Quality Assurance Organization Selection Factors for Highway Design and Construction Projects

Elizabeth Kraft[1] and Keith R. Molenaar, M.ASCE[2]

Abstract: A project quality assurance organization (QAO) assigns project quality responsibilities and relationships, both for design and construction. In the highway sector, all project quality roles and responsibilities have historically been assigned to the state highway agency (SHA), an accepted and well-understood industry practice. However, increasing use of alternative project delivery methods and reductions in SHA staffing are having an impact on traditional QAO practices. SHAs are increasingly selecting alternative QAOs, but they are making these selections in an ad hoc manner because of limited staff knowledge and experience, and a lack of guidance from the research community. Highway design and construction quality research focuses almost exclusively on inspections, observations, corporate quality, warranties, and materials testing, resulting in a gap in the research about shifts in project quality roles and responsibilities. This research extends the civil engineering quality management body of knowledge by identifying factors that influence the selection of QAOs and rating the appropriateness of the QAOs for each selection factor. Because of the complexity of the topic, scope of the decision process, and the limited project data available, structured interviews and the Delphi method were chosen to explore the selection factors. The research discovered 10 factors: project size, project complexity, project delivery method, project schedule sensitivity, availability of agency project staff, agency project staff experience, agency culture, industry ability to manage their own quality, trust between agency and industry, and amount of quality risk to shift away from the agency. The research provides the highway industry with new understanding of the effects that each selection factor has on the fundamental QAOs. This fundamental knowledge will allow SHAs to make more informed QAO selections.
DOI: 10.1061/(ASCE)ME.1943-5479.0000289.

Author keywords: Project management; Highway construction; Highway design; Quality management; Quality assurance; Quality control.

Introduction

Traditionally, all design and construction quality activities were the responsibility of state highway agencies (SHA), with the exception of possibly construction quality control (QC). Because of increasing acceptance of alternative project delivery methods and reductions in SHA staffing levels, quality roles are beginning to shift to other project participants (designer, contractor, engineer, design-builder, construction manager, and/or concessionaire). Although the quality activities required for highway projects remain the same, the project participants responsible for the activities are shifting (Gransberg et al. 2008). A QAO is the assignment of the responsibility for project quality roles and activities for both design and construction.

SHAs have been left to assign responsibility for project quality roles and activities in an informal manner because of minimal guidance from industry and the transportation research community. The vast majority of civil and construction engineering research regarding highway quality focuses on construction QC, such as inspections, materials, testing, observation, assurance, and specifications (Minchin et al. 2008; Miron et al. 2008; Hughes 2005; Erickson 1989; Smith 1998). The 1990s saw a focus on quality-related research throughout many construction sectors regarding topics such as Total Quality Management (TQM), International Organization for Standardization (ISO) 9000, and the Baldridge system (Chini and Valdez 2003; Dikmen et al. 2005; Kasi 1995; Elliot 1991; Schmitt et al. 2000). However, this research was focused at the corporate or enterprise level, not at the project level (Kasi 1995; Burati Jr. 1992; Burati Jr. et al. 1992; Oswald and Burati Jr. 1992; Deffenbaugh 1993). Gransberg et al. (2008) identify highway quality project management roles and tasks and their relationships on design-build projects. Gransberg and Shane (2010) briefly commented on the assignment of quality management roles on construction manager/general contractor projects. Recognizing the need for work in project QAOs, the National Cooperative Highway Research Program (NCHRP) of the National Academies solicited a research effort to provide guidance on alternative quality management systems for highway projects (Kraft 2013). Kraft and Molenaar (2013) identify a novel set of five fundamental QAOs in the highway industry and is used for the basis of this research to identify QAO selection factors.

This research builds upon the body of knowledge in civil engineering quality management and advances the understanding of the five fundamental QAOs in particular. The research identifies factors that influence project QAO selection. It also develops ratings for the appropriateness of the fundamental QAOs for each of the selection factors. The relationship discovered between the selection factors and the fundamental QAOs provides guidance for the selection of an appropriate project QAO. It also continues to develop the character for each novel QAO. Finally, this research provides the industry with guidance as to the selection of an appropriate QAO for an individual project.

