk and uncertainties would consistently rank in the top DQR quartile. Four FPBs projects and four major highway projects ranked higher than the highest ranked resurfacing project. Considering these findings, we believe that DQRs of resurfacing projects should be ranked together with FPB and major highway projects.

Consistent with our theory that DQR probably correlates with project type, however, DQR average of major bridge projects at 35.3 is 8.5 DQR positions lower than the average of the other three project types. The major bridges also have a much smaller DQR standard deviation and accordingly a much smaller range of DQR. These findings – at first – imply that major bridges ought to be ranked separately from the other three project-types. However, before reaching a conclusion, we should consider two other factors:

- First, the research includes only four major bridges, a small quantity of data points in comparison to 20 FPBs, 20 major highways, and nine resurfacing projects.
- Second, none of the projects is purely one project-type; we cast each project by its prevalent type (e.g., major highway projects include bridge construction and both the FPB and major bridge projects involve highway construction).

Considering these factors, we believe that major bridges should be ranked along with the other project-types in this research.

For the purpose of correlating management practices to DQR, our research indicates that all highway, bridge, and resurfacing projects should be ranked together in the same scale:

DQR = (BV+QE+EW+DREW) ÷ 4

SUMMARY

Design quality can be measured quantifiably. However, no single metric is sufficiently reliable or complete as an indicator. The metric model that is most practical and reliable combines four metrics:

- Variation among construction bidders' prices.
- Deviations of final construction quantities from those estimated.
- Construction extra work orders.
- Design-related construction extra work orders.

These are expressed mathematically as …

$$DQR = (BV+QE+EW+DREW) \div 4$$

Where each term is expressed as the rank of a project relative to other projects.

Chapter 6

MANAGEMENT PRACTICES CHOSEN

Initially, this research stemmed from a desire to evaluate the effects of "salary and overhead caps" on design quality. Subsequently, the scope of the research was broadened to study the influences of several other management practices as well. PMI advises that successful projects hinge on skillful discipline in nine knowledge areas affecting planning, organizing, leading, and control. Successful management of project scope, cost, schedules, quality, personnel, communications, procurement, and risk, together with their integration, are key to fulfilling project requirements to satisfy stakeholders' needs and interests. When choosing the management practices to analyze, we selected practices that are often used for managing civil engineering projects. We categorized these practices by PMI's nine primary knowledge areas. In this Chapter, we present these practices in the framework of PMI's nine knowledge areas and the processes of planning, organizing, leading, and control.

MANAGING SCOPE

In evaluating project scope management, we sought to determine design management's rigor in planning, organizing, leading, and controlling the scope of services:

- Was a detailed scope of services prepared?
- Was a work breakdown structure (WBS) used in developing the scope?
- Did management routinely compare actual to planned deliverables?
- Was the design scope of services adjusted promptly, when needed?

"Scope management includes the processes required to ensure that the design includes all of the services required, and only the services required, to complete the [design] successfully. It is primarily concerned with defining and controlling what is and what is not included in the [design]." (PMI's PMBOK, p.47)

MANAGING COST

In evaluating project cost management, we sought to determine design management's thoroughness in planning, organizing, leading, and controlling the cost of design services and overall project costs:

- Was the design budget developed rationally using design scope, explicit tasks, labor classifications, salary rates, and other directly related costs?
- Was actual cost incurred routinely compared to budgeted cost-by-task?
- Were actual incurred costs of design routinely checked?
- Was the process known as "earned value" used to compare costs to budget?

"Project cost management includes the processes required to ensure that the project is completed within the approved budget." (PMBOK, p.73)

- Does a State's Department of Transportation (DOT) back-charge design consultants, where appropriate, for construction changes through "cost recovery"?
- Did DOT seek to recover costs from design consultants for construction changes on this project? If yes, how much was sought by DOT?

MANAGING SCHEDULE (TIME)

"Project time management includes the processes required to ensure timely completion of the project." (PMBOK, p. 59)

In evaluating project schedule management, we sought to determine design management's thoroughness in planning, organizing, leading, and controlling the timeliness of design services:

- Was a detailed schedule prepared for each task and each deliverable (submittal)?
- Were milestone dates set at the start [of design] for deliverable submissions?
- Was design schedule performance reviewed at least monthly?
- Were deliverables always submitted on time, sometimes late, often late, or usually late?
- Were sponsoring agency reviews of deliverables always on time, sometimes late, often late, or chronically late?
- Did late reviews by the sponsoring agency disrupt the designer's workflow?

MANAGING PROJECT STAFF (HUMAN RESOURCES)

"Project human resource management includes the processes required to make the most effective use of the people involved with the project." (PMBOK, p. 93)

In evaluating project design staff management, we sought to determine design management's thoroughness in planning, organizing, leading, and controlling the quality of staffing:

- Was a detailed plan prepared for staffing each task and deliverable?
- Did the staffing plan consider skills and experience needed?
- Did the staffing plan consider resource availability and workload balancing?
- As the design progressed:
  - Was staffing appropriate for needs?
  - Was the design project manager appropriately experienced for this project?
    - Technically?
    - Managerially?
- Were technical staff technically proficient?

MANAGING QUALITY

In evaluating project design quality management, we sought to determine design management's thoroughness in planning, organizing, leading, and controlling the quality of design services:

- What is your DOT's normal policy (written or unwritten) for reviewing designer's deliverables, such as data, computations, designs, plans, specifications, and quantity estimates produced by designers?
    - DOT is ultimately responsible and accountable for the quality of design. Therefore, DOT rigorously and thoroughly reviews and corrects all deliverables by private design consultants, including data, computations, plans, profiles, cross-sections, specifications, quantity estimates, and unit-cost estimates.

> *"Design quality management includes the processes required to ensure that the project will satisfy the needs for which it was undertaken." (PMBOK, p. 83)*

    - DOT shares responsibility and accountability for design quality with design consultants. DOT expects design consultants to perform detailed design quality control such as reviews of data, computations, plans, profiles, cross-sections, specifications, quantity estimates, and unit-cost estimates. DOT's responsibility is to assure that design consultant is performing quality control.
    - DOT administers design quality assurance by rigorously selecting only those design consultants who have proven track records in design quality control.
    - DOT's policy for assuring design quality varies depending on the risk associated with each specific project.
- Are sponsoring agency's standard design requirements readily available to designers, well organized, and clearly presented in documents or electronic files?
- Are revisions to design standards promptly communicated to designers?
- Are design standards consistent with contractual terms?
- Were design submittals rigorously reviewed by DOT?
- Were design submittals reviewed sufficiently to assure that the designer used reasonable care in meeting requirements?
- Were the submittals simply spot-checked to assure that the designer applied quality control?
- Did DOT representatives visit designer's office to review design progress and quality?
- Did DOT meet with the designer at least monthly to review design progress, resolve issues, and assure design quality?
- Were design submittals nearly always excellent, very good, typical of most submittals, poorer than most, or especially poor and unacceptable?
- What processes were used to assess the project's constructability?
    - In-progress review by design team?
    - Review at end of design by design team?
    - Review by sponsoring agency staff outside design team?
    - Review by private consultant independent of design team?
    - Review by DOT specialists independent of personnel assigned to design process?
    - Review by construction management specialty firm?
    - Review by construction contractor (non-bidding firm)?
    - Design not reviewed for constructability before inviting construction bids?
- Did constructability review prompt major revisions, some revisions, few revisions, or no revisions to plans, specifications, or construction cost estimates?

- Was value engineering performed? If so, by sponsoring agency's staff, design engineer, or a third party?

MANAGING PROCUREMENT

> *"Project procurement management includes the processes required to acquire goods or services from outside the organization." (PMBOK, p. 123)*

In evaluating project procurement management, we sought to determine the relationship of the method of compensation for design services and design quality.

Design services for state administered highway and bridge projects are provided by design units within the state DOT or by private design firms. Private firms are compensated for their design services by two basic methods:

- Lump sum (or fixed price) – used very sparingly by state DOTs.
- Cost reimbursement (or cost plus) – widely used by state DOTs.

With the latter method, design consultants are compensated for salary costs of staff members who work on the project under contract, as well as other indirect project costs. Indirect project costs (or overhead expenses) are those required to operate a design firm that are indirectly attributable to the cost of delivering projects to clients (e.g., rent, telephone services, offices furnishings, employee benefits, and computer software and hardware). Compensation for indirect costs is commonly expressed as a percentage of the direct salary cost.

Furthermore, the design consultant is reimbursed for certain other expenses directly attributable to the project. Costs of subconsultants and travel accommodations are normally considered directly reimbursable costs.

The design consultant is also paid a fee, considered profit for the work. Fees usually range from 10% to 20% of the combined costs of direct salaries and indirect expenses, depending on the risks associated with the project. Most cost reimbursement contracts by state DOTs have maximum dollar amounts. Many states also set maximum expenditures for each category of cost, i.e., direct salaries, indirect costs, subconsultant cost, and other direct expenses.

During the past three decades, many state DOTs have had contractual policies limiting reimbursements for salaries and indirect expenses. This practice is known as "capping." Salary caps are generally expressed as dollars per hour and indirect expense caps as a percentage of total direct salaries. The objectives of "capping" are to transfer some risks associated with cost reimbursement from the sponsoring DOT to the design consultant and to control costs.

Design consultants and their professional societies have argued that capping hampers their ability to produce good quality designs. Capping salary rates, especially when the caps are below market rates, is a disincentive for assigning the most experienced staff to the design task at hand. Capping indirect expense rates discourages firms from spending money to advance their capabilities (e.g., computer-aided design). Conversely, state DOTs have argued that solicitation for design services is heavily sought by design firms, an indication that design firms want state DOT work. In addition, state DOTs have limited budgets and must ensure that stakeholders receive the best value for services provided.

One purpose of this research is to determine the correlation between procurement compensation practices and design quality.

> *"Project communications management includes the processes required to ensure timely and appropriate generation, collection, dissemination, storage, and ultimate disposition of project information … Everyone involved in the project must be prepared to send and receive communications in the project 'language' and must understand how the communications they are involved in as individuals affect the project as a whole." (PMBOK, p. 83)*

MANAGING COMMUNICATIONS, RISK, AND INTEGRATION

For this discussion, we have combined communications, risk, and integration management because the management practices researched relate to all three knowledge areas. In evaluating these practices, we sought to determine design management's thoroughness in planning, organizing, leading, and controlling communications, risk, and integration:

> *"Project risk management includes the processes concerned with identifying, analyzing, and responding to project risk. It includes maximizing the results of positive events and minimizing the consequences of adverse events." (PMBOK, p. 111)*

- Does DOT endorse partnering with private design consultants?
- Does DOT participate in partnering sessions with an association(s) representing private design consultants?
- Has DOT implemented policy or procedural changes derived from partnering sessions with associations?
- Was this project designed under a "partnering agreement?"
- Was commercially marketed project management software used in planning and/or managing this project?
    - If yes, was the software Primavera, Microsoft project, Artemis, or other?

> *"Project integration management includes the processes required to ensure that the various elements of the project are properly coordinated. It involves making tradeoffs among competing objectives and alter-natives in order to meet or exceed stakeholder needs and expectations. All project management processes are integrative to some extent." (PMBOK, p. 39)*

SUMMARY

This research sought to determine the correlation between design management practices and design quality. We studied the nine knowledge areas identified by PMI as essential to project success and common to managing design of highway/bridge projects and other projects for the built-environment:

Scope Management	Procurement Management
Cost Management	Communications Management
Schedule (or Time) Management	Risk Management
Human Resources Management	Integration Management
Quality Management	

Chapter 7

CORRELATING MANAGEMENT PRACTICES WITH DQR

The metric model chosen for measuring design quality is DQR as presented in Chapter 5. The management practices chosen for correlation with DQR are presented in Chapter 6. In this Chapter, we present the results of correlating management practices with DQR and opinions of the influences that management practices have on design quality.

DETERMINING CORRELATIONS

The basic information compiled for each highway and bridge project included data needed for computing that project's DQR and data pertaining to practices used in managing each project's design. Matrices of "Management Practices versus DQR" for the 53 projects researched are shown in Tables 3A through 3J. Projects are listed in rows and identified by acronyms and type (see rows 3 through 53 in columns A through E). Projects are listed by DQR from 1, the highest rank, to 53, the lowest rank (see column O). Columns A through E and O are repeated on each of the 10 tables. The remaining columns on each table identify practices used in managing each project (see columns AB through BY).

DQR average for "yes" and "no" responses to each management practice question are listed in rows 56 and 57. For example, in Table 3A, the DQR average of the 11 projects that used WBS to develop the scope of design services is 19.0 (see cell AC56). The DQR average of the 38 projects not using WBS is 28.4 (see cell AC57). In that the DQR average for all 53 projects is 26.8, these findings indicate that the practice of using WBS correlates with projects having above-average DQR and higher design quality. Projects not using WBS rank below average and have lower design quality.

1	Project Type & Rank						Scope Management Practices
2	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	DQR	Detailed Scope of Services Prepared?
3	LUTE	x				1	no data
4	AMNO			x		2	yes
5	TAME			x		3	yes
6	HUBB	x				4	yes
7	BEAR			x		5	no
8	BOMO			x		6	yes
9	JMNO	x				7	yes
10	BUIA	x				7	no
11	MAME			x		9	yes
12	FAME	x				9	yes
13	SANT				x	9	yes
14	PAME	x				12	yes
15	RAME	x				13	yes

By itself, a detailed scope does not necessarily correlate with design quality.

SCOPE MANAGEMENT

Four management practices were researched relating to scope management. The results of these correlations are listed in columns AB to AE in Table 3A and are described below.

Detailed Scope of Design Services

A detailed scope of design services was prepared for 47 projects, not prepared for two projects, and there were no responses for four projects. The two projects without a detailed scope rank in the highest quartile, placing 5th and 7th in the DQR (see insert at left).

TABLE 3A HERE

Table 3A. Management Practices vs. DQM Rankings

	A	B	C	D	E	O	AB	AC	AD	AE
1	Project Type & Rank						Scope Management Practices			
2	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	DQR	Detailed Scope of Services Prepared?	Work Breakdown Structure Used for Scope?	Routinely Compared Deliverables to Plan?	Promptly Changed Design Scope, When Needed?
3	LUTE	X				1	no data	no data	no data	no data
4	AMNO			X		2	yes	yes	no	yes
5	TAME			X		3	yes	no	yes	yes
6	HUBB	X				4	yes	no	yes	no
7	BEAR			X		5	no	no	no	no
8	BOMO			X		6	yes	no	yes	yes
9	JMNO	X				7	yes	yes	no	yes
10	BUIA	X				7	no	no	no	no
11	MAME			X		9	yes	no	yes	yes
12	FAME	X				9	yes	yes	yes	no
13	SANT				X	9	yes	no	yes	no
14	PAME	X				12	yes	yes	no	no
15	RAME	X				13	yes	yes	no	no
16	SAME	X				14	yes	yes	yes	no
17	LOMO			X		14	yes	no	yes	yes
18	IPSW				X	16	yes	no	yes	no
19	NASH	X				17	yes	no	yes	no
20	KOMO			X		18	yes	no	yes	yes
21	PERR				X	19	yes	no	yes	no
22	SANY				X	20	yes	no	no	yes
23	DUIA				X	21	yes	yes	no	yes
24	THAY				X	21	yes	no	yes	no
25	KUIA				X	23	yes	yes	no	yes
26	WHIT	X				24	yes	no	yes	no
27	ABER	X				25	yes	no	yes	no
28	GROV		X			26	yes	no	yes	no
29	WAME			X		27	yes	no	yes	yes
30	CAME			X		28	yes	no	yes	yes
31	MOMO			X		28	yes	no	yes	yes
32	KENO				X	30	yes	no	yes	no
33	LEAR			X		31	yes	yes	no	no
34	RIPP	X				32	yes	no	yes	no
35	TANY		X			33	yes	yes	yes	no
36	BRAC		X			34	yes	no	yes	no
37	NODD	X				35	yes	no	yes	no
38	FORG	X				36	yes	no	yes	no
39	NOMO			X		36	yes	no	yes	yes
40	POMO			X		36	yes	no	yes	yes
41	SEAR			X		39	no data	no data	no data	no data
42	MUTE			X		40	no data	no data	no data	no data
43	ONOT	X				41	yes	no	yes	no
44	POWW	X				42	yes	no	yes	no
45	SHAW	X				42	yes	no	yes	no
46	QUIN			X		44	yes	no	yes	no
47	MEAR			X		44	yes	yes	no	no
48	FALL	X				46	yes	no	yes	no
49	PAST			X		47	yes	no	yes	no
50	CONN		X			48	yes	no	yes	no
51	WOMO			X		49	yes	no	yes	yes
52	KUTE				X	50	no data	no data	no data	no data
53	PONT			X		51	yes	no	yes	no
54	CRYS	X				52	yes	no	yes	no
55	MILL	X				53	yes	no	yes	no
56	Avg DQM Rank for "Yes"						27.2	19.0	29.1	20.4
57	Avg DQM Rank for "No"						6.0	28.4	16.8	29.2

The practice of requiring a detailed scope of services for design is virtually universal among state transportation agencies. It was not possible to correlate this practice with DQR because it was used in managing all but two of the projects reporting data. Logically, one would expect that its absence would lead to low rankings. We believe that the high DQR of the two projects having no detailed scope were influenced by other favorable management practices, irrespective of the absence of detailed scopes of design services. We reason that a detailed scope of design services is an *aid* to design quality; however, the presence or absence of a detailed scope does not, in itself, necessarily correlate with design quality. Appropriately drawn design scopes influence quality; badly drawn scopes detract from quality. ***Our findings regarding the correlation between detailed scope of design services and DQR are inconclusive.***

Work Breakdown Structure (WBS)

A WBS was used in managing the scope of 11 projects (see Chart 1). The average rank of these projects was 19.0 or 9.4 positions better than the DQR of 38 projects on which WBS was not used and nearly eight positions better than the average rank of all projects. Eight of the 11 that used WBS rank in the higher two quartiles. Six projects rank in the top quartile and one in the lowest. Seven projects **not** using WBS rank in the top DQR quartile, 11 in the bottom quartile, and 17 of 38 rank in the higher two quartiles. PMI advocates using WBS for managing scope to improve project performance. ***We found that using WBS for design scope development correlates with good design quality.***

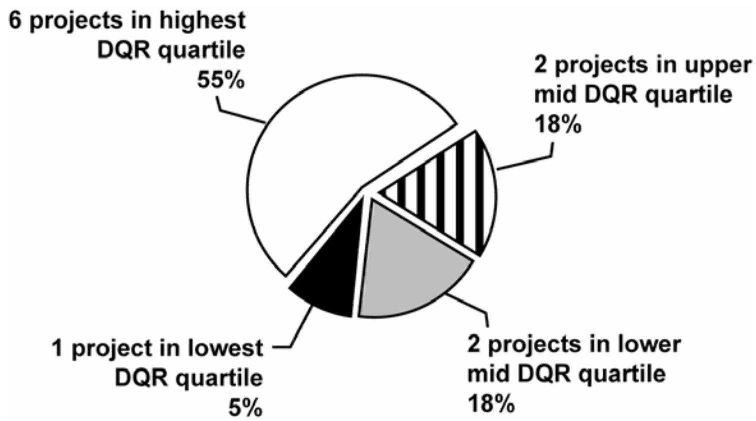


Chart 1. Using WBS for design scope development showed exceptional bias to higher design quality.

Prompt Changes to Design Scope

Sixteen projects reported that design scope was adjusted promptly when needed (see Chart 2). The average rank of these projects was 20.4 or 8.8 positions better than the 33 projects reporting that scope adjustments were not implemented promptly and 6.4 positions better than the average rank of all projects. Five of the 16 reporting prompt scope adjustments rank in the top quartile, 10 in the top two, and one in the lowest quartile. ***Prompt design scope adjustments, when needed, directly correlate with good design quality.***

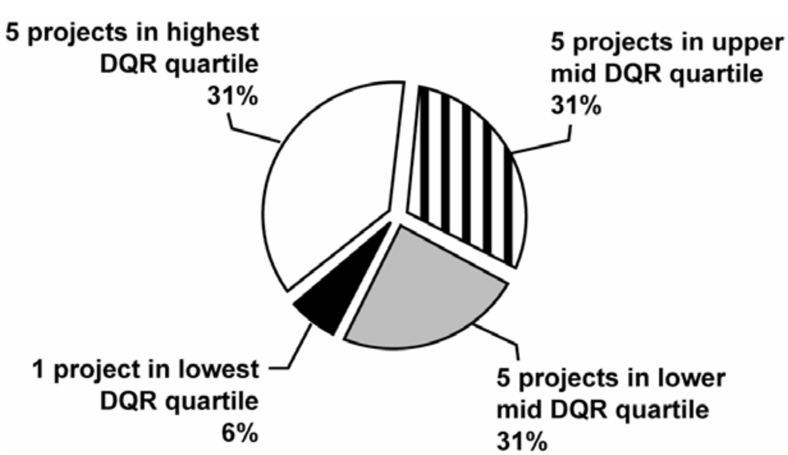


Chart 2. Prompt design scope changes correlate with higher design quality.

Comparing Deliverables to Plan

Management compared actual deliverables to those planned on 38 projects. DQR average of these projects is 29.1 or 12.3 positions below the average of the 11 projects reporting no practice of comparing actual to planned deliverables and 3.8 positions below the average of all projects. The 11 that were not subjected to this practice have a DQR average of 16.8 or 10 positions better than the average of all projects. Six of the eleven rank in the top quartile and one in the bottom quartile. ***Routine comparisons of actual deliverables to those originally envisioned during the design planning process correlate with poor design quality.***

Summary: Correlating Design Scope Management with Design Quality

DQR correlates directly with the quality of design scope management. Use of WBSs for scope development and prompt changes to design scopes correlate directly with high DQR and good design quality. Conversely, rigid comparisons of actual deliverables to those that were originally conceived during design planning correlate with low DQR and poor design quality.

COST AND PROCUREMENT MANAGEMENT

Six cost-related practices and one procurement management practice were researched. The results of these correlations are listed in columns AF to AL in Table 3B and discussed in detail below.

Rational Design Budget

Forty-one projects had rationally developed design budgets – or "built-up" budgets. The DQR average for these projects is 28.8, which is 2.0 ranking positions below the average of all projects. Nine projects with an average ranking of 13.6 were reported as **not** having rationally developed design budgets. Four of these nine rank in the highest quartile and seven in the top two quartiles (see insert at right). ***Rationally developed design budgets correlate with low DQR and poor design quality.***

1	Project Type & Rank						Cost and Procurement Management Practices
2	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	DQR	Design Budget Developed Rationally?
3	LUTE	x				1	no data
4	AMNO			x		2	no
5	TAME			x		3	yes
6	HUBB	x				4	yes
7	BEAR			x		5	no
8	BOMO			x		6	yes
9	JMNO	x				7	no
10	BUIA	x				7	yes
11	MAME			x		9	yes
12	FAME	x				9	yes
13	SANT				x	9	no
14	PAME	x				12	yes
15	RAME	x				13	yes
16	SAME	x				14	yes
17	LOMO			x		14	yes
18	IPSW				x	16	no
19	NASH	x				17	yes
20	KOMO			x		18	yes
21	PERR				x	19	no
22	SANY				x	20	yes
23	DUIA				x	21	yes
24	THAY				x	21	no
25	KUIA				x	23	yes

Seven of nine projects *without* "built-up" budgets rank in the top 25 projects, indicating that rationally developed budgets correlate with poor design quality.

Review of Actual Costs versus Budgeted Cost

Ten projects were subjected to routine comparisons of actual costs incurred versus budgeted costs. The average rank of these 10 projects was 24.3 or 2.5 positions better than the 39 projects that were not subject to routine comparisons of actual cost to budgeted costs. Of the 10 projects so reviewed, two rank in the highest DQR quartile, one in the lowest, and five each in the upper two and lower two quartiles, respectively. ***Projects subjected to comparisons of actual costs to budgeted costs correlate directly with DQR and good design quality, but the correlation is relatively weak.***

Table 3B. Management Practices vs. DQM Rankings

	A	B	C	D	E	O	AF	AG	AH	AI	AJ	AK	AL
1	Project Type & Rank						Cost and Procurement Management Practices						
2	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	DQR	Design Budget Developed Rationally?	No Caps on Designer Comp Rates?	Routinely Compared Actual Costs to Budgeted Costs?	Routinely Checked Expended Costs?	Used "Earned Value" Analyses?	State DOT Policy Advocates "Cost Recovery" ?	State DOT Backcharged Designer on This Project?
3	LUTE	X				1	no data	yes	no data	no data	no data	no data	no data
4	AMNO			X		2	no	yes	no	no	no	no	no
5	TAME			X		3	yes	no	yes	yes	no	no	no
6	HUBB	X				4	yes	no	no	yes	no	yes	no
7	BEAR			X		5	no	yes	no	no	no	no	no
8	BOMO			X		6	yes	yes	yes	no	no	yes	no
9	JMNO	X				7	no	yes	no	no	no	no	no
10	BUIA	X				7	yes	yes	no	no	no	yes	no
11	MAME			X		9	yes	no	no	yes	no	no	no
12	FAME	X				9	yes	no	no	yes	no	no	no
13	SANT				X	9	no	yes	no	yes	no	yes	no
14	PAME	X				12	yes	no	no	no	no	no	no
15	RAME	X				13	yes	no	no	no	no	no	no
16	SAME	X				14	yes	no	no	no	no	no	no
17	LOMO			X		14	yes	yes	yes	no	no	yes	no
18	IPSW				X	16	no	yes	no	yes	no	yes	no
19	NASH	X				17	yes	no	no	yes	no	yes	no
20	KOMO			X		18	yes	yes	yes	no	no	yes	no
21	PERR				X	19	no	yes	no	yes	no	yes	no
22	SANY				X	20	yes	yes	yes	yes	no	no	no
23	DUIA				X	21	yes	yes	no	yes	no	yes	no
24	THAY				X	21	no	yes	no	yes	no	yes	no
25	KUIA				X	23	yes	yes	no	yes	no	yes	no
26	WHIT	X				24	yes	no	no	yes	no	yes	no
27	ABER	X				25	yes	no	no	yes	no	yes	no
28	GROV		X			26	yes	no	no	yes	no	yes	no
29	WAME			X		27	yes	no	no	yes	no	no	no
30	CAME			X		28	yes	no	no	yes	no	no	no
31	MOMO			X		28	yes	yes	yes	no	no	yes	no
32	KENO				X	30	no	yes	no	yes	no	yes	no
33	LEAR			X		31	yes	yes	no	no	no	no	no
34	RIPP	X				32	yes	no	no	yes	no	yes	no
35	TANY		X			33	yes	yes	yes	yes	no	no	no
36	BRAC		X			34	yes	no	no	yes	no	yes	no
37	NODD	X				35	yes	no	no	yes	no	yes	no
38	FORG	X				36	yes	no	no	yes	no	yes	no
39	NOMO			X		36	yes	yes	yes	no	no	yes	no
40	POMO			X		36	yes	yes	yes	no	no	yes	no
41	SEAR			X		39	no data	yes	no data	no data	no data	no data	no data
42	MUTE			X		40	no data	yes	no data	no data	no data	no data	no data
43	ONOT	X				41	yes	no	no	yes	no	yes	no
44	POWW	X				42	yes	no	no	yes	no	yes	no
45	SHAW	X				42	yes	no	no	yes	no	yes	no
46	QUIN			X		44	yes	no	no	yes	no	yes	no
47	MEAR			X		44	yes	yes	no	no	no	no	no
48	FALL	X				46	yes	no	no	yes	no	yes	no
49	PAST			X		47	yes	no	no	yes	no	yes	no
50	CONN		X			48	yes	no	no	yes	no	yes	no
51	WOMO			X		49	yes	yes	yes	no	no	yes	no
52	KUTE				X	50	no data	yes	no data	no data	no data	no data	no data
53	PONT			X		51	yes	no	no	yes	no	yes	no
54	CRYS	X				52	yes	no	no	yes	no	yes	no
55	MILL	X				53	yes	no	no	yes	no	yes	yes
56	Avg DQM Rank for "Yes"						28.8	23.3	24.3	29.3	na	30.4	53.0
57	Avg DQM Rank for "No"						13.6	30.1	26.8	20.1	26.3	17.1	26.5

Routinely checking expended costs as design progresses correlates with lower design quality.

Routine Checking of Expended Costs

Thirty-three projects had design costs checked regularly throughout design. The average rank of these projects was 29.3. Five rank in the highest quartile, while 10 rank in the lowest.

The average rank of 16 projects reporting that expended costs were **not** regularly checked was 20.1 or 6.7 positions better than those projects having regular cost reviews. Seven of the projects that were not regularly checked rank in the top quartile, two in the lowest, 10 in the top two quartiles, and six in the lower two quartiles. ***The practice of routinely checking expended design costs as design progresses correlates with lower DQR and poorer design quality.***

Earned Value Analyses

No project used "earned value." Although earned value is a long-standing highly revered method used by project management disciplinarians for controlling scope, cost, and schedule, it is not commonly used in civil engineering projects. ***We are unable to determine the correlation of earned value analyses to design quality.***

Capping Salary and Overhead Rates for Designer Compensation

Salary and overhead rates for compensating designers were "capped" on 27 projects and not capped on 26 projects (see Charts 3 and 3A). The DQR average for those projects **without** caps is 23.3 or 6.8 positions higher than the ranking of those projects with caps. Seven of the projects **without** caps rank in the top DQR quartile and three in the bottom. Six projects **with caps** rank in the top quartile and 10 in the bottom. ***The practice of capping salary and overhead rates for compensating design consultants correlates with lower DQR and poorer design quality.***

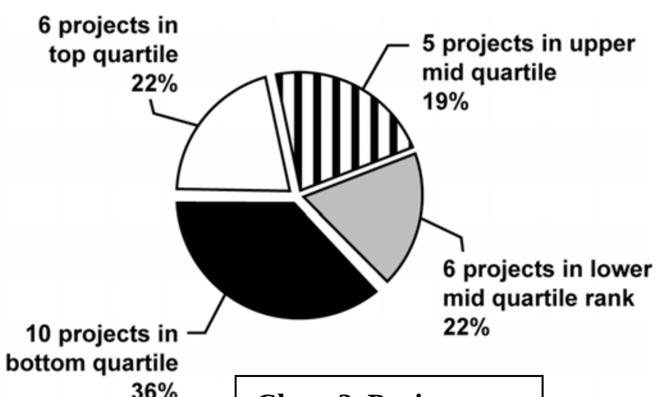


Chart 3. Projects *with* caps (27).

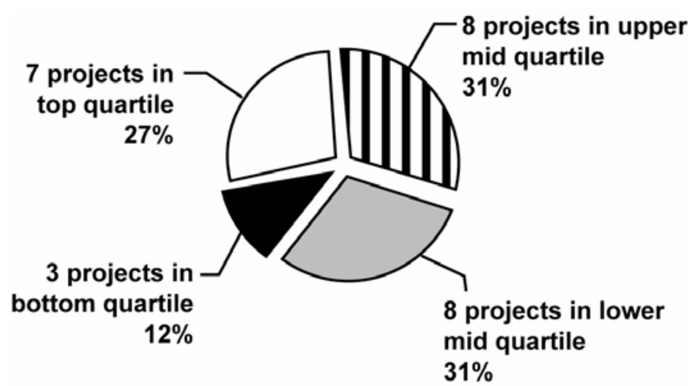
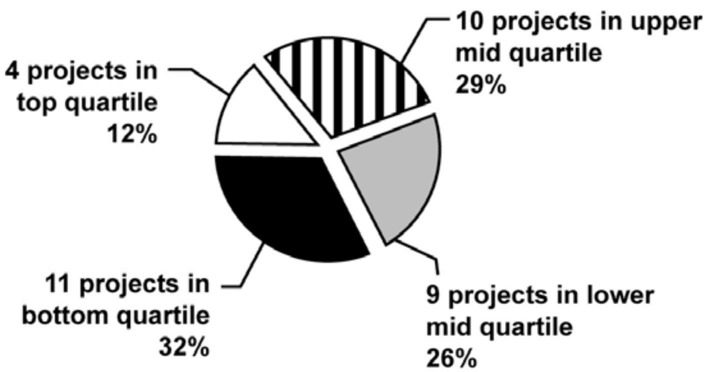


Chart 3A. Projects *without* caps (26).

Capping salaries and overhead rates for design consultants may lead to lower design quality.

Cost Recovery Policies

Thirty-four projects were designed under the sponsorship of DOTs that advocate cost recovery of construction extra work from design consultants. Fifteen projects were designed under the sponsorship of DOTs that don't advocate cost recovery from design consultants (see Charts 4 and 4A). The DQR average of projects in "cost recovery" DOTs was 30.4 with four projects ranking in the top quartile and 11 in the bottom. The DQR average of projects designed under the sponsorship of DOTs that **do not** have policies advocating cost recovery is 17.1 with eight of the 15 in the top quartile and one in the bottom. ***Projects designed under the sponsorship of DOTs that do not advocate recovering costs of construction change orders from design consultants correlate with high DQR and good design quality. Projects designed under the sponsorship of DOTs that advocate cost recovery correlate with low DQR and poor design quality.***



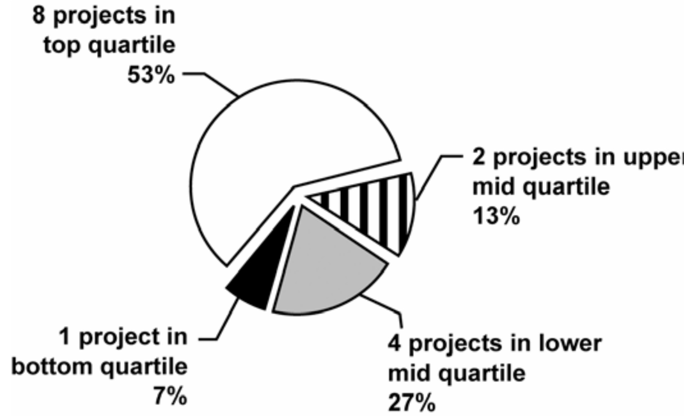


Chart 4. Projects sponsored by DOTs that advocate cost recovery (34).

Chart 4A. Projects sponsored by DOTs that do not advocate cost recovery (15).

Cost recovery policies may thwart good design quality.

Summary: Correlating Design Cost and Procurement Management with Design Quality

Practices for managing design costs have mixed correlations with DQR. Projects having rationally developed (or "built-up") design budgets and regular checking of expended cost have lower DQR than those that do not. Paradoxically, we found that routine comparisons of actual costs by task to budgeted costs correlate with higher DQR.

These apparent contradictions probably have subtle roots. Comparisons of costs to budgets by task are measures of productivity toward specific goals. Rational design budgets and cost-checking support good quality when linked to clear goals and are based on the effort needed to achieve those goals. These management practices, however, interfere with good quality when used primarily to limit design costs. We reason that rational design budgets and cost reviews correlate directly with good design quality when budgets and incurred costs are specifically linked to design submittals and deliverables, rather than simply developed from labor classifications, labor rates, hours, and activities. However, the data from our research only partially supports our reasoning that design cost management - when appropriately linked and integrated with management of scope, schedule, staffing, and quality - will correlate with higher DQR.

Earned value analysis is a proven method for measuring the productivity of cost expenditures. Project management professionals have used this methodology extensively to produce more for less. No project in our research reported using earned value. This finding may indicate that highway and bridge designers lag behind in using effective project management tools and skills.

The practice of capping correlates directly with lower DQR. Projects that are **not** subject to capping are more likely to have good design quality than projects that are subject to capping.

Projects sponsored by agencies having policies that advocate cost recovery for construction changes from designers directly correlate with lower DQR and poorer design quality.

SCHEDULE MANAGEMENT

Six schedule-related management practices were researched. The results of these correlations are listed in columns AM to AS in Table 3C.