[1]Dye Management Group, Skyline Tower, Suite 1901, 10900 Northeast 4th St., Bellevue, WA 98004; formerly, Graduate Assistant, Civil, Environmental and Architectural Engineering, Univ. of Colorado, Boulder, CO 80309-0428 (corresponding author). E-mail: elizabeth.kraft@colorado.edu

[2]Professor, Dept. of Civil, Environmental, and Architectural Engineering, Univ. of Colorado, Boulder, CO 80309-0428. E-mail: keith.molenaar@colorado.edu

Note. This manuscript was submitted on February 6, 2013; approved on February 12, 2014; published online on May 27, 2014. Discussion period open until October 27, 2014; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Management in Engineering***, © ASCE, ISSN 0742-597X/04014069(9)/$25.00.

Five Fundamental Quality Assurance Organizations

A QAO is analogous to an organizational chart that assigns the roles and responsibilities within the company and identifies the relationships between these parties. The project quality roles and responsibilities included in a QAO are quality assurance (QA), QC, acceptance, and independent assurance for both design and construction. This research used the *Transportation Research Circular Number E-C137* (Transportation Research Board 2009) definitions for QA, acceptance, and independent assurance, which are included in the Appendix. It is important to note that there is no single QAO that is appropriate for every project. In fact, it is possible that multiple QAOs could be successfully implemented on a single project. The five fundamental QAOs, as defined by the previous research effort on alternative quality systems for highway design and construction projects, are deterministic, assurance, variable, oversight, and acceptance (Kraft and Molenaar 2013). Each of these are defined and described briefly here.

The *deterministic QAO* is the traditional approach to quality in the highway industry, and the agency retains all control for all quality on the project. While the contractor may implement the QC, the agency dictates the QC means and methods for the project. In the *assurance QAO*, the agency is responsible for all aspects of the QA except for QC. In the *variable QAO*, the design and construction phases of a given project take different approaches to quality. For example, in a design build (DB) project, the design phase may take a proactive approach to quality by assigning both design QA and QC responsibilities to the party contracted to perform the scope of work, while the construction phase takes a reactive approach by assigning construction QC responsibility only to the party contracted to perform the scope of work.

In the *oversight QAO*, agencies take on an oversight role by assigning design QA, design QC, construction QA, and construction QC to the parties that are contracted to perform these scopes of work. The *acceptance QAO* is primarily used in the Public Private Partnership (PPP) project delivery method. It can also be applied to DB project delivery, but its use is more prevalent in PPP delivery. The term PPP applies to concessionaire and its designer and contractor, which is almost exclusively a design-builder. All quality roles and responsibilities are the responsibility of the concessionaire or private entity, except verification testing and final acceptance, which are the responsibility of the agency. The concessionaire is the party the agency contracts with in a PPP project. Table 1 summarizes the assignment of the roles and responsibilities for each QAO.

Research Methodology

This exploratory research used a mixed-method approach in two phases: (1) identification of the selection factors through project-based interviews; and (2) rating the appropriateness of the fundamental QAOs to each category of the selection factors and validation through a Delphi approach. No previous research has attempted to determine QAO selection factors or their relationship with QAOs. The identification of the selection factors is exploratory because of the complexity of the selection and the difficulty in obtaining performance data. The number of confounding variables in the selection and the small set of projects from which to draw evidence point this research toward qualitative methods to leverage the experience of experts in the field. Claxton (Claxton et al. 1980) states that one of the three major reasons for exploratory research is to provide a preliminary evaluation of ideas, which may be of interest when identifying choice criteria. "A major strength of exploratory methods is the ability to identify major issues or attributes associated with a particular research problem" (Claxton et al. 1980).