Detailed Schedules of Tasks and Deliverables

Eighteen projects had detailed schedules of tasks and deliverables. The average ranking of these projects is 31.4 or 8.1 positions lower than the 31 projects not having detailed task and deliverable schedules and 4.6 positions lower than the average of all projects. Of the 18 with detailed schedules, three are in the highest quartile and seven in the lowest. ***Projects having detailed schedules of tasks and deliverables correlate with low DQR and poor design quality.***

Milestone Dates in Design Plan

The design plans for 25 projects carried specific milestone dates for deliverables. The average ranking of these projects is 19.8 or 13.3 positions better than the 24 projects reported as not having milestone dates and 7.0 positions higher than the average of all projects. Of the 25 **with** milestone dates, 10 projects (40%) rank in the top quartile and two in the bottom (see Chart 5). Of the 24 projects **without** milestone dates, two (8%) rank in the top quartile and 10 in the bottom (see Chart 5A). ***Projects having design plans with milestone dates correlate with high DQR and good design quality.***

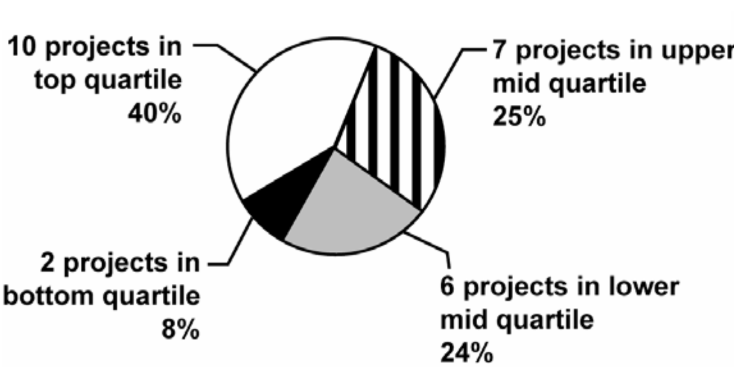


Chart 5. Projects *with* milestone dates (25).

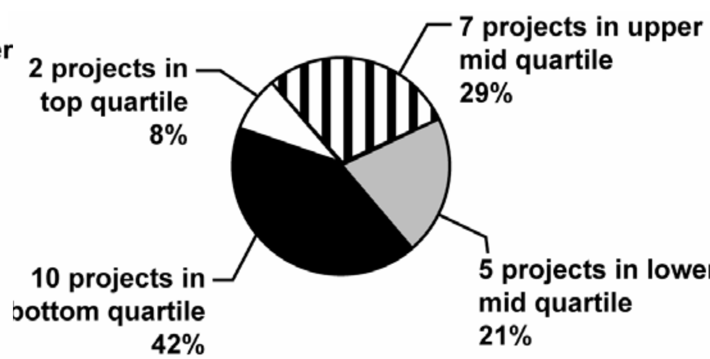


Chart 5A. Projects *without* milestone dates (24).

Designs with milestone dates rank much higher in quality than those without such dates.

Table 3C. Management Practices vs. DQM Rankings

	A	B	C	D	E	O	AM	AN	AO	AP	AQ	AR	AS
1	Project Type & Rank						Schedule Management Practices						
2	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	DQR	Prepared Detailed Schedule by Task and Deliverable?	Design Plan Included Milestone Dates?	Submittals Usually On-time?	Submittals Usually Late?	State DOT Reviews of Submittals Usually On-time?	DOT Reviewed Schedule at Least Monthly?	Was Design Reviewed at Least Monthly?
3	LUTE	X				1	no data	no data	no data	no data	no data	no data	no data
4	AMNO			X		2	yes	yes	yes	no	yes	yes	no
5	TAME			X		3	no	yes	yes	no	yes	yes	yes
6	HUBB	X				4	yes	no	yes	no	yes	no	no
7	BEAR			X		5	no	yes	yes	no	yes	no	no
8	BOMO			X		6	no	yes	yes	no	yes	yes	no
9	JMNO	X				7	yes	yes	yes	no	yes	yes	no
10	BUIA	X				7	no	yes	yes	no	yes	no	no
11	MAME			X		9	no	yes	yes	no	yes	yes	yes
12	FAME	X				9	no	yes	yes	no	yes	yes	yes
13	SANT				X	9	no	no	no data	no data	no data	no	no
14	PAME	X				12	no	yes	yes	no	yes	yes	yes
15	RAME	X				13	no	yes	no	yes	yes	yes	yes
16	SAME	X				14	no	yes	no	yes	yes	yes	yes
17	LOMO			X		14	no	yes	yes	no	yes	yes	no
18	IPSW				X	16	no	no	no data	no data	no data	no	no
19	NASH	X				17	yes	no	yes	no	yes	no	no
20	KOMO			X		18	no	yes	yes	no	yes	yes	no
21	PERR				X	19	no	no	no data	no data	no data	no	no
22	SANY				X	20	no	yes	yes	no	yes	yes	no
23	DUIA				X	21	no	yes	yes	no	yes	yes	yes
24	THAY				X	21	no	no	no data	no data	no data	no	no
25	KUIA				X	23	no	yes	yes	no	yes	yes	yes
26	WHIT	X				24	yes	no	yes	no	yes	no	no
27	ABER	X				25	yes	no	yes	no	yes	no	no
28	GROV		X			26	no	no	no data	no data	no data	no	no
29	WAME			X		27	no	yes	yes	no	yes	yes	yes
30	CAME			X		28	no	yes	yes	no	yes	yes	yes
31	MOMO			X		28	no	yes	yes	no	yes	yes	no
32	KENO				X	30	no	no	no data	no data	no data	no	no
33	LEAR			X		31	yes	yes	yes	no	yes	no	no
34	RIPP	X				32	yes	no	yes	no	yes	no	no
35	TANY		X			33	yes	yes	yes	no	yes	yes	no
36	BRAC		X			34	no	no	no data	no data	no data	no	no
37	NODD	X				35	yes	no	no	yes	no	no	no
38	FORG	X				36	yes	no	no	yes	no	no	no
39	NOMO			X		36	no	yes	yes	no	yes	yes	no
40	POMO			X		36	no	yes	yes	no	yes	yes	no
41	SEAR			X		39	no data	no data	no data	no data	no data	no data	no data
42	MUTE			X		40	no data	no data	no data	no data	no data	no data	no data
43	ONOT	X				41	yes	no	yes	no	yes	no	no
44	POWW	X				42	yes	no	yes	no	yes	no	no
45	SHAW	X				42	yes	no	yes	no	yes	no	no
46	QUIN			X		44	no	no	no data	no data	no data	no	no
47	MEAR			X		44	yes	yes	yes	no	yes	no	no
48	FALL	X				46	yes	no	yes	no	yes	no	no
49	PAST			X		47	no	no	no	yes	no	no	no
50	CONN		X			48	no	no	no data	no data	no data	no	no
51	WOMO			X		49	no	yes	yes	no	yes		no
52	KUTE				X	50	no data	no data	no data	no data	no data	no data	no data
53	PONT			X		51	no	no	yes	no	yes	no	no
54	CRYS	X				52	yes	no	yes	no	yes	no	no
55	MILL	X				53	yes	no	no	yes	no	no	no
56	Avg DQM Rank for "Yes"						31.4	19.8	24.8	33.0	24.2	18.0	15.9
57	Avg DQM Rank for "No"						23.3	33.1	33.0	24.8	42.8	31.5	29.0

On-Time Deliverables

Projects with "on-time" deliverables and on-time deliverable reviews rank considerably higher than those with "late" deliverables and/or reviews.

In 34 projects, deliverables were submitted "on-time." The average rank of these is 24.8 or 8.2 positions higher than the six projects reporting that deliverables were usually late. Of the "on-time" projects, 10 rank in the highest quartile and eight in the lowest. Of the six "late" projects, two rank in the highest quartile and one in the lowest. ***On average, projects having "on-time" design deliverables rank considerably higher in DQR and design quality than those having "late" design deliverables.***

On-Time DOT Reviews

In 36 projects, DOT usually reviewed deliverables "on-time." The average rank of these projects is 24.2 or 18.6 positions higher than the four projects reporting that reviews were usually later than scheduled. Of the "on-time" projects, 11 rank in the highest quartile and eight in the lowest. All four projects reporting "late" reviews rank in the lower two quartiles. ***On average, projects having "on-time" deliverable reviews rank considerably higher in DQR and design quality than projects having "late" reviews.***

Monthly Schedule Reviews

Twenty projects had design schedule reviews at least monthly (see Chart 6). The average rank of these projects is 18.0 or 13.5 positions higher than the 28 projects reported as not having design schedules reviewed at least monthly (see Chart 6A). Of those reporting monthly reviews, eight rank in the highest quartile and zero in the lowest. Of those reporting no monthly review, four rank in the highest quartile and 11 in the lowest. ***On average, projects having design schedule reviews at least monthly rank much higher in DQR and design quality than projects having less frequent schedule reviews.***

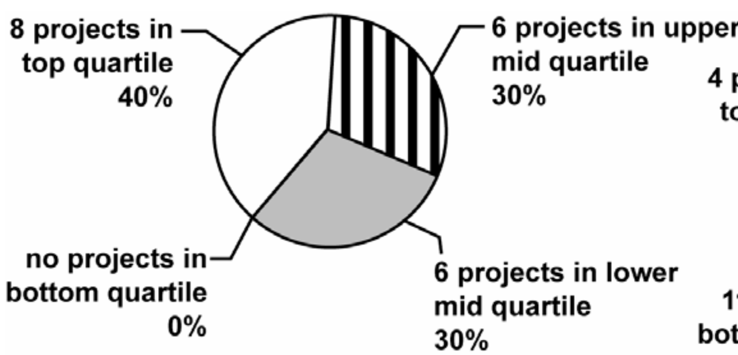


Chart 6. Projects *with* monthly schedule reviews (20).

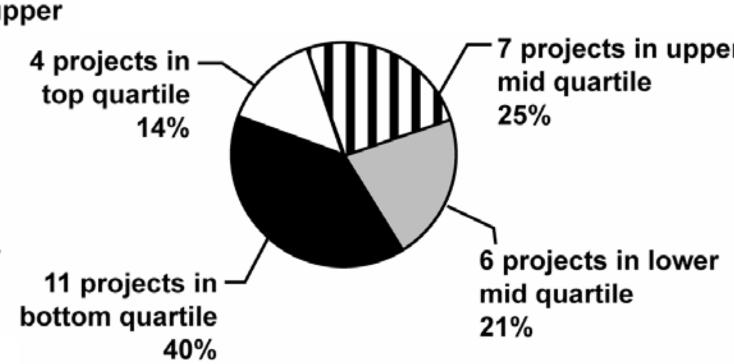


Chart 6A. Projects *without* monthly schedule reviews (28).

Monthly schedule reviews lead to higher design quality.

Monthly Design Quality Reviews

Ten projects had design quality progress reviews by DOT staff at least monthly (see Chart 7). The DQR average of these projects was 15.9 as compared to 29.0 for the 39 projects reported as not having design quality progress reviews at least monthly (see Chart 7A). Of the 10 projects having monthly design quality reviews, five rank in the top quartile, zero in the bottom, and nine in the upper two quartiles. Of the 39 not reviewed at least monthly, seven rank in the top quartile, 12 in the bottom, 17 in the upper two quartiles, and 22 in the lower two quartiles. ***The practice of sponsoring agency staff conducting design quality progress reviews <u>at least monthly</u> correlates with high DQR and good design quality.***

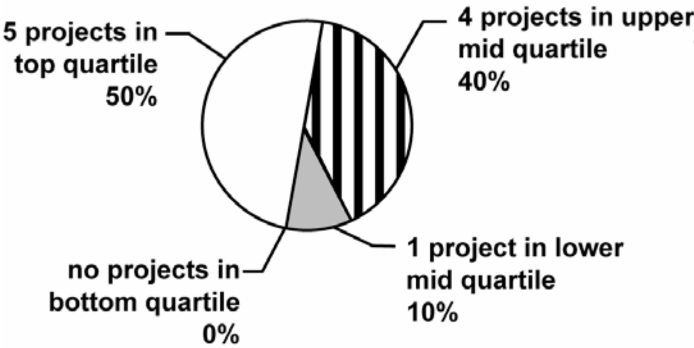


Chart 7. Projects *with* monthly DOT progress reviews (10).

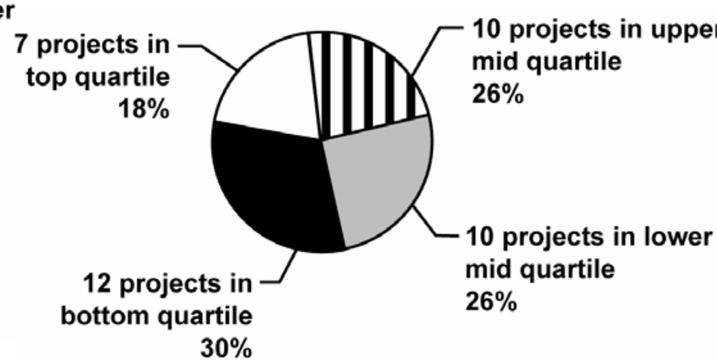


Chart 7A. Projects *without* monthly DOT progress reviews (39).

Monthly project reviews by DOT (or the sponsoring agency) favorably impact design quality.

Summary: Correlating Design Schedule Management with Design Quality

DQR correlates directly with the quality of time management during design. Designs having planned milestones, timely submissions, timely reviews of deliverables, and monthly quality and schedule reviews have much more favorable DQR and better design quality than projects not subject to these design schedule management practices.

HUMAN RESOURCE MANAGEMENT

Eight human resource-related management practices were researched. The results of these correlations are listed in columns AT to BA in Tables 3D and 3E.

Detailed Staffing Plan by Task and Deliverable

Five projects had detailed plans for staffing each task and deliverable (see Chart 8). The average rank of these projects is 14.6 or 13.0 positions higher than the 44 projects without such staffing plans. Of the five with staffing plans, two rank in the top quartile and all rank in the upper quartiles. Of the 44 without

Table 3D. Management Practices vs. DQM Rankings

	A	B	C	D	E	O	AT	AU	AV	AW
1	**Project Type & Rank**						**Human Resources Management Practices**			
2	**Project Acronym**	**Footprint Bridge**	**Major Bridge**	**Major Highway**	**Resurface**	**DQR**	**Detailed Staffing Plan by Task and Deliverable?**	**Staff Plan Considered Skills and Experience Needed?**	**Staff Availability Workload Balancing Considered in Planning?**	**Design Appropriately Staffed for Needs?**
3	LUTE	X				**1**	no data	no data	no data	no data
4	AMNO			X		**2**	yes	no	yes	yes
5	TAME			X		**3**	no	yes	no	no
6	HUBB	X				**4**	no	yes	no	yes
7	BEAR			X		**5**	no	yes	yes	no
8	BOMO			X		**6**	no	no	no	yes
9	JMNO	X				**7**	yes	no	yes	yes
10	BUIA	X				**7**	no	yes	no	yes
11	MAME			X		**9**	no	yes	no	yes
12	FAME	X				**9**	no	no	no	yes
13	SANT				X	**9**	no	yes	no	yes
14	PAME	X				**12**	no	no	no	yes
15	RAME	X				**13**	no	no	no	no
16	SAME	X				**14**	no	no	no	yes
17	LOMO			X		**14**	no	no	no	yes
18	IPSW				X	**16**	no	yes	no	yes
19	NASH	X				**17**	no	yes	no	yes
20	KOMO			X		**18**	no	no	no	yes
21	PERR				X	**19**	no	yes	no	yes
22	SANY				X	**20**	yes	yes	yes	yes
23	DUIA				X	**21**	yes	yes	yes	yes
24	THAY				X	**21**	no	yes	no	yes
25	KUIA				X	**23**	yes	yes	yes	yes
26	WHIT	X				**24**	no	yes	no	yes
27	ABER	X				**25**	no	yes	no	yes
28	GROV		X			**26**	no	yes	no	yes
29	WAME			X		**27**	no	yes	no	no
30	CAME			X		**28**	no	yes	no	no
31	MOMO			X		**28**	no	no	no	yes
32	KENO				X	**30**	no	yes	no	yes
33	LEAR			X		**31**	no	yes	yes	no
34	RIPP	X				**32**	no	yes	no	yes
35	TANY		X			**33**	no	no	no	yes
36	BRAC		X			**34**	no	yes	no	yes
37	NODD	X				**35**	no	yes	no	yes
38	FORG	X				**36**	no	yes	no	yes
39	NOMO			X		**36**	no	no	no	yes
40	POMO			X		**36**	no	no	no	yes
41	SEAR			X		**39**	no data	no data	no data	no data
42	MUTE			X		**40**	no data	no data	no data	no data
43	ONOT	X				**41**	no	yes	no	yes
44	POWW	X				**42**	no	yes	no	yes
45	SHAW	X				**42**	no	yes	no	yes
46	QUIN			X		**44**	no	yes	no	yes
47	MEAR			X		**44**	no	yes	yes	no
48	FALL	X				**46**	no	yes	no	yes
49	PAST			X		**47**	no	yes	no	yes
50	CONN		X			**48**	no	yes	no	yes
51	WOMO			X		**49**	no	no	no	yes
52	KUTE				X	**50**	no data	no data	no data	no data
53	PONT			X		**51**	no	yes	no	yes
54	CRYS	X				**52**	no	yes	no	yes
55	MILL	X				**53**	no	yes	no	yes
56	Avg DQM Rank for "Yes"						14.6	28.9	19.1	27.1
57	Avg DQM Rank for "No"						27.6	19.8	27.7	21.6

Table 3E. Management Practices vs. DQM Rankings

	A	B	C	D	E	O	AX	AY	AZ	BA
1	Project Type & Rank						Human Resources Management Practices			
2	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	DQR	Design Staffing Very Inadequate for Needs?	Project Manager Appropriately Experienced?	Design Project Manager Lacked Management Skills?	Technical Staff Proficient?
3	LUTE	X				1	no data	no data	no data	no data
4	AMNO			X		2	no	yes	no	no
5	TAME			X		3	no	yes	no	yes
6	HUBB	X				4	no	yes	no	yes
7	BEAR			X		5	no	yes	no	yes
8	BOMO			X		6	no	yes	no	yes
9	JMNO	X				7	no	yes	no	no
10	BUIA	X				7	no	yes	no	yes
11	MAME			X		9	no	yes	no	yes
12	FAME	X				9	no	yes	no	yes
13	SANT				X	9	no	yes	no	yes
14	PAME	X				12	no	no	yes	yes
15	RAME	X				13	yes	no	yes	no
16	SAME	X				14	no	no	yes	yes
17	LOMO			X		14	no	yes	no	yes
18	IPSW				X	16	no	yes	no	yes
19	NASH	X				17	no	yes	no	yes
20	KOMO			X		18	no	yes	no	yes
21	PERR				X	19	no	yes	no	yes
22	SANY				X	20	no	yes	no	yes
23	DUIA				X	21	no	yes	no	yes
24	THAY				X	21	no	yes	no	yes
25	KUIA				X	23	no	yes	no	yes
26	WHIT	X				24	no	yes	no	yes
27	ABER	X				25	no	yes	no	yes
28	GROV		X			26	no	yes	no	yes
29	WAME			X		27	no	yes	no	yes
30	CAME			X		28	no	yes	no	yes
31	MOMO			X		28	no	yes	no	yes
32	KENO				X	30	no	yes	no	yes
33	LEAR			X		31	no	yes	no	yes
34	RIPP	X				32	no	yes	no	yes
35	TANY		X			33	no	yes	no	no
36	BRAC		X			34	no	yes	no	yes
37	NODD	X				35	no	yes	no	yes
38	FORG	X				36	no	yes	no	yes
39	NOMO			X		36	no	yes	no	yes
40	POMO			X		36	no	yes	no	yes
41	SEAR			X		39	no data	no data	no data	no data
42	MUTE			X		40	no data	no data	no data	no data
43	ONOT	X				41	no	yes	no	yes
44	POWW	X				42	no	yes	no	yes
45	SHAW	X				42	no	yes	no	yes
46	QUIN			X		44	no	yes	no	yes
47	MEAR			X		44	no	yes	no	yes
48	FALL	X				46	no	yes	no	yes
49	PAST			X		47	no	yes	no	yes
50	CONN		X			48	no	yes	no	yes
51	WOMO			X		49	no	yes	no	yes
52	KUTE				X	50	no data	no data	no data	no data
53	PONT			X		51	no	yes	no	yes
54	CRYS	X				52	no	yes	no	yes
55	MILL	X				53	no	yes	no	yes
56	Avg DQM Rank for "Yes"						13.0	27.3	13.0	26.9
57	Avg DQM Rank for "No"						26.6	22.6	27.2	22.0

staffing plans, 10 rank in the top quartile and 12 in the bottom. ***Detailed staffing plans correlate with high DQR and good design quality.***

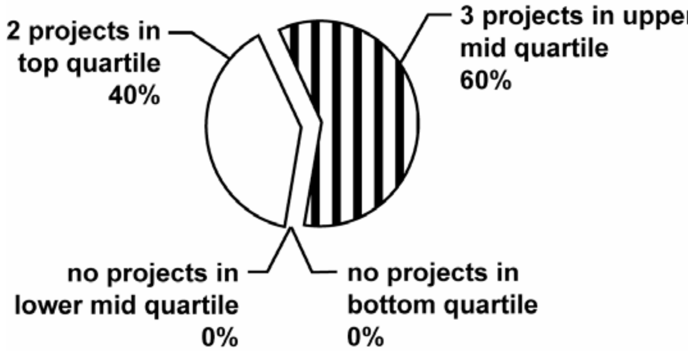


Chart 8. Detailed staffing plans correlate directly with high DQR.

Skills and Experience Plan

Thirty-five projects had staffing plans that considered skills and experience needed for design. The average rank of these projects was 28.9 or 9.1 positions below the 14 projects reported as not considering staff skills and experience in developing design plans. Of the 35 that considered skills and experience, six rank in the top quartile and 11 in the bottom. Of the 14 projects not considering skills and experience, six rank in the top quartile and one in the bottom. ***Staffing plans that consider skills and experience for design planning correlate with low DQR and design quality***.

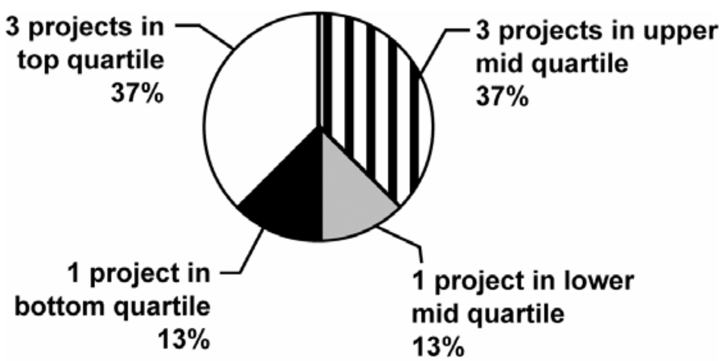


Chart 9. Considering staff availability while planning for design leads to higher design quality.

Staff Availability Considered in Design Planning

Eight projects considered staff availability and workload balancing while developing the design plan (see Chart 9). The average rank of these projects was 19.1 or 8.6 positions higher than the average rank of the 41 projects that did not consider staff availability and workload balancing in planning design. Of the eight projects, three rank in the top quartile and one in the bottom. Of the 41 projects, nine rank in the top quartile and 11 in the bottom. ***In planning for design, consideration of staff availability and workload balancing correlates with good design quality.***

Appropriate Staffing

Forty-two designs were staffed appropriately for project needs. The average rank of these projects is 27.1 or 5.5 positions lower than the seven project designs not staffed appropriately. Of the 42 projects staffed appropriately, nine rank in the top quartile and 11 in the bottom. Of the seven **not** staffed appropriately, three rank in the top quartile and one in the bottom. ***Appropriate staffing correlates with low DQR and poor design quality.***

Adequacy of Design Staff

Forty-eight projects had adequate design staffing; one project had inadequate design staffing. ***These results are inconclusive for determining correlations of staffing adequacy to DQR.***

Project Managers' Experience

The key to staffing is in its "timing." Having experienced people available at the appropriate time during design leads to higher design quality.

Forty-six projects had appropriately experienced project managers. The average rank of these projects was 27.2 with 10 projects ranking in the top quartile and 12 in the bottom. The average rank of the three projects reporting that the project manager's experience was inappropriate is 13.0 or 14.2 positions higher than those reporting that project managers were appropriately experienced. Of these three projects, two rank in the top quartile and immediately below the top quartile. These results imply that design quality correlates inversely to project management experience. However, the three projects all have powerful offsetting practices in other management practices, particularly in scope, schedule, quality, and communication-risk-integration management. ***Projects staffed with project managers having inappropriate experience correlate with high DQR and good design quality.***

Technical Staff Proficiency

Forty-five projects were staffed with technical personnel who were proficient in their respective technologies. The DQR average of these projects is 26.9 with nine projects ranking in the top quartile, 12 in the bottom, 22 in the upper two quartiles, and 23 in the lower two quartiles. Four projects were staffed with personnel who were **not** proficient in their respective technologies. The average ranking of these projects is 13.8, with three projects ranking in the top quartile and one project in the next to lowest quartile. These results **imply** that design quality correlates inversely to project staff's technical proficiency. However, these four projects all have powerful offsetting practices in other management practices, particularly in scope, schedule, quality, and communication-risk-integration management. ***These tests of correlation of technical staff proficiency indicate that staff proficiency correlates with low DQR and poor design quality.***

Our statistical research of the correlation between project staffing and design quality is inconclusive.

Summary: Correlating Human Resource Management with Design Quality

Projects with detailed plans for staffing design tasks and deliverables and workload balancing correlate strongly and directly with design quality.

Nearly all projects were reported as being appropriately and adequately staffed with competent and proficient project managers and technical staff. Paradoxically, however, the few projects having staff shortcomings rank far above the many that were staffed well. We reason that the negative influences of staffing deficiencies were offset by more powerful influences. Those projects with staffing deficiencies were aggressively managed particularly in scope, schedule, quality, and communication-risk-integration.

Secondly, responses to questions pertaining to competence of other people, particularly peers and competitors, are more subject to respondents' biases than responses to other questions. We believe that it is unlikely that nearly every project was as "perfectly" staffed as the responses suggest. Some of those projects reporting "good" staffing and having low rankings may actually have poorer staffing than reported.

In summary, our statistical research of the correlation between project staffing and design quality is inconclusive. ***Nonetheless, we conclude, through experience and reasoning, that appropriate,***

adequate, competent, and proficient staff are more likely to deliver design quality for highway and bridge projects than staff who do not have these qualities. Also, these findings may indicate that effective use of other management practices such as scope, schedule, and communications probably offset (to some degree) staffing weaknesses.

QUALITY MANAGEMENT PRACTICES

Twenty-one quality-related management practices were researched. The results of these correlations are listed in columns BB to BT in Tables 3F through 3I.

Clear, Stated Design Standards

Forty-nine projects were sponsored by DOTs having design standards that are readily available to designers, exceptionally well organized, and clearly presented in documentation and or electronic files. No projects were reported as being sponsored by DOTs not meeting these criteria.

Adequacy, availability, and consistency of DOT design standards are likely factors in design quality.

Forty-five projects were sponsored by DOTs that **promptly** communicate revisions of design standards to designers. Four projects had revisions to standards that were **not** communicated to designers promptly. Two of these four projects rank in the top quartile, zero in the bottom, and two in the 3rd quartile.

Forty-eight projects reported that the design standards were clear and consistent with the terms of design consultants' contract.

Virtually all projects had access to quality DOT standards. ***Adequacy, availability, and consistency of DOT design standards are likely factors in design quality. However, our results are inconclusive, because DQR is a comparative ranking process and virtually all projects reported quality design standards.***

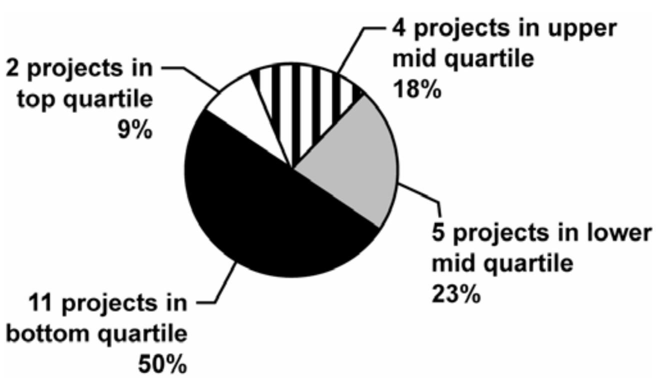


Chart 10. When sponsoring agencies rigorously review design deliverables, design quality is negatively impacted.

Quality Reviews by State DOT

Twenty-two projects were subjected to rigorous detailed reviews by DOT staff (see Chart 10). The average rank of these projects was 35.4 or 16.5 positions lower than the 22 projects reported as **not** subjected to rigorous detail reviews by DOT staff. Of the 22 projects experiencing rigorous reviews, two rank in the top quartile, six in the upper two quartiles, 11 in the bottom, and 16 in the lower two quartiles. ***The practice of sponsoring agency staff conducting rigorously detailed reviews of design deliverables correlates with low DQR and poor design quality***.

Fifteen projects were **not** subject to rigorous DOT reviews, but were reviewed sufficiently to assure that the designer used reasonable care in meeting requirements. The average rank of these projects was 20.6 or 14.8 positions higher than the average rank of those projects that were rigorously reviewed. Of the 15 projects, five rank in the top quartile, one in the bottom, and 10 in the upper two quartiles.

Table 3F. Management Practices vs. DQM Rankings

	A	B	C	D	E	O	BB	BC	BD	BE
1	Project Type & Rank						Quality Management Practices			
2	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	DQR	Are State DOT Design Standards Adequate?	Does DOT Communicate Standards Revisions Promptly??	DOT Checks Submittals Rigorously and Thoroughly?	DOT Reviews Submittals to Assure Reasonable Care?
3	LUTE	X				1	no data	no data	no data	no data
4	AMNO			X		2	yes	yes	no	yes
5	TAME			X		3	yes	no	no	no
6	HUBB	X				4	yes	yes	yes	yes
7	BEAR			X		5	yes	yes	yes	no
8	BOMO			X		6	yes	yes	no	yes
9	JMNO	X				7	yes	yes	no	yes
10	BUIA	X				7	yes	no	no	yes
11	MAME			X		9	yes	yes	no	yes
12	FAME	X				9	yes	yes	no	no
13	SANT				X	9	yes	yes	no data	no
14	PAME	X				12	yes	yes	no	no
15	RAME	X				13	yes	yes	no	no
16	SAME	X				14	yes	yes	no	no
17	LOMO			X		14	yes	yes	no	yes
18	IPSW				X	16	yes	yes	no data	no
19	NASH	X				17	yes	yes	yes	yes
20	KOMO			X		18	yes	yes	no	yes
21	PERR				X	19	yes	yes	no data	no
22	SANY				X	20	yes	yes	no	yes
23	DUIA				X	21	yes	yes	no	yes
24	THAY				X	21	yes	yes	no data	no
25	KUIA				X	23	yes	yes	no	yes
26	WHIT	X				24	yes	yes	yes	yes
27	ABER	X				25	yes	yes	yes	yes
28	GROV		X			26	yes	yes	yes	no
29	WAME			X		27	yes	no	no	no
30	CAME			X		28	yes	no	no	no
31	MOMO			X		28	yes	yes	no	yes
32	KENO				X	30	yes	yes	no data	no
33	LEAR			X		31	yes	yes	yes	no
34	RIPP	X				32	yes	yes	yes	yes
35	TANY		X			33	yes	yes	no	yes
36	BRAC		X			34	yes	yes	yes	no
37	NODD	X				35	yes	yes	yes	yes
38	FORG	X				36	yes	yes	yes	yes
39	NOMO			X		36	yes	yes	no	yes
40	POMO			X		36	yes	yes	no	yes
41	SEAR			X		39	no data	no data	no data	no data
42	MUTE			X		40	no data	no data	no data	no data
43	ONOT	X				41	yes	yes	yes	yes
44	POWW	X				42	yes	yes	yes	yes
45	SHAW	X				42	yes	yes	yes	yes
46	QUIN			X		44	yes	yes	yes	no
47	MEAR			X		44	yes	yes	yes	no
48	FALL	X				46	yes	yes	yes	yes
49	PAST			X		47	yes	yes	yes	no
50	CONN		X			48	yes	yes	yes	no
51	WOMO			X		49	yes	yes	no	yes
52	KUTE				X	50	no data	no data	no data	no data
53	PONT			X		51	yes	yes	yes	no
54	CRYS	X				52	yes	yes	yes	yes
55	MILL	X				53	yes	yes	yes	yes
56	Avg DQM Rank for "Yes"						26.3	26.8	35.4	27.1
57	Avg DQM Rank for "No"						na	16.3	18.9	25.3

Table 3G. Management Practices vs. DQM Rankings

	A	B	C	D	E	O	BF	BG	BH
1	Project Type & Rank						Quality Management Practices		
2	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	DQR	Does State DOT Simply Spot Check Submittals?	Does State DOT Conduct Reviews in Designers' Offices?	Fair to Good Quality Design Submittals?
3	LUTE	X				1	no data	no data	no data
4	AMNO			X		2	no	no	yes
5	TAME			X		3	yes	no	yes
6	HUBB	X				4	yes	no	no data
7	BEAR			X		5	no	no	yes
8	BOMO			X		6	yes	yes	yes
9	JMNO	X				7	no	no	yes
10	BUIA	X				7	no	no	yes
11	MAME			X		9	yes	no	yes
12	FAME	X				9	yes	no	yes
13	SANT				X	9	yes	no	no data
14	PAME	X				12	yes	no	yes
15	RAME	X				13	yes	no	no
16	SAME	X				14	yes	no	yes
17	LOMO			X		14	yes	yes	yes
18	IPSW				X	16	yes	no	no data
19	NASH	X				17	yes	no	no data
20	KOMO			X		18	yes	yes	yes
21	PERR				X	19	yes	no	no data
22	SANY				X	20	no	no	yes
23	DUIA				X	21	yes	yes	yes
24	THAY				X	21	yes	no	no data
25	KUIA				X	23	yes	yes	yes
26	WHIT	X				24	yes	no	no data
27	ABER	X				25	yes	no	no data
28	GROV		X			26	yes	no	no data
29	WAME			X		27	yes	no	yes
30	CAME			X		28	yes	no	yes
31	MOMO			X		28	yes	yes	yes
32	KENO				X	30	yes	no	no data
33	LEAR			X		31	no	no	yes
34	RIPP	X				32	yes	no	no data
35	TANY		X			33	no	no	yes
36	BRAC		X			34	yes	no	no data
37	NODD	X				35	yes	no	no data
38	FORG	X				36	yes	no	no data
39	NOMO			X		36	yes	yes	yes
40	POMO			X		36	yes	yes	yes
41	SEAR			X		39	no data	no data	no data
42	MUTE			X		40	no data	no data	no data
43	ONOT	X				41	yes	no	no data
44	POWW	X				42	yes	no	no data
45	SHAW	X				42	yes	no	no data
46	QUIN			X		44	yes	no	no data
47	MEAR			X		44	no	no	yes
48	FALL	X				46	yes	no	no data
49	PAST			X		47	yes	no	no data
50	CONN		X			48	yes	no	no data
51	WOMO			X		49	yes	yes	yes
52	KUTE				X	50	no data	no data	no data
53	PONT			X		51	yes	no	no data
54	CRYS	X				52	yes	no	no data
55	MILL	X				53	yes	no	no data
56	Avg DQM Rank for "Yes"						27.8	25.7	20.1
57	Avg DQM Rank for "No"						18.6	26.5	13.0