Selection Factor Identification Methodology

When the party responsible for the quality roles on a project differs from the traditional assignments (the deterministic QAO), the SHA staff ultimately decides how the roles are assigned and has to manage the impacts of the changing quality roles on a project. Therefore, the SHA project personnel must have the appropriate knowledge regarding the assignment of project QAO roles. Highway quality terminology is sometimes overlapping and inconsistent between states (Transportation Research Board 2009); as such, project-based interviews provided context and reference points allowing for increased clarity in an SHAs specific understanding of various quality terminology. State highway projects from across the country were selected to participate in the research. Projects were selected based on geographic location, size, schedule, and delivery method to ensure internal validity of the process. The final number of projects included in the research was based on the heterogeneity of the projects and the saturation of selection factors.

Structured interviews were conducted with SHA staff on 23 projects from 13 different states. The unit of analysis for the interviews was the project. Each interview focused on the experiences and insights of the SHA project personnel regarding the project quality roles and the factors that influenced the assignment of these roles on the project. When there was not a single project manager from project concept through completion, multiple SHA staff from one project were interviewed in order to gather data on the full project cycle: preconstruction, design, and construction. The projects varied in size, delivery method, location, scope, and duration, as depicted in Table 2. Questionnaires were completed by SHA personnel prior to the interview to gain project data, information about the SHA's experience, and the respondent's background. Individual projects that did not meet the criteria for a broad understanding of QAOs and individuals without a minimum of five years of experience were excluded from the study.

A total of 10 selection factors were identified through the SHA project interviews. Any factors that were a condition of

Table 1. Roles and Responsibilities of the Five Fundamental QAOs [From Kraft and Molenaar (2013), Table 1, p. 30. Reproduced with Permission of the Transportation Research Board]

QAO	Design QA	Design QC	Construction QA	Construction QC	Project acceptance
Deterministic	Agency	Agency	Agency	Contractor/agency	Agency
Assurance	Agency	Designer	Agency	Contractor	Agency
Variable	Designer	Designer	Agency	Contractor	Agency
Oversight	Designer	Designer	Contractor	Contractor	Agency
Acceptance	PPP[a]	PPP	PPP	PPP	Agency

[a]PPP = public private partnership (could be a concessionaire, design builder, etc.).

J. Manage. Eng.

Table 2. Characteristics of Projects Participating in Selection Factor Interviews

Characteristic category	Percentage of projects with that characteristic (%)
Project delivery method	
Public private partnership	10
Construction manager general contractor	20
Design build	55
Design bid build	15
Project size	
<$100 million	33
$100–$500 million	44
$500–$1 billion	6
>$1 billion	17
Project duration	
<24 months	39
24–36 months	17
36–48 months	17
>48 months	28
Project QAO	
Deterministic	5
Assurance	47
Variable	0
Oversight	37
Acceptance	11

circumstances occurring after the request for proposal (RFP) or request for qualifications (RFQ) process, such as the experience of the contractor's project management staff, were excluded because this information is unknown at the time of QAO selection.

Selection Factor Appropriateness Ratings Methodology

The purpose of the second phase of the research was to understand how the previously identified selection factors influence the selection of the project QAO and to validate the selection factors identified in the project based interviews. It also served to validate the completeness of the selection factors. A Delphi study was conducted to establish the relationship between the 10 selection factors, and the five fundamental QAOs. The Delphi method was selected because it allows for the aggregation of expert judgments through the anonymity of expert panel members, iteration, controlled feedback, and consensus while minimizing the normal biases inherent with unstructured interactive groups. "Delphi is also preferred to subjective research methodologies such as traditional surveys or focus groups because of the exceptionally high quality of the participants, ability to minimize judgment-based bias, and ease of implementation in an increasingly global industry" (Hallowell and Gambatese 2010).

The Delphi method is a group research method without any face-to-face interaction between the expert panel members. Delphi is considered to be the more reliable technique to obtain expert consensus on a topic (Rowe and Wright 1999). There are four key features necessary for defining a Delphi study procedure: anonymity, iteration, controlled feedback, and the statistical aggregation of group response (Rowe and Wright 1999).