Table 3H. Management Practices vs. DQM Rankings

	A	B	C	D	E	O	BI	BJ	BK	BL	BM	BN
1	Project Type & Rank						Quality Management Practices					
2	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	DQR	In-progress Construct-ability Reviews by DN Team?	Construct-ability Reviews by Design Team at End of Design?	Construct-ability Review by Other DOT Staff?	Construct-ability Review by Consultants?	Construct-ability Review by DOT Specialists?	Construct-ability Review by Const Mgmt Firm?
3	LUTE	X				1	no data	no data	no data	no data	no data	no data
4	AMNO			X		2	no	no	yes	no	no	no
5	TAME			X		3	yes	yes	no	no	no	no
6	HUBB	X				4	yes	yes	yes	no	no	no
7	BEAR			X		5	yes	yes	no	no	yes	no
8	BOMO			X		6	yes	yes	yes	no	no	no
9	JMNO	X				7	no	no	yes	no	no	no
10	BUIA	X				7	no	no	no	no	yes	no
11	MAME			X		9	yes	yes	no	no	no	no
12	FAME	X				9	no	no	no	no	yes	no
13	SANT				X	9	yes	yes	no	no	no data	no
14	PAME	X				12	no	no	no	no	yes	no
15	RAME	X				13	no	no	no	no	yes	no
16	SAME	X				14	no	no	no	no	yes	no
17	LOMO			X		14	yes	yes	yes	no	no	no
18	IPSW				X	16	yes	yes	no	no	no data	no
19	NASH	X				17	yes	yes	yes	no	no	no
20	KOMO			X		18	yes	yes	yes	no	no	no
21	PERR				X	19	yes	yes	no	no	no data	no
22	SANY				X	20	yes	yes	yes	no	yes	no
23	DUIA				X	21	yes	yes	yes	no	yes	no
24	THAY				X	21	yes	yes	no	no	no data	no
25	KUIA				X	23	yes	yes	yes	no	yes	no
26	WHIT	X				24	yes	yes	yes	no	no	no
27	ABER	X				25	yes	yes	yes	no	no	no
28	GROV		X			26	yes	yes	yes	no	no	no
29	WAME			X		27	yes	yes	no	no	no	no
30	CAME			X		28	yes	yes	no	no	no	no
31	MOMO			X		28	yes	yes	yes	no	no	no
32	KENO				X	30	yes	yes	no	no	no data	no
33	LEAR			X		31	yes	yes	no	no	yes	no
34	RIPP	X				32	yes	yes	yes	no	no	no
35	TANY		X			33	yes	no	no	no	yes	no
36	BRAC		X			34	yes	yes	yes	no	no	no
37	NODD	X				35	yes	yes	yes	no	no	no
38	FORG	X				36	yes	yes	yes	no	no	no
39	NOMO			X		36	yes	yes	yes	no	no	no
40	POMO			X		36	yes	yes	yes	no	no	no
41	SEAR			X		39	no data	no data	no data	no data	no data	no data
42	MUTE			X		40	no data	no data	no data	no data	no data	no data
43	ONOT	X				41	yes	yes	yes	no	no	no
44	POWW	X				42	yes	yes	yes	no	no	no
45	SHAW	X				42	yes	yes	yes	no	no	no
46	QUIN			X		44	yes	yes	no	no	no	no
47	MEAR			X		44	yes	yes	no	no	yes	no
48	FALL	X				46	yes	yes	yes	no	no	no
49	PAST			X		47	yes	yes	no	no	no	no
50	CONN		X			48	yes	yes	yes	no	no	no
51	WOMO			X		49	yes	yes	yes	no	no	no
52	KUTE				X	50	no data	no data	no data	no data	no data	no data
53	PONT			X		51	yes	yes	no	no	no	no
54	CRYS	X				52	yes	yes	yes	no	no	no
55	MILL	X				53	yes	yes	yes	no	no	no
56	Avg DQM Rank for "Yes"						28.1	29.1	29.2	na	19.3	na
57	Avg DQM Rank for "No"						9.1	12.1	22.5	26.3	30.1	26.3

Table 3I. Management Practices vs. DQM Rankings

	A	B	C	D	E	O	BO	BP	BQ	BR	BS	BT
1	**Project Type & Rank**						**Quality Management Practices**					
2	**Project Acronym**	**Footprint Bridge**	**Major Bridge**	**Major Highway**	**Resurface**	**DQR**	**Constructability Review by Non-bidding Contractor?**	**Constructability Not Reviewed Prior to Bidding?**	**Major Changes from Constructability Review?**	**Some Changes from Constructability Review?**	**Was Value Engineering Performed?**	**State DOT Performed Value Engineering?**
3	LUTE	X				1	no data	no data	no data	no data	no data	no data
4	AMNO			X		2	no	no	no	no	no	no
5	TAME			X		3	no	no	no	no	no	no
6	HUBB	X				4	no	no	no	no	no	no
7	BEAR			X		5	no	no	no	yes	no	no
8	BOMO			X		6	no	no	no	yes	no	no
9	JMNO	X				7	no	no	no	no	no	no
10	BUIA	X				7	no	no	no	no	no	no
11	MAME			X		9	no	no	no	no	no	no
12	FAME	X				9	no	no	no	no	no	no
13	SANT				X	9	no	no	no data	no data	no	no
14	PAME	X				12	no	no	no	no	no	no
15	RAME	X				13	no	no	no	no	no	no
16	SAME	X				14	no	no	no	no	no	no
17	LOMO			X		14	no	no	no	yes	no	no
18	IPSW				X	16	no	no	no data	no data	no	no
19	NASH	X				17	no	no	no	no	no	no
20	KOMO			X		18	no	no	no	no	no	no
21	PERR				X	19	no	no	no data	no data	no	no
22	SANY				X	20	no	no	no	no	no	no
23	DUIA				X	21	no	no	no	no	no	no
24	THAY				X	21	no	no	no data	no data	no	no
25	KUIA				X	23	no	no	no	no	no	no
26	WHIT	X				24	no	no	no	no	no	no
27	ABER	X				25	no	no	no	no	no	no
28	GROV		X			26	no	no	no	yes	no	no
29	WAME			X		27	no	no	no	no	no	no
30	CAME			X		28	no	no	no	yes	no	no
31	MOMO			X		28	no	no	no	yes	yes	yes
32	KENO				X	30	no	no	no data	no data	no	no
33	LEAR			X		31	no	no	no	yes	no	no
34	RIPP	X				32	no	no	no	yes	no	no
35	TANY		X			33	no	no	no	no	no	no
36	BRAC		X			34	no	no	no	yes	no data	no data
37	NODD	X				35	no	no	no	yes	no	no
38	FORG	X				36	no	no	no	yes	no	no
39	NOMO			X		36	no	no	no	no	no	no
40	POMO			X		36	no	no	no	yes	yes	yes
41	SEAR			X		39	no data	no data	no data	no data	no data	no data
42	MUTE			X		40	no data	no data	no data	no data	no data	no data
43	ONOT	X				41	no	no	no	yes	no	no
44	POWW	X				42	no	no	yes	no	no	no
45	SHAW	X				42	no	no	no	yes	no	no
46	QUIN			X		44	no	no	no	yes	no	no
47	MEAR			X		44	no	no	no	yes	no	no
48	FALL	X				46	no	no	no	yes	no	no
49	PAST			X		47	no	no	no	yes	no	no
50	CONN		X			48	no	no	no	yes	no	no
51	WOMO			X		49	no	no	no	yes	yes	yes
52	KUTE				X	50	no data	no data	no data	no data	no data	no data
53	PONT			X		51	no	no	no	yes	no	no
54	CRYS	X				52	no	no	no	yes	no	no
55	MILL	X				53	no	no	no	yes	no	no
56	Avg DQM Rank for "Yes"						na	na	42.0	36.0	37.7	37.7
57	Avg DQM Rank for "No"						26.3	26.3	26.8	17.4	25.4	25.4

Seven projects were neither rigorously reviewed nor reviewed for reasonable care, but were spot checked by DOT as a quality assurance procedure (see Chart 10A). The average rank of these projects was 15.1 or 20.3 positions better than those that were rigorously reviewed and 5.5 positions better than those reviewed for reasonable care in meeting requirements. Four of the seven projects subjected to only spot checking rank in the top quartile and six of the seven in the top two quartiles. ***The practice of sponsoring agency staff conducting reviews to assure that designers used reasonable care correlates with high DQR and good design quality. The practice of sponsoring agency staff spot checking to assure that the designer applied quality control correlates with very high DQR and good design quality.***

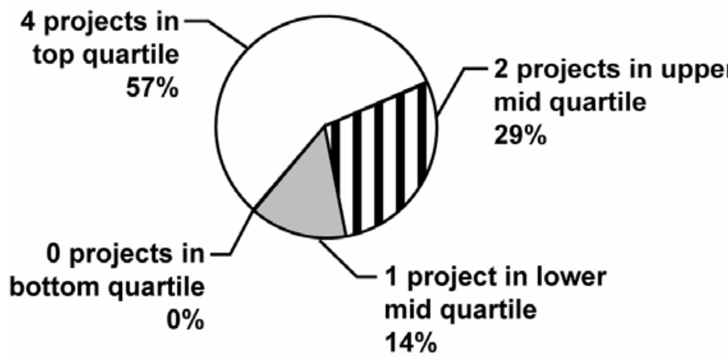


Chart 10A. "Spot checking" by the sponsoring agency is most effective in promoting design quality.

Nine projects were subjected to DOT design progress reviews **in designers' offices** rather than in DOT offices. The average rank of these projects is 25.7 or 0.8 positions better than the average of 40 projects that were never reviewed in the designers' offices. One of the nine projects ranks in the top quartile, one in the bottom, four in the top two quartiles, and five in the bottom two quartiles. ***The practice of conducting design progress meetings in designers' offices rather than in DOT offices correlates with DQR average and average design quality.***

The average rank of 24 projects reported to have had "fair to good" deliverables is 20.1. One project, reported as having "poor" deliverables, has a DQR of 13.0. The average rank of those projects reporting "no data" is 33.0. The average rank of projects reporting "fair to good" deliverables and a spot checking review process is 15.5 or 11.2 positions better than those projects reporting "fair to good" deliverables with rigorous reviews. ***The practice of DOT staff spot checking designs to assure quality correlates with reports of "fair to good" deliverables, high DQR ratings, and good design quality.***

Properly developed designs include appropriate detailed cross-checking procedures by designers and negate the need for rigorous checking by sponsoring agencies.

We reason that designers assume more responsibility for the quality of their services when sponsoring agency staff spot check for quality assurance rather than rigorously review in detail. Review processes that encourage reviewers to require revisions based upon personal preferences discourage designers' from assuming full responsibility and accountability for their deliverables. Properly developed designs include appropriate detailed cross-checking procedures by designers and negate the need for rigorous checking by sponsoring agencies.

The sponsoring agency is responsible for assuring that the designers' services are rigorous and thorough. When sponsoring agency staff require that designs align with their personal preferences, the agency usurps the role of the designer.

In general, end-of-design constructability reviews hamper design quality.

Constructability Reviews

Forty-two projects were reviewed for constructability by the design team as the design progressed. The DQR average of these projects is 28.1 as compared to an average rank of 9.1 for the seven projects reporting that the design team had not reviewed for constructability as the design progressed. Of the 42 projects, six rank in the top quartile, 12 in the bottom, 18 in the upper two quartiles, and 24 in the lower two quartiles. Of the seven without reviews, six rank in the top quartile and all seven in the top two quartiles. ***The practice of design teams reviewing projects for constructability as the design progresses correlates with low DQR and poor design quality.***

Forty-one projects had constructability reviews by the design team as part of the final review process. The DQR average of these projects is 29.1 as compared to an average rank of 12.1 for the eight projects reporting that the design team had not conducted a constructability review as part of the final review process. Of the 41 with reviews, six rank in the top quartile, 12 in the bottom, 18 in the upper two quartiles, and 23 in the lower two quartiles. Of the eight without reviews, six rank in the top quartile, zero in the bottom, and the other two in the middle two quartiles. ***The practice of design teams reviewing projects for constructability as a part of the final design review correlates with low DQR and poor design quality.***

Twenty-eight projects had constructability reviews by DOT staff who were not on the design team. The DQR average of these projects is 29.2 as compared to an average rank of 22.2 for the 21 projects reported as not having other DOT staff review for constructability. Of the 28 projects with reviews, four rank in the top quartile, eight in the bottom, 13 in the upper two quartiles, and 15 in the lower two quartiles. ***The practice of having DOT staff who are not part of the design team review projects for constructability correlates with low DQR and poor design quality.***

No projects were reviewed for constructability by private consultants or construction management specialists who were independent of the design team or non-bidding construction contractors. ***The correlation of the practice of having private firms (i.e., design consultants who are independent of the design team, construction management specialists, or non-bidding contractors) review projects for constructability with DQR and design quality is inconclusive because of insufficient research data.***

Twelve projects were reviewed by construction specialists on DOT staff who were not part of the design team. The DQR average of these projects is 19.3 as compared to 30.1 for 32 projects not reviewed by DOT construction specialists. Of the 12 projects reviewed, five rank in the top quartile, one in the bottom, nine in the top two quartiles, and three in the bottom two quartiles; nine of these had no design revisions resulting from the review, three had minor revisions, and zero had major changes. ***The practice of having construction specialists on DOT staff review for constructability correlates with high DQR and good design quality. The constructability reviews, however, prompted no major design revisions and very few minor revisions. From this data, we can not conclude that constructability reviews by specialists contribute to better design quality.***

Twenty-four projects had design revisions following constructability reviews (see Chart 11). The DQR average for these projects is 33.3 as compared to 17.4 for 21 projects reporting no revisions following constructability reviews (see Chart 11A). Of the 24 with changes, two rank in the top DQR quartile, 12 in the bottom, four in the upper two quartiles, and 20 in the bottom two quartiles. Of the 21 projects reported to have no design changes following constructability reviews, nine rank in the top quartile, one in the bottom, 17 in the top two quartiles, and four in the bottom two quartiles. ***Projects experiencing***

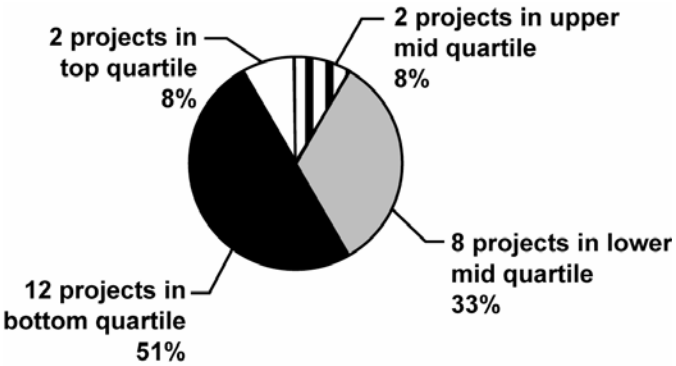


Chart 11. Projects with design revisions following constructability reviews (24).

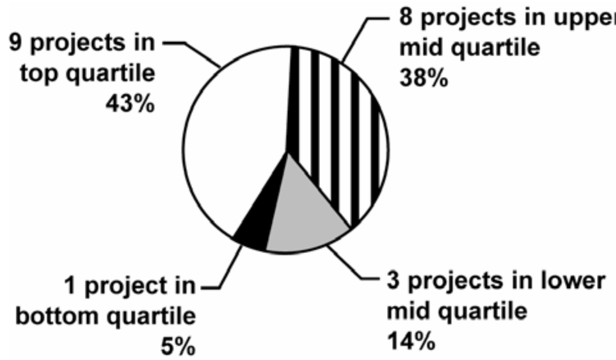


Chart 11A. Projects with *no* design revisions following constructability reviews (21).

When constructability reviews lead to design revisions, design quality is low.

design revisions following constructability reviews correlate with low DQR and poor design quality. Projects experiencing <u>no</u> design revisions following constructability reviews correlate with high DQR and high design quality.

Value Engineering

Three projects were reported as having been "value engineered," all by DOT staff. The average ranking of these projects is 37.7 as compared to 25.4 for the 45 projects reported as not having been value engineered. One of these projects ranks in the bottom quartile and all three rank in the bottom two quartiles. ***The three projects that experienced value engineering correlate with very low DQR and poor design quality.***

Summary: Correlating Quality Management Practices with Design Quality

The most effective quality management is "do things right once, the first time." Practices that involved "checking and fixing" correlate with projects having lower DQRs and poorer design quality than those projects not subjected to "checking and fixing." Projects revised by detailed reviews by sponsoring agents, constructability reviews, and value engineering rank low in average DQR and design quality. Conversely, of the 53 projects, 10 designs were neither detailed checked by the sponsoring agencies, nor subjected to formal constructability reviews or formal value engineering. The DQR average of these 10 projects is 15.0. Five of these projects are in the top quartile (50%) and eight are in the upper two quartiles (80%) (see Chart 12).

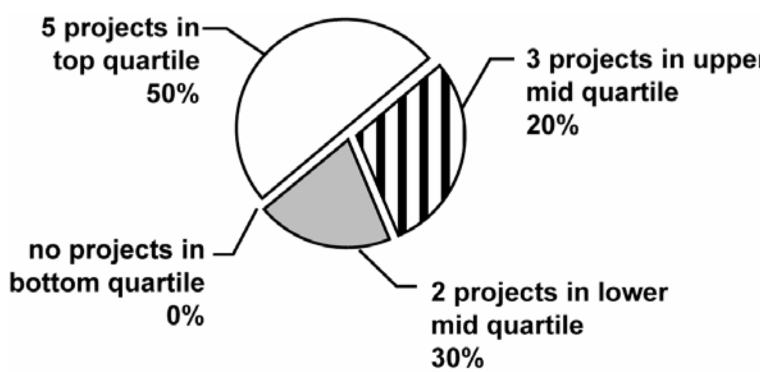


Chart 12. Eight out of 10 projects *not* subjected to formal review processes rank in the top two DQR quartiles. Clearly, projects designed "right the first time" are of higher quality than those that need rework.

“Inspection to improve quality is too late, ineffective, costly.”

From Out of The Crisis, W. Edwards Deming, p.28

Design quality, including constructability and value, is best assured by incorporating these characteristics as the design progresses, not by rework.

It is counterintuitive that reviews, checking, and detailed inspection correlate with low quality. The world-renowned quality guru, W. Edwards Deming, often spoke about this paradox. He advised that built-in systematic inspections and rework processes discourage management from seeking out and correcting the underlying causes for the defects in the systems that created the need for inspection and rework. Those engaged in inspection processes have equity in and difficulty fixing underlying systemic shortcomings. System overseers are responsible for finding and fixing its shortcomings.

COMMUNICATIONS, INTEGRATION, AND RISK MANAGEMENT PRACTICES

Five management practices relating to communications, integration, and risk were researched. The results of these correlations are listed in columns BU to BY in Table 3J.

Partnering of State Transportation Agency and Design Associations

Forty projects had DOTs participating in partnering sessions with associations representing private design consultants. The DQR average of these 40 projects is 27.7 as compared to 20.1 for nine projects reported by DOTs that have not participated in partnering sessions with associations representing private design consultants. Of the 40 projects in participating DOTs, eight rank in the top quartile, 11 in the bottom, 19 in the top two quartiles, and 21 in the bottom two quartiles. Of the nine projects in non-participating DOTs, four rank in the top quartile, one in the bottom, six in the top two quartiles, and three in the bottom two. ***Projects designed under the sponsorship of DOTs that participate in partnering sessions with associations representing private design consultants correlate with low DQR and poor design quality.***

Thirty-six projects had implemented policies that stem from DOT partnering sessions with associations representing design consultants. The DQR average of these projects is 28.9 as compared to 19.1 for 13 projects reported by DOTs that have **not** implemented policies stemming from partnering with design consultant associations. Of the 36 projects from DOTs with policies, six rank in the top DQR quartile, 11 in the bottom, 17 in the upper two quartiles, and 19 in the bottom two. Of the 13 from DOTs without policies, six rank in the top quartile, one in the bottom, eight in the top two quartiles, and five in the bottom two. ***Projects designed for DOTs that have policies stemming from partnering sessions with associations representing private design consultants correlate with low DQR and poor design quality. Vis-à-vis, projects sponsored by DOTs that have policies stemming from partnering ranked lower than those of DOTs without such policies.***

Table 3J. Management Practices vs. DQM Rankings

	A	B	C	D	E	O	BU	BV	BW	BX	BY
1	Project Type & Rank						Communications~Risk~Integration Management Practices				
2	Project Acronym	Footprint Bridge	Major Bridge	Major Highway	Resurface	DQR	Does State DOT Partner with Consultants' Associations?	Has DOT Implemented Policy Changes from Partnering?	DOT Endorses Partnering with Design Consultants	Partnering Agreement with Designer for This Project?	Was Commercial PM Software Used for This Project?
3	LUTE	X				1	no data	no data	no data	no data	no data
4	AMNO			X		2	yes	yes	yes	no	yes
5	TAME			X		3	yes	no	yes	no	yes
6	HUBB	X				4	yes	yes	yes	no	no
7	BEAR			X		5	no	no	yes	no	no
8	BOMO			X		6	yes	yes	yes	no	no
9	JMNO	X				7	yes	yes	yes	no	yes
10	BUIA	X				7	yes	yes	yes	no	no
11	MAME			X		9	yes	no	yes	no	no
12	FAME	X				9	no	no	yes	yes	yes
13	SANT				X	9	yes	yes	yes	no	no
14	PAME	X				12	no	no	yes	yes	no
15	RAME	X				13	no	no	yes	yes	yes
16	SAME	X				14	no	no	yes	yes	yes
17	LOMO			X		14	yes	yes	yes	no	no
18	IPSW				X	16	yes	yes	yes	no	no
19	NASH	X				17	yes	yes	yes	no	no
20	KOMO			X		18	yes	yes	yes	no	no
21	PERR				X	19	yes	yes	yes	no	no
22	SANY				X	20	no	no	no	no	no
23	DUIA				X	21	yes	yes	yes	no	no
24	THAY				X	21	yes	yes	yes	no	no
25	KUIA				X	23	yes	yes	yes	no	no
26	WHIT	X				24	yes	yes	yes	no	no
27	ABER	X				25	yes	yes	yes	no	no
28	GROV		X			26	yes	yes	yes	no	no
29	WAME			X		27	yes	no	yes	no	no
30	CAME			X		28	yes	no	yes	no	yes
31	MOMO			X		28	yes	yes	yes	no	no
32	KENO				X	30	yes	yes	yes	no	no
33	LEAR			X		31	no	no	yes	no	no
34	RIPP	X				32	yes	yes	yes	no	no
35	TANY		X			33	no	no	no	no	yes
36	BRAC		X			34	yes	yes	yes	no	no
37	NODD	X				35	yes	yes	yes	no	no
38	FORG	X				36	yes	yes	yes	no	no
39	NOMO			X		36	yes	yes	yes	no	no
40	POMO			X		36	yes	yes	yes	no	no
41	SEAR			X		39	no data	no data	no data	no data	no data
42	MUTE			X		40	no data	no data	no data	no data	no data
43	ONOT	X				41	yes	yes	yes	no	no
44	POWW	X				42	yes	yes	yes	no	no
45	SHAW	X				42	yes	yes	yes	no	no
46	QUIN			X		44	yes	yes	yes	no	no
47	MEAR			X		44	no	no	yes	no	no
48	FALL	X				46	yes	yes	yes	no	no
49	PAST			X		47	yes	yes	yes	no	no
50	CONN		X			48	yes	yes	yes	no	no
51	WOMO			X		49	yes	yes	yes	no	no
52	KUTE				X	50	no data	no data	no data	no data	no data
53	PONT			X		51	yes	yes	yes	no	no
54	CRYS	X				52	yes	yes	yes	no	no
55	MILL	X				53	yes	yes	yes	no	no
56	Avg DQM Rank for "Yes"						27.7	28.9		12.0	13.6
57	Avg DQM Rank for "No"						20.1	19.1	26.5	27.6	28.8

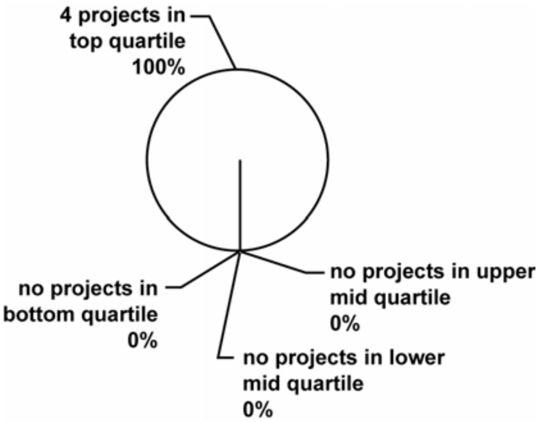


Chart 13. All four projects that had DOT partnering with a private design consultant scored in the top DQR quartile.

Partnering of State Transportation Agencies and Private Design Consultants

Four projects were designed under a partnering agreement between DOT and a private design consultant; all four rank in the top quartile (see Chart 13). The DQR average of these projects is 12.0 as compared to 27.6 for 45 projects reported as not having been designed under a DOT/private design consultant partnering agreement. ***The practice of partnering between DOT and a private design consultant correlates with very high DQR and excellent design quality.***

Forty-seven projects had DOTs that endorse partnering with private design consultants. The DQR average of these projects is 26.3 as compared to 26.5 for two projects reported by a state that has not endorsed partnering with design consultants. Of the 47 projects for DOTs that endorse partnering, 12 rank in the top quartile, 12 in the bottom, 24 in the top two quartiles, and 23 in the bottom two. The two projects designed for DOTs that do not endorse partnering with private design consultants rank 20 and 33, practically equidistant on either side of the 26.8 average of all projects. ***Projects designed for DOTs that endorse partnering with private design consultants correlate with average DQR and average design quality.***

Project Management Software (PMS)

Eight projects were reported as using commercially available PMS to plan and/or manage the design process (see Chart 14). The DQR average of these projects is 13.6 as compared to 28.8 for the 41 projects that did not use this software. Of the eight projects, six rank in the top quartile and two in the lower-mid quartile. ***The practice of using commercially available PMS to plan and/or manage design processes correlates with high DQR and good design quality.***

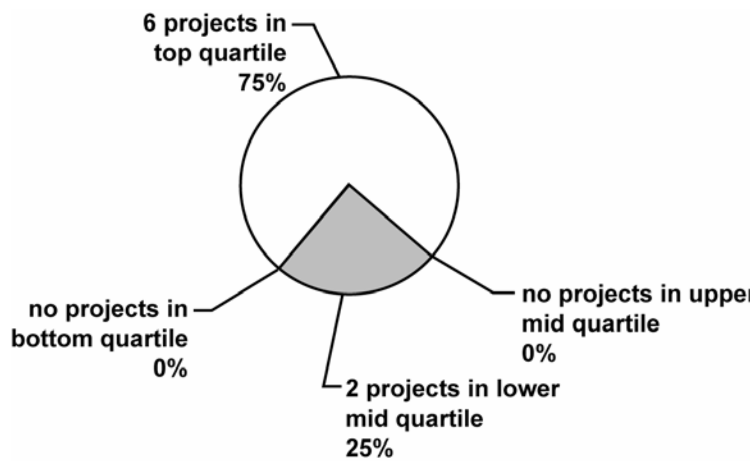


Chart 14. Using PMS positively impacts design quality.

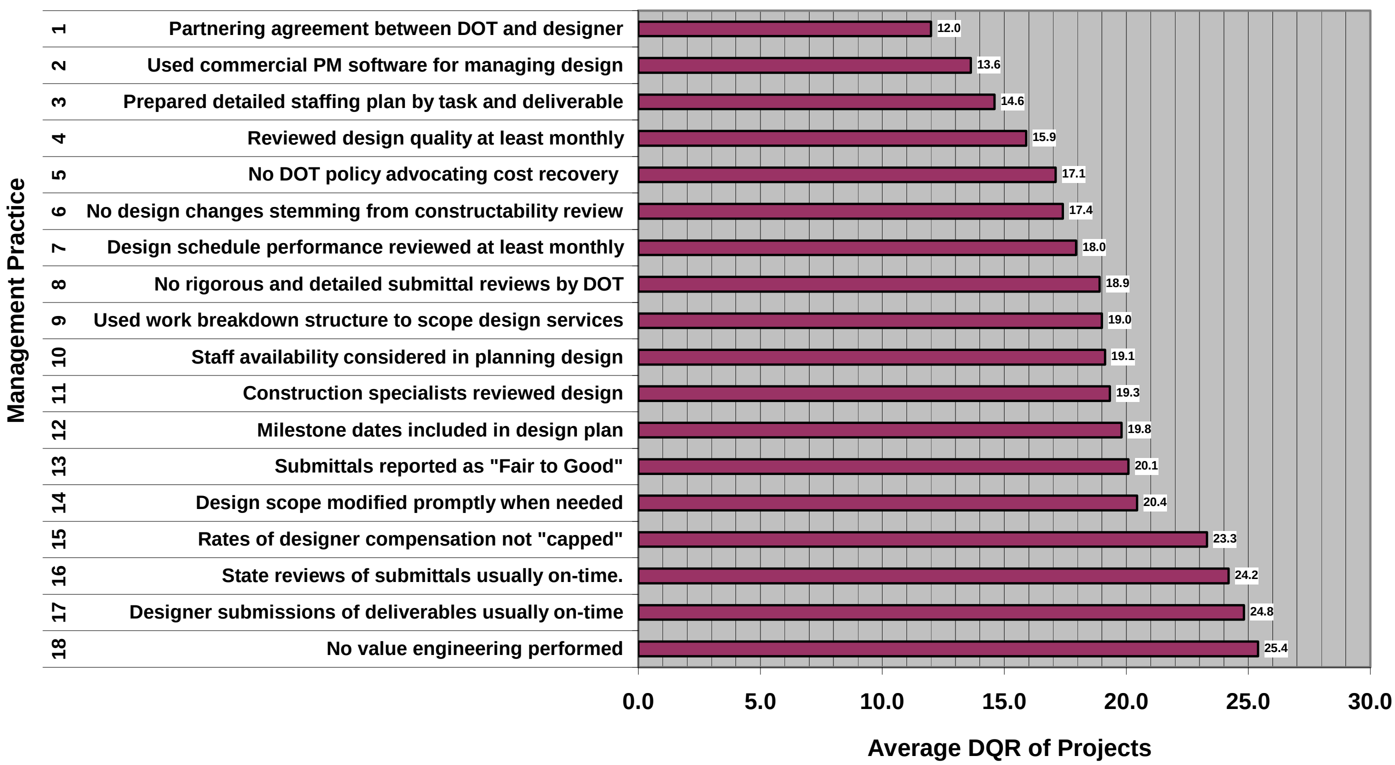
PATTERNS OF MANAGEMENT PRACTICES INFLUENCING DESIGN QUALITY

In Chapter 1, we defined design quality as *everything* prior to construction that bears on stakeholders' satisfaction. If *everything* before construction determines design quality, then ***many*** factors affect DQR as a measurement of design quality. DQR is the net result of many influences working together. PMI advises that successful projects hinge on successfully managing scope, time, cost, quality, human resources, communication, procurement, risk, and integration of each with the others. Our findings align with PMI's knowledge. Combinations of management practices collectively influence DQR.

Practices Normally Found in Higher-Ranking Projects

We have listed, charted, and ranked those management practices that when present were normally in higher-ranking projects (see Chart 15). The practices are ranked from top to bottom with the one having the strongest direct correlation to high DQR at the top of the chart.

Chart 15. Average DQR Position of Management Practices Normally Found in Higher-Ranking Projects



Scanning down the list of these practices, one can see a pattern of practices in support of the PMI knowledge areas. Partnering and project management software top the list. These support communications, integration, and risk management.

Time management practices appear throughout the list (see management practices numbers 4, 7, 12, 14, 16, and 17). These six practices all relate to “getting things done on-time.”

Human resources management practices (i.e., staffing) appear in number 3 and 10. WBS in support of scope management is number 9.

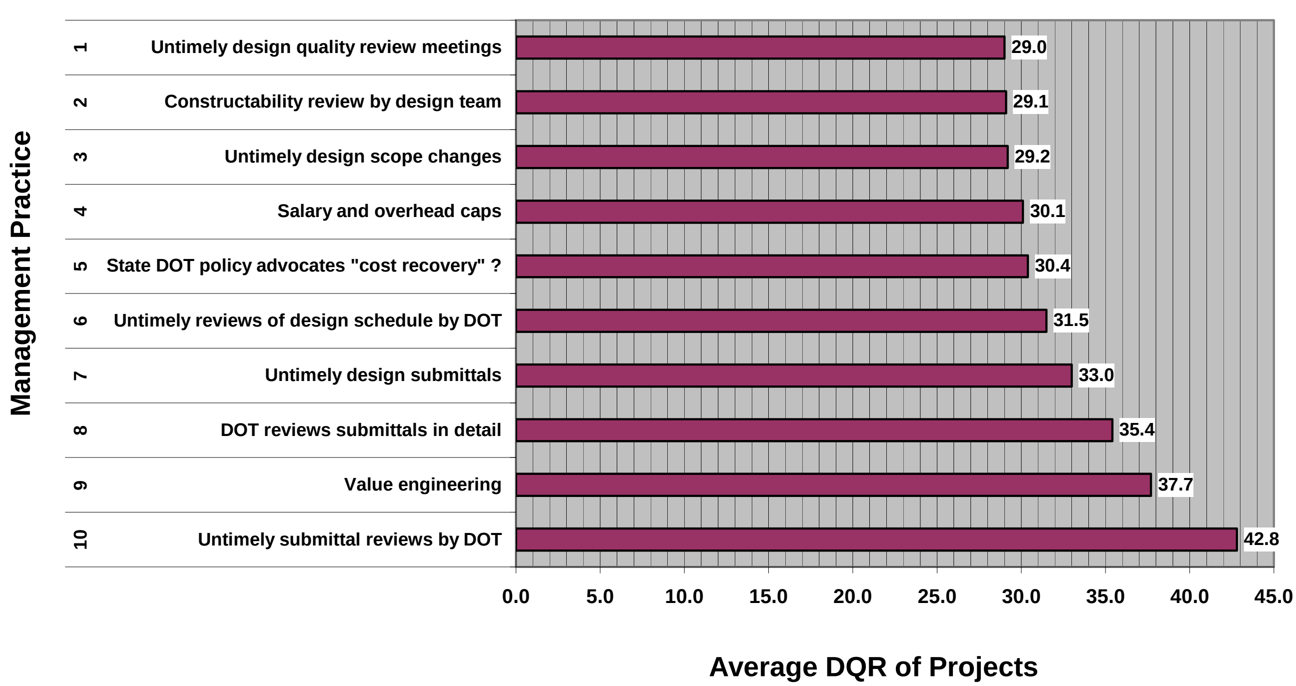
Five practices of the remaining seven indicate that the ***absence*** of cost recovery policies, changes from constructability reviews, detailed reviews of submittals by DOTs, salary and overhead caps, and value engineering may positively influence design quality (see numbers 5, 6, 8, 15, and 18). We discuss these practices below, under *Practices Normally Found in Lower-Ranking Projects*.

No. 13, "Submittals Reported as 'Fair to Good'" is simply a benchmark to show that survey respondents who judged the submittals to be "fair to good" correlate favorably with DQR.

Practices Normally Found in Lower-Ranking Projects

We have listed, charted, and ranked those management practices that when present were normally in lower-ranking projects (see Chart 16). In this chart, one can also see patterns of practices that support PMI knowledge areas.

Chart 16. Average DQR Position of Management Practices Normally Found in Lower-Ranking Projects



Untimely design events cause projects to rank poorly by DQR. Untimely design quality review meetings, design scope changes, design submittals, DOT submittal reviews, and DOT schedule reviews are all negative time management practices that influence low DQR rankings and poor quality (see management practices numbers 1, 3, 6, 7, and 10).

Salary and overhead caps, together with DOT policies that advocate cost recovery, correlate with lower ranking projects (see numbers 4 and 5). We acknowledge that these policies are intended to provide better value to the tax-paying public by …

- limiting the design costs, and
- recovering costs for design shortcomings from design firms.

However, the research shows that the presence of these policies correlates with low DQR and poorer quality projects. Design changes from constructability reviews are indicative of the design team's inability to "do it right the first time." Design professionals may consider this characterization of design reviews to be insensitive to the complexities of design technologies and management. But as W. Edwards Deming advises …

> "We should work on the process, not the outcome of the processes." (and)
>
> "Build in quality."