Anonymity is accomplished by the fact that the panel members never met face to face, or even knew who was included in the panel. The Delphi process consisted of an iterative process that included three rounds of questionnaires completed independently by each of the panel members. Each subsequent questionnaire included feedback from the previous responses and additional questions building on the results of the previous questionnaire. This continued until each rating reached a consensus. Hallowell and Gambatese (2010) defines consensus for a Delphi study as the absolute deviation within one unit on a 10-point scale. Because this research uses a four-point scale, consensus was defined as the absolute deviation within one half a unit of the four-point scale, which is equivalent to 1/8 standard deviation. Three rounds were required to reach consensus. This is in agreement with Hallowell and Gambatese (2010) suggestion that a Delphi study needs at least three rounds to ensure understanding of any possible outliers.

During the three Delphi rounds, a panel of 12 experts rated the appropriateness of each QAO. A data collection matrix was created for each selection factor that compared the selection factor categories with each of the QAOs. Because this aspect of the research requires a holistic view of highway project quality in order to bridge the gap between selection factors and fundamental QAOs, experts needed to have a broad knowledge of overall highway quality. As a result experts were defined as meeting at least three of the five following criteria: (1) worked a minimum of 15 years in the industry; (2) sat on at least one panel or committee regarding quality; (3) held at least two different quality positions in highway agencies; (4) published on the topic of highway quality; or (5) written agency quality procedures, policies, or manuals. The resulting pool of experts was from SHAs, the Federal Highway Administration, and private companies within the industry.

Each round of the Delphi study included a quick guide to the fundamental QAOs, the objective of the Delphi study, quality, factor and QAO definitions, and the appropriateness scale to ensure consistency in understanding of the concepts being evaluated. Also included was the feedback from the previous Delphi round. Based on the number of categories for each of the 10 selection factors and five fundamental QAOs, a total of 180 judgments were needed. Because it was unrealistic to ask the experts to complete all 180 judgments for each Delphi round, each round the experts were asked to make judgments for a randomly selected portion of the 180 judgments. The first round asked each expert to rate one randomly selected QAO for each project factor category, a total of 36 judgments. After the first round, 48 ratings had reached consensus, and 55 had been narrowed down to two ratings. The second round asked the experts to select between two ratings for 55 judgments and use the four-point rating scale for 19 judgments randomly selected from the ratings that had not reached consensus or been narrowed down to two options. The third round required the experts to complete the final 35 ratings that had not yet reached consensus.

The appropriateness scale used for all rounds of the Delphi study is: fatal flaw (denoted with X), less than appropriate (−), appropriate (+), and very appropriate (++). The fatal flaw rating (X) indicates that for that particular category of selection factor, the implementation of the associated QAO has potential to harm the success of the project, effectively eliminating that QAO from further consideration. A less than appropriate rating (−) indicates that for the particular category of selection factor, the corresponding QAO is feasible, but not the best option. If this QAO is implemented, there may be extra measures needed to accommodate this particular selection factor. An appropriate rating (+) indicates that the QAO is feasible for that particular selection factor category, meaning it neither harms nor improves the success of the project. Finally, the very appropriate rating (++) indicates that a project falling into that particular category can be improved by the implementation of the associated QAO.

Analysis and Discussion

The structured interviews resulted in a list of 10 factors that influence the selection of a project QAO, as listed in Table 3.

Table 3. Factor Categories and Factors that Influence the Selection of a Project QAO

Selection factor group	Selection factor
Project	Project size
	Project complexity
	Schedule sensitivity
	Project delivery method
Agency	Culture
	Staff availability
	Staff experience
	Amount of quality risk shift away from agency
Industry	Ability to manage their own quality
	Trust between industry and agency

The Delphi study further validated the 10 selection factors because the experts did not add or delete any of the selection factors. The 10 factors are organized into three groups for ease of discussion: project, agency, and industry as shown in Table 3. It should be noted that selection factors pertaining to specific contractor qualifications or personnel qualifications were considered, but needed to be excluded because this information is not available until after the QAO is selected.

After three rounds of the Delphi study, 93% of the ratings, 168 out of the 180 relationship judgments, had reached consensus; the remaining 7% either had an outlier or were split between two ratings that included appropriate and a rating on either side of appropriate. The selection factors that did not reach consensus and should not be a sole determining factor when selecting a QAO are noted in the summary tables for each selection factor in the following sections.

The following three sections present each of the selection factor groups, and define each of the factors and the relationship between the fundamental QAOs and the factors. Additionally, each factor has a table summarizing the final appropriateness ratings of each of the fundamental QAOs to the selection factor categories using the four-point appropriateness scale from the Delphi study.

Project Factors

Because each highway design and construction project is unique, it was anticipated that there would be project factors that influence the selection of a QAO; however, it was not known which project factors would be influential. The research identified four: project size, project complexity, project schedule sensitivity, and project delivery method.

Project size is determined by the budget of the project including both design and construction and is divided into five different categories. Table 4 presents the appropriateness ratings of the fundamental QAOs for each project size factor category. As project size increases, the need for agency resources increases, risks increase, and the project generally requires the agency to shift some of the quality responsibility to other project participants in order to minimize project delay resulting from quality activity coordination between contractor and agency. The appropriateness ratings reflect these needs. As the project size increases, the appropriate QAO shifts from deterministic toward acceptance, shifting the amount of quality responsibility away from the SHA to another project participant.

The two project size selection factor categories that received a fatal flaw rating were projects larger than $500 million and $2 billion. These fatal flaw ratings were received by the deterministic QAO and eliminate it as a QAO candidate for projects larger than

Table 4. Project Size Factor Appropriateness Ratings

Project size	Deterministic	Assurance	Variable	Oversight	Acceptance
< $10 million	++	++	+	+[a]	−
$10–$50 million	++	++	+	+	+
$50–$500 million	−	+	+	++	++[a]
$500 million–$2 billion	X	−	+	++[a]	++
> $2 billion	X	−	+	++[a]	++

[a]Should not be the determining factor and should be considered in conjunction with the other factors.

$500 million. Inherent to projects of this size are the needs for expertise that resides outside of the agency and for the agency to share the risk of the project. The deterministic QAO assigns all quality responsibility and risk to the agency, which conflicts with the needs of a project larger than $500 million; a large project requires a large amount of quality personnel that can react quickly to the needs of the project schedule and expertise specific to the project. Additionally, the deterministic QAO would require an immense number of agency personnel for a project larger than $500 million that typically do not exist within the agency. Acceptance received a very appropriate rating for projects larger than $500 million for two reasons: first, the acceptance QAO shifts the most risk away from the agency; second, it supplies the largest number of outside resources. Additionally, acceptance is primarily used for PPP projects that are frequently larger than $500 million because of their project financing structure. Oversight is also considered to be very appropriate, but it does not shift as much of the risk and it does provide for slightly more involvement of the agency in the quality of the project.

Projects under $10 million are considered to be typical projects for the SHA where it would not be worth creating the infrastructure to support a QAO that substantially diverges from the traditional deterministic QAO. As the QAO shifts from deterministic to acceptance, more agency and industry experience is required as is the amount of infrastructure needed to manage the QAO. However, QAOs that diverge farther away from deterministic can be implemented on projects less than $10 million if the agency has an ability to implement the alternative QAO through past experience and has the infrastructure in place to manage the alternative QAO.

Project complexity is related to how similar the project is to a typical SHA project. The definition of a typical project is based on the experience in the locality of the project. One region may consider a particular type of bridge design to be typical whereas the same design could be considered new and complex in another region that has never used the same type of bridge design. Complexity can result from characteristics including project scope, design requirements and constraints, construction methods, site conditions, budget and funding constraints, quality requirements, project delivery method, and specialty materials. Project complexity has three categories: low, medium, and high, and the corresponding appropriateness ratings are shown in Table 5.

Table 5. Project Complexity Factor Appropriateness Ratings

Project complexity	Deterministic	Assurance	Variable	Oversight	Acceptance
Low	++	+	+	+	+
Medium	+	+	+	+[a]	+
High	−	+	++	++	++

[a]Should not be the determining factor and should be considered in conjunction with the other factors.

Table 6. Schedule Sensitivity Factor Appropriateness Ratings

Schedule sensitivity	Deterministic	Assurance	Variable	Oversight	Acceptance
Low	+	+	+	+	+
Medium	−	+	+	+	+
High	−	+	+	++	++

Table 7. Project Delivery Method Factor Appropriateness Ratings

Project delivery method	Deterministic	Assurance	Variable	Oversight	Acceptance
Design-bid-build	++	+	+	+[a]	−
Design-build	−	−	+	++	−
CMGC/CMAR	−	+	+	++	+
PPP/DBOM	X	−	−	+	++

[a]Should not be the determining factor and should be considered in conjunction with the other factors.

Overall, the project complexity ratings were relatively consistent, and there was not a fatal flaw rating. All QAOs are appropriate for all project complexity factors, except for the deterministic for a high complexity project. High complexity projects require expertise outside of the agency and thus, require outside expertise to manage the quality. Low complexity projects are typical projects for the agency and do not require quality abilities external to the agency. As a result, the deterministic QAO is very appropriate, whereas all other QAOs are still appropriate. There was no difference in appropriateness ratings for medium complexity projects, all QAOs are appropriate.

Project schedule sensitivity refers to the vulnerability of the project schedule to changes because of delays, conflicts, and/or events outside of the designer and/or contractor's control. Examples of these are coordination of observations, inspections, and/or testing performed by the agency. In order to coordinate quality tasks, the availability of staff external to the contractor (agency or third party) and the lead time required to schedule these resources may not be in complete conjunction with the timing of the work, which results in a delay of schedule. Schedule becomes more sensitive when a project is being constructed around the clock and has less float. Project sensitivity has three categories: low, medium, and high. The corresponding appropriateness ratings are shown in Table 6.

Overall project schedule sensitivity had no fatal flaw ratings and little fluctuation in the overall appropriateness ratings. All QAOs are at least appropriate for all levels of schedule sensitivity, except for deterministic. Deterministic is less than appropriate for both medium and high schedule sensitivity projects because the contractor cannot control the schedule because of the reliance on the agency for all aspects of quality. Schedule sensitivity can be assuaged if there is a good quality plan and communication plan among all parties involved in the day-to-day quality of the project.

Project delivery methods is "the process by which a construction project is comprehensively designed and constructed for an owner including project scope definition, organization of designers, constructors and various consultants, sequencing of design and construction operations, execution of design and construction, and closeout and start-up" (Touran et al. 2011). Project delivery method has four categories: design-bid-build (DBB), DB, construction manager general contractor (CMGC), and PPP. The project delivery method appropriateness ratings are summarized in Table 7.

As the amount of project responsibility shifts away from the agency—DBB to PPP—the amount of project quality responsibility shifts away from the agency, from deterministic to acceptance, allowing both the project responsibilities and the quality responsibilities to remain in sync. There is great diversity in the ratings. The PPP category received the only fatal flaw rating, which corresponded to the deterministic QAO. Inherently the definitions of PPP, where the agency relinquishes the majority of project roles and responsibilities, and the deterministic QAO, where the agency retains all project quality roles and responsibilities, are not in alignment and, therefore, cannot be combined on the same project.

The very appropriate QAO for DBB is deterministic and the less than appropriate is acceptance; all other QAOs are appropriate. Because DBB is a linear and segregated approach to project delivery that typically uses a low bid procurement method, the agency is extensively involved in the day-to-day management and decisions on the project. This project delivery method is very well suited to the deterministic QAO, which relies on the agency being responsible for all quality roles. Conversely, the acceptance of QAO shifts the most quality responsibilities away from the agency, which is fundamentally in conflict with the DBB delivery method, as reflected by the appropriateness ratings.

The DB delivery method is very appropriate to the oversight QAO, appropriate for the variable QAO, and less than appropriate for the deterministic, assurance, and acceptance QAOs. Because DB shifts the majority of the day-to-day responsibility