The DQR average of 21 projects reporting **no** design changes stemming from constructability reviews is 17.4 or 18.6 positions better than the 23 projects reporting design changes stemming from constructability reviews and 9.4 positions better than the DQR average of all 53 projects. The 21 projects that "got it right the first time" also reported using these favorable management practices.

- *Partnering agreements.* Of all 53 projects, four reported having partnering agreements between the sponsoring agency and the designer. None of the four reported design revisions stemming from constructability reviews.
- *Commercial project management software.* Only one of the eight projects (12%) that used commercial project management software for design management reported design changes stemming from constructability reviews.
- *Design staffing plan*. None of the five projects (0%) that considered staff availability and workload balancing in staffing plans reported design changes stemming from constructability reviews.
- *Monthly design quality review*. One of the 10 projects (10%) that held design quality reviews at least monthly during the design process reported design changes stemming from constructability reviews.
- *Cost recovery*. Of 34 projects with a policy of cost recovery from designers for construction change orders, 19 (56%) reported design changes stemming from constructability reviews. Of 15 projects ***without*** a policy for cost recovery, four (27%) reported design changes stemming from constructability reviews.
- *Monthly design schedule review*. Only five of 20 projects (25%) having design schedule reviews at least monthly reported design changes stemming from constructability reviews.

Constructability reviews are inspections to fix that which has not been done right the first time. Good design quality negates the need for end-of-design constructability reviews.

- *Rigorous detailed checking by DOT*. Fifteen of 21 projects (76%) reporting that design submittals were rigorously checked in detail by DOT staff were also reported as having design changes stemming from constructability reviews.
- *Work breakdown structure.* Nine of 11 projects (82%) using WBS for design scope management reported having ***no*** design changes stemming from constructability reviews.
- *Design staff availability*. Five of eight projects (63%) that considered availability of design staff and workload balancing in design planning reported having ***no*** design changes stemming from constructability reviews.

- *Construction specialists*. Nine of 12 projects (75%) using construction specialists in design reviews reported having ***no*** design changes stemming from constructability reviews.
- *Milestone dates*. Sixteen of 21 (76%) projects that set milestones dates for deliverables during design planning reported having ***no*** design changes stemming from constructability reviews.
- *"Fair to good" design submittals*. Fifteen of 21 (71%) projects reporting "fair to good" design submittals also reported having ***no*** design changes stemming from constructability reviews.
- *Timely design scope changes*. Ten of 16 projects (63%) reporting that design scope changes, when needed, were timely also reported having ***no*** design changes stemming from constructability reviews.
- *Salary and overhead caps.* Fifteen of 27 (56%) projects having salary and overhead caps reported having design changes stemming from constructability reviews. Eight of 26 projects (31%) ***not*** having salary caps reported having design changes stemming from constructability reviews.
- *Timely DOT reviews of design submittals*. Twenty-one of 36 projects (58%) reporting timely reviews of submittals by DOT reported ***no*** design changes stemming from constructability reviews.
- *Timely design submittals*. Nineteen of 34 projects (56%) having timely design submissions reported ***no*** design changes stemming from constructability reviews. Four of six projects (67%) reporting that design submissions were usually late reported having design changes stemming from constructability reviews.
- *Value engineering.* All three of the projects (100%) that were subjected to value engineering reported having design changes stemming from constructability reviews.

SUMMARY

Many individual design management practices correlate directly with design quality rankings, many do not, and some have little or no correlation. Working together, however, those design management practices that support scope, procurement, schedule, staffing, quality, communications, integration, and risk management have the strongest direct correlations with good design quality rankings. Following are management practices common to higher-ranking projects.

- Scope management
  - ❑ WBS for scope planning.
  - ❑ Design scope amended promptly, when needed.
- Schedule management
  - ❑ Milestone dates included in design plan.
  - ❑ Design schedule review at least monthly.
  - ❑ Designer submittals usually on-time.
  - ❑ Sponsoring agency reviews of designer submittals usually on-time.

- Staffing Management
  - Staff availability and workload balancing considered in design plan.
  - Detailed staffing plan by task and deliverable.
- Quality Management
  - Design quality review at least monthly.
  - Sponsoring agency reviews designer’s quality assurance process regularly.
  - Design review by construction specialists as design progresses.
- Communications, Risk, and Integration Management
  - Use of commercial project management software for design management.
  - Partnering between sponsoring agency and designer.

Following are management practices having the strongest correlations to poor design quality and most common to lower-ranking projects.

- Cost Management
  - Value engineering.
  - Cost recovery.
- Procurement Management
  - Salary and overhead caps.
- Schedule Management
  - Untimely design submittals, agency reviews, and design scope changes.
- Quality Management
  - Through rigorous reviews, sponsoring agency usurps designer’s responsibilities for design quality by requiring design revisions based on reviewer’s personal preferences.

Successful schedule management practices are especially powerful in influencing design quality. Designs produced on a planned schedule from beginning to end represent other influences also being successfully managed. Realistic schedules require knowledge, skill, and experience in setting requirements and in planning, organizing, leading, and controlling scope, cost, quality, staffing, communications, risks, procurement, and their integration.

Chapter 8

FORECASTING DESIGN QUALITY AND CONTROLLING PROJECTS IN PROGRESS

DQR is valuable in correlating design management practices with design quality and for improving performance of future projects; however, these metrics are not useful in controlling projects in-progress. In this Chapter, we discuss metrics for improving performance while designs are in-progress.

COST AND SCHEDULE PERFORMANCE

Measures of cost and schedule performance are the metrics most commonly used by project management professionals for controlling performance as projects progress. The foundation of these metrics is a measurement known as "earned value." Earned value is "what we got for what we spent." It measures, in project management terms, the budgeted cost-of-work performed. For purposes of measuring design management, we define it as the Budgeted Cost of Deliverables Produced (BCDP). When related to actual cost or actual schedules, earned value measures the effectiveness of scope, cost, and time management.

We found that CPI does not correlate with other measurements for design quality in highway and bridge projects.

Cost Performance

In project management circles, cost performance is measured by the ratio of the budgeted cost-of-work performed to the actual cost of work performed. For purposes of measuring design progress, we have defined it as the ratio of Budgeted Cost of Deliverables Produced (BCDP) to the Actual Cost of Deliverables Produced (ACDP) or the ratio of Earned Value to Actual Cost of specified deliverables. This measure is known as the Cost Performance Index (CPI) and is mathematically expressed as CPI = BCDP/ACDP. In our model tests on actual projects, we found that CPI does not correlate with other measurements for design quality in highway and bridge projects.

Schedule Performance Index, expressed mathematically:

SPI = BCDP / BCDS

Where:

SPI	= Schedule Performance Index
BCDP	= Budgeted Cost of Deliverables Produced
BCDS	= Budgeted Cost of Deliverables Scheduled

Schedule Performance

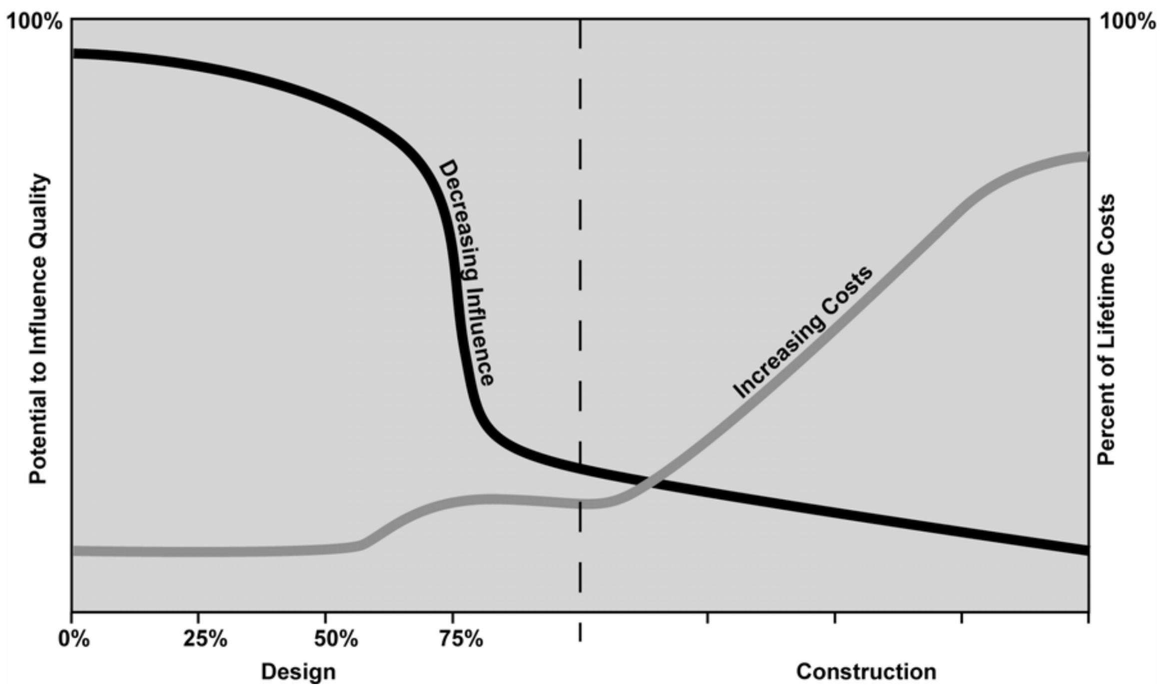
In project management circles, schedule or time performance is measured by the ratio of Earned Value to the budgeted cost-of-work scheduled. This measure is known as the Schedule Performance Index (SPI). For purposes of measuring design management, we have defined SPI as the ratio of Earned Value to Budgeted Cost of Deliverables Scheduled (BCDS). SPI is "value we earned for the time spent." In tests of actual projects, we found that SPI rankings correlate directly with DQR rankings. As such, rankings by SPI are predictors of design quality. In practical terms, the following data are needed

SPI rankings - "value we earned for the time spent" - correlate directly with DQR rankings.

for this measurement:

1. Budgeted cost allocated by design deliverable.
2. Schedule of milestone dates by deliverable.
3. Schedule of budgeted costs by proposed milestone date by deliverable.
4. Measurement of budgeted cost by actual milestone date by deliverable.

We found that SPI measurements on the dates when design services are scheduled to be 25%, 50%, and 75% complete provide the most reliable predictors of design quality. SPI measurements at 25% completion are especially valuable because the opportunities for adequate remedies are greatest in the initial design stage. At 25% completion, enough design has been completed to fix project limits and details, but enough time remains to redirect the project, if needed. At 25%, enough time remains to "do it right once." SPI measurements at 50% and 75% completion are valuable to design managers in determining that the project is continuing on the planned course.



The opportunities to influence quality at the least cost happen early in a project – another reason why "quality" means doing it right once, the first time. ***(From <u>Quality in the Constructed Project</u>, American Society of Civil Engineers, 1988.)***

When SPI is less than 1.00, the design is behind schedule. Conversely, when SPI is greater than 1.00, the design is ahead of schedule. If SPI is between 0.90 and 0.95, the project is reasonably close to being on schedule and management should put the project on its "watch list" to again measure the SPI next month.

When SPI is between 0.75 and 0.90, the project is slipping behind schedule. Management should meet with the design manager to discuss the causes for being behind schedule and remedies to get back on track.

- Does management agree with the work progress being reported by the project team?
- What elements of the design are behind schedule?
- What actions are being taken to overcome the delay?
- Is management confident that the design manager has properly planned and is appropriately managing the project?
- Are the critical success factors well defined?
- Are the key stakeholders fully engaged?
- Is the design plan appropriate for the services to be rendered?
- What resources are needed to get back on schedule?

SPI measurements at 25% completion are especially valuable because the opportunities for adequate remedies are greatest in the initial design stage.

Management should measure SPI and meet with the design manager each month until SPI exceeds 0.90.

If SPI is between 0.60 and 0.75, design quality should be assessed. Management should meet with the design manager and key technical personnel to determine the cause for being materially behind schedule.

- Upon review of the SPI measurements and general review of design deliverables, does management agree with the work progress being reported by the project team?
- What element(s) of the design is(are) behind schedule?
- What actions are being taken to overcome the delay?
- Is management confident that the design manager has properly planned and is appropriately managing the project?
- Are the critical success factors well defined?
- Has the support of key stakeholders been fully enlisted?
- Is the design plan appropriate for the services to be rendered?
- What resources are needed to get back on schedule?

Management should measure SPI and meet with the design manager and key stakeholders each month until SPI exceeds 0.90.

If SPI is less than 0.60, design quality is at risk. Management should congregate key stakeholders to delve into the underlying cause for being severely behind schedule.

- Upon review of the SPI measurements and general review of design deliverables, does management agree with the work progress being reported by the project team?
- Do all stakeholders continue to subscribe to the critical success factors, design requirements, and scope of design services?
- What element(s) of the design is(are) behind schedule?

- What actions are being taken to overcome the delay?
- Is management confident that the design manager has properly planned and is appropriately managing the project?
- Are the critical success factors well defined?
- Has the support of key stakeholders been fully enlisted?
- Is the design plan appropriate for the services to be rendered?
- What resources are needed to get back on schedule?
- What resources are needed to remedy the schedule delay?

SPI may well be one of the most valuable tools for controlling risks in design.

Management should consider becoming directly involved in working alongside the design manager until the design shortcomings are remedied. Management should measure SPI and meet with the design manager and key staff weekly until SPI exceeds 0.90.

SUMMARY

The direct correlation of SPI to design quality rankings is one of the more valuable findings of this research. SPI provides sponsors of highway and bridge projects and leaders and managers of design organizations a simple metric for continuously measuring design schedule progress and design quality. As a predictor, SPI is the “red flag” of potential risks. Risks that, when unforeseen and unmanaged, grow into costly construction and post-construction problems:

- Unbalanced and uncompetitive construction bids.
- Costly construction changes and quantity deviations.
- Complaints, disputes, and litigation.
- Damaged business relationships and reputations.
- Increased costs of liability insurance.
- Financial losses.
- Major distractions of leaders and managers from more productive opportunities.

Chapter 9

COST OF POOR DESIGN QUALITY

Oftentimes people infer that "quality" means "expensive." Such thinking has quality confused with exorbitance. "Perfect" quality is everything needed to address stakeholders' needs – not one bit more, not one bit less. Quality is value. Quality is evident when stakeholders' requirements have been met. Designers provide quality, in large part, by producing documents that accurately represent stakeholders' requirements to bidding contractors. Construction changes, represented by quantity variations and extra work, indicate design shortcomings requiring remedies to satisfy stakeholders' requirements. In this Chapter, we discuss costs of remedying design shortcomings. We call these extra expenditures "costs of poor design quality."

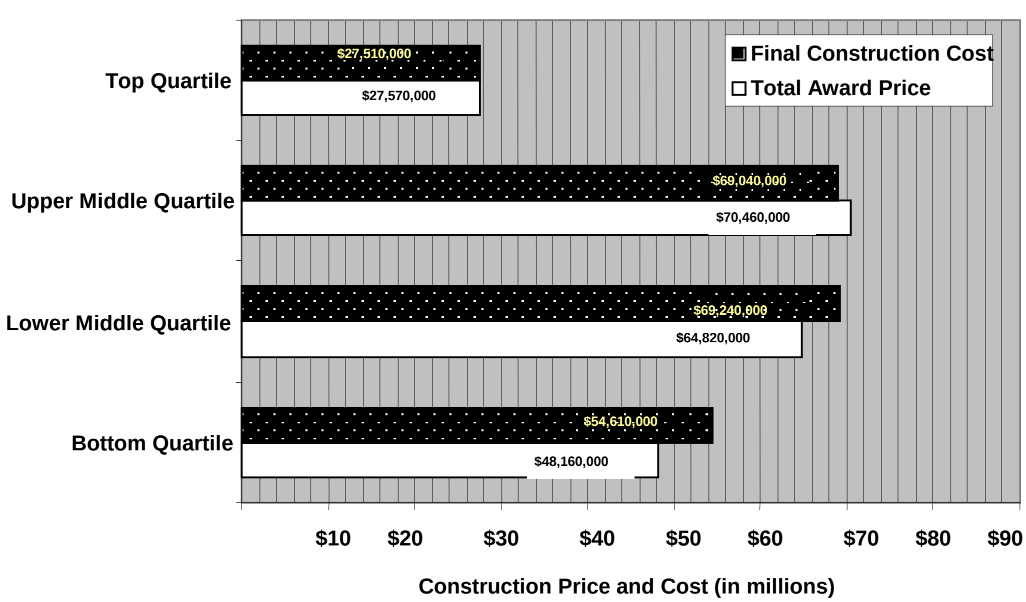
In our research, low-ranking projects overran the award price by 13.2% and high-ranking projects were 0.2% less than the award price.

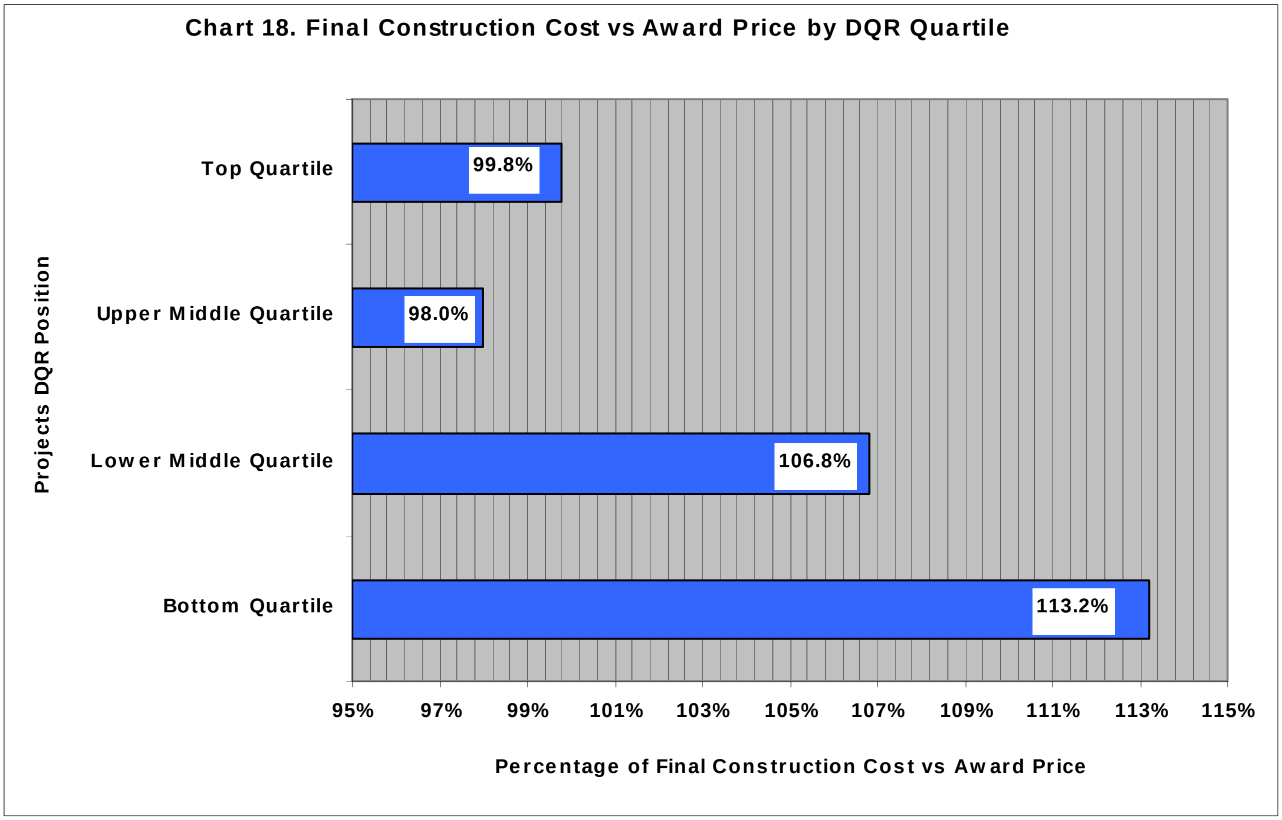
CONSTRUCTION COST VERSUS AWARD PRICE

The total price awarded to the successful bidders of the 53 projects analyzed was $211,000,000 as compared to a total final construction cost of $220,310,000, a net overrun of $9,310,000 or 4.4% more than awarded.

- The construction cost of projects ranking in the top quartile netted $60,000 or 0.2% less than the price awarded (see Charts 17 and 18).

Chart 17. Final Construction Cost vs Award Price by Quartile





- The construction cost of projects ranking in the upper-middle quartile netted $1,420,000 or 2.0% less than the award price.
- The construction cost of projects ranking in the lower-middle quartile netted $4,420,000 or $6.8% more than the total award price.
- The construction cost of projects ranking in the bottom quartile netted $6,350,000 or 13.2% more than the total award price.
- The final construction cost of the 14 top-ranking projects was 13.4% [(13.2% - (- 0.2%)] closer to the office estimates than that of the 13 bottom-ranking projects.
- The total construction cost of the 14 projects ranking in the top quartile is virtually equal to the total construction award price of these projects, whereas the total construction cost of the 13 projects ranking in the bottom quartile is 13.29% greater the total award price of these projects.
- Little or no difference between construction cost and award prices, as occurred in the top quartile, indicates that documents prepared during design correctly represent the construction required to address stakeholders' interests on the whole.
- Material differences between construction cost and award prices, as occurred in the bottom quartile, indicate that documents prepared during design ***inadequately*** represent the construction required to address stakeholders' interests.

ACTUAL CONSTRUCTION COST VERSUS MARKET PRICE

The absolute difference between constructed and estimated quantities is a measure of design quality for each construction item. The sum of the products of these differences and their respective bid prices measure the overall accuracy of the quantity estimates. Neither overestimated nor underestimated bid quantities, in themselves, change the quantities actually constructed. The quantities actually constructed are those needed to satisfy project requirements, irrespective of estimating quality. Misestimated quantities do, however, very significantly influence the unit-prices bid for those items.

The Role of Unbalancing

The antidotes to unbalanced bids are plans, specifications, and bid quantities that accurately represent the construction required to satisfy stakeholders' expectations.

Misestimated quantities encourage bidders to quote above-market unit-prices for underestimated items and below-market prices for overestimated items. This practice is known as "bid unbalancing." The purpose of unbalancing is to increase bidders' project revenues and profits by over-pricing items that are underestimated in the bid tabulation and under-pricing items that are overestimated. In order to maintain competitive bids for each project as a whole, bidders discount the pricing of lump sum items by the sum of the products of the marginal increases in unit-prices and the underestimated bid quantities. In turn, bidders reverse this process when pricing overestimated bid quantities by increasing the price of lump sum items by the product of the marginal difference between bid quantities and the bidder's estimate and the bid price.

Construction bidders who are skillful in unbalancing bids are distinctly advantaged in winning profitable projects, but only if quantities provided in the bid sheets are significantly misestimated. Quality estimates preclude the opportunity to unbalance bids. The antidotes to unbalanced bids are plans, specifications, and bid quantities that accurately represent the construction required to satisfy stakeholders' expectations.

Unbalanced Bid Prices Increase Construction Costs Above Competitive Market Prices

The 53 projects analyzed had a total of 4,914 construction line items, of which 1,021 are in the projects in the top quartile, 1,096 in the upper-mid quartile, 1,561 in the lower-mid quartile and 1,236 in the bottom quartile. Of the 4,914 line items, the constructed quantities of 1,540 items overran the estimated bid quantities, the constructed quantities of 1,871 items underran the estimated bid quantities, and the constructed quantities of 1,503 items were equal to the estimated bid quantities.

We reason that rational bidders will only quote unbalanced unit-prices for those items that are "significantly" misestimated. Items that are only marginally misestimated are too risky to misquote. To estimate the cost of poor design quality, we assumed that bidders quoted unbalanced bids for only those items having actual constructed quantities of 50% more or 50% less than the estimated quantities. Also, we assumed that bidders quoted unit-prices equal to the product of the market unit-price multiplied by the ratio of the constructed quantities to the bid quantities, except for overestimated items. We assumed that the maximum price reduction for overestimated items is half the market price. Expressed mathematically, the cost of poor design quality for each unit-priced construction item that meets this criteria is as follows:

Estimated Cost of Poor Design Quality =
(Market Price – Bid Price) x (Office Estimated Quantity – Final Quantity)
Where Market Price = (Bid Price) x (Office Estimated Quantity/Final Quantity)

Based upon these assumptions, which we believe are conservatively low, we estimate that the cost of poor design quality attributable to bid unbalancing across all 53 projects is $16,300,000 or 7.7% of the total award price. Costs associated with bid unbalancing are in addition to those that would have been incurred had the estimates been more precise.

The prices of low-ranking projects are more than 110% of market prices.

The cost of poor design quality attributable to bid unbalancing for all projects ranked in the bottom quartile is $4,988,000 or 10.4% of the total price of awards as compared to $1,018,000 and 3.7% for all projects ranking in the top quartile. The increased cost of low-ranking projects was nearly three times that of high-ranking projects.

SUMMARY

Quantities misestimated by designers and so listed in bid tabulations induce bidders to misquote or "unbalance" their prices. Unbalanced bids very significantly increase the actual cost of construction as compared to market prices. We estimate that the total actual cost of all of the projects researched was 7.7% greater than market prices because of bid unbalancing. The *increased* cost of lower-ranking projects was nearly three times that of higher-ranking projects. We estimate that the prices of low-ranking projects are more than 110% of market prices. *High-ranking projects are also less likely to overrun contract award prices than low-ranking projects. In our research, low-ranking projects* ***overran*** *award prices by 13.2% and high-ranking projects* ***underran*** *award prices by 0.2%.*

APPENDIX A

DATA SURVEY

Data for projects sponsored by MassHighway were excerpted by researchers from original project files located in MassHighway's central offices at 10 Park Plaza and supplemented through interviews of MassHighway staff who are familiar with each project.

Data for projects sponsored by states other than MassHighway were solicited by mail, email and telephone and submitted by officials of each state. Data included:

- Copies of construction bid tabulations for each payment line item, including item ID and description, estimated quantity, units and unit bid price.
- Final payment tabulation for each construction contract, including: item IDs and descriptions, final quantities, unit prices and extended amounts.
- Description and amounts paid for each construction change order, including opinion of cause of change order and relevant correspondence.
- Design Quality Data Survey and a followup interview with DOT staff, as appropriate (see data survey, attached).

DESIGN QUALITY DATA SURVEY

Project No.___________________________ ***(project identification number assigned by state DOT)***

•Construction Cost: ____ up to $2 million ____ more than $2 million

•Design and Construction Periods:

Design started:________ (year)

Design completed:________ (year)

Construction started:_________ (year)

Construction completed:__________ (year)

•Project Type: ***(circle the letter that best fits the project)***

a. New bridge(s)

b. New highway(s)

c. Combination of new bridge(s) and/or new highway(s)

d. Rebuilding bridge

e. Rebuilding highway

f. Rebuilding bridge(s) and highway(s)

g. Roadway resurfacing

•Design Deliverables: who produced each of these design elements? ***(circle the letter that best fits)***

	State's DOT	Consultant	Not Required
Define project needs & requirements:	a	b	c
Land surveys:	a	b	c
Soils engineering:	a	b	c
Environmental services:	a	b	c
Conceptual designs:	a	b	c
Preliminary design:	a	b	c
Detailed design:	a	b	c
Construction plans, profiles and section:	a	b	c
Construction specifications:	a	b	c
Construction quantity estimates:	a	b	c
Construction cost estimates:	a	b	c

•Design Partnering: ***(circle the letter that best fits)***

a. Has your State's DOT endorsed partnering with private design consultants? **YES NO**

b. Does your State's DOT participate in partnering sessions with an association(s) representing private design consultants? **YES NO**

c. Has your State's DOT implemented policy and/or procedural changes derived from partnering sessions with the association(s)? **YES NO**

d. Is the contract with the private design consultant for *this* project characterized as a "partnering agreement" by your State's DOT? **YES NO**

•Design Reviews:

What is your State DOT's normal policy (written or unwritten) for reviewing designer's deliverables, such as: data, computations, designs, plans, specifications, and quantity estimates produced by designers? ***(circle the letter that best fits)***

a. State's DOT is ultimately responsible and accountable for the quality of design. Therefore, State's DOT rigorously and thoroughly reviews and corrects all deliverables by private design consultants, including: data, computations, plans, profiles, cross sections, specifications, quantity estimates, and unit costs estimates.

b. State's DOT shares responsibility and accountability for design quality with design consultants. State's DOT expects design consultants to perform detailed design quality control such as reviews of data, computations, plans, profiles, cross sections, specifications, quantity estimates, and unit cost estimates. State's DOT's responsibility is to assure that design consultant is performing quality control.

c. State's DOT administers design quality assurance by rigorously selecting only those design consultants who have proven track records in design quality control.

d. State DOT's policy for assuring design quality varies depending on the risk associated with each specific project.

°Design reviews on this project: ***(circle all that apply)***

a. The design deliverables for this project were rigorously reviewed in detail by State's DOT.
b. The design deliverables were reviewed by State's DOT to determine that the designer used reasonable care in meeting requirements.
c. The design deliverables were spot checked to assure that the designer applied quality control.
d. State's DOT visited the designer and reviewed design progress.
e. State's DOT met with the designer at least monthly to review design progress, resolve issues, and assure design quality.

•Project management processes and tools: What management processes and/or tools were used in planning, organizing, managing, and/or controlling the design of this project?

°Project Management tools: ***(circle all that apply)***
Used commercially available PM software to plan and/or manage design:

a. Primavera
b. Microsoft Project
c. Artemis
d. Other________________________

°Scope of design services and deliverables: ***(circle all that apply)***

a. Prepared detailed scope of services.
b. Used Work Breakdown Structure in scope development.
c. Routinely compared actual design deliverables to those planned.
d. Adjusted the scope of work promptly when needed.
e. Other (explain) _________________________.

°Design staffing: ***(circle all that apply)***

a. Prepared detailed plan for staffing each design task and deliverable.
b. Staff planning included consideration of skills and experience needed.
c. Plan considered resource availability and workload balancing.
d. Throughout the design, staffing was appropriate for needs.
e. At times, design staffing was very inadequate for the needs.
f. Design project manager was appropriately experienced for the project.
g. Design project manager was technically appropriate, but lacked management skills.
h. Principal technical person(s) were appropriately experienced for this project.

°Budget and cost: ***(circle all that apply)***

a. Rationally developed design budget from scope of work, explicit tasks, labor classifications, salary rates and other directly related costs.
b. Routinely compared actual costs incurred by task to its budgeted cost.
c. Routinely checked actual cost expended for design.
d. Used the process known as "Earned Value" to compare costs to budget.
e. Other (explain) _____________________________________.

°Schedule and time management: ***(circle all that apply)***

a. A detailed schedule was prepared for each task and deliverable.
b. Milestone dates for deliverable submissions were set at the start.
c. Schedule performance was reviewed at least monthly.

°Design Deliverables were: ***(circle the letter that best fits)***

a. Always submitted before the scheduled due date.

b. Generally on time.

c. Frequently late.

d. The design ran behind schedule from start to finish.

°State DOT's reviews of designer's submittals for this project were: ***(circle the letter that best fits)***

a. Always on time.

b. Were generally on time with some being late.

c. Were often late in being returned to the designer.

d. Were chronically late and probably delayed the designer's schedule.

e. Materially delayed the design work and disrupted the workflow.

°Quality standards: ***(circle all that apply)***

Our State DOT's design requirements are:

a. Readily available to designers, exceptionally well organized, and clearly presented in documentation and/or electronic files.

b. Promptly communicated to designers when revised.

c. Clear and consistent with terms in design contracts.

°Quality of deliverables: ***(circle the letter that best fits)***

Design deliverables for this project were:

a. Nearly always excellent. Seldom required revisions.

b. Generally, very good. Fewer revisions required than usual.

c. Typical of most submittals for designs. Some revisions needed.

d. Poorer than most. More revisions than usual. Below standard.

e. Especially poor and unacceptable. Caused delays and conflict.

•<u>Constructibility Reviews:</u>

°What processes were used to assess the constructibility of this project prior to soliciting construction proposals? ***(circle all that apply)***

a. Reviewed by design team as design progressed.

b. Reviewed by design team as part of final design review process.

c. Reviewed by staff who were not part of design team.

d. Reviewed by private consultant(s) independent of the design team.

e. Reviewed by State's DOT construction specialists independent of personnel assigned to design process.

f. Reviewed by construction management specialty firm.

g. Reviewed by construction contractor (non-bidder).

h. Design not reviewed for constructibility prior to inviting construction bids.

°Were remedial changes made to the design based upon the constructibility reviews? ***(circle the letter that best fits)***

a. Major revisions were made to the plans and/or specifications.

b. Some revisions were made.

c. Very few revisions made.

d. No revisions were made.

•<u>Cost Recovery:</u>

a. Does your State's DOT back-charge design consultants, where appropriate, for construction change orders through "cost recovery?" **YES NO**

If yes, what year was your State's DOT cost recovery process implemented? __________

b. Did your State's DOT seek to recover costs from the design consultants for construction change order(s) on this project? **YES NO**

If yes, approximate amount sought: $______________

•Value Engineering:

Was value engineering performed? If so, by whom? (***circle all that apply***)

a. State's DOT.

b. Design engineer.

c. A third party.

Letter Soliciting Data from State Departments of Transportation

Re: Data Request for Design Quality Research

Dear Mr.:

The Massachusetts Highway Department has contracted with The Engineering Center to research design quality in highway/bridge projects. This is a two-phase project specifically geared to assess management influences on design quality. In Phase I, we developed a model for measuring design quality. In this second phase, we are evaluating influences of management practices on highway design quality.

In Phase I, we used MassHighway data, supplemented by data from 15 other states. We are now seeking additional data to analyze the influences of the several management practices under study.

Our research is programmed to determine whether design quality is influenced by:

1. Designer compensation: Do fixed price, cost-plus, and/or incentive-based compensation for private design firms influence design quality?
2. "Capping" reimbursement rates: Does the practice of capping the rate of reimbursing private design firms for salary costs and/or overhead costs influence design quality?
3. Design partnering: Does partnering between private designers and the sponsoring transportation agency influence design quality?
4. Project management tools: Does the use of project management tools, such as PM software for design management, influence design quality?
5. Design reviews: Do detailed design reviews by the sponsoring agency influence design quality?
6. Constructibility reviews: Do formal constructibility reviews influence design quality?
7. Design staffing: Do design team selection processes influence design quality?
8. Cost recovery: Does the process of recovering costs for construction change orders from private designers influence design quality?

We are asking that your agency provide certain data for a few highway and/or bridge projects, including:

1. Bid Tab: Tabulation of construction bids for each payment line item and bidder. This should include the item description, estimated quantity, units, and unit price.
2. Final Payment Tab: Tabulation of final payment to the construction contractor listing each line item, its final quantity, unit price, and actual payment amount.
3. Construction Change Orders: A description and the amount paid for each construction change order.
4. A telephone interview with the person in your agency who is most familiar with each project you provide. We have enclosed a copy of the Data Survey, which we will use in the telephone interview.

In making selections of projects, we ask that you try to include both:

- Projects that were "troublesome" and projects that were not.
- Projects for which the designer's compensation was "capped" and projects for which designer compensation was "uncapped."
- Fixed price and cost plus design compensations.

We fully appreciate that we are asking you to contribute some of your agency's staff time to provide the requested data. Based upon our research findings to date, we believe this research has already provided "break-through" results for continuously improving the quality of highway projects. We now have strong evidence that design scheduling materially influences design quality and construction costs. We believe that this phase of the research will reveal the influences of management practices on design quality and provide a basis for continuously improving design management practices. In appreciation for your agency's assistance, MassHighway's Chief Engineer will forward you a copy of the final report for this research.

I will telephone you within the next two weeks to follow up on our request. In the interim, if you have any questions or comments, please contact me.

Very truly yours,

Melvin E. Jones
Research Director
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Direct phone: (617) 305-4109
Fax: (617) 227-6783
Email: mjones@engineers.org

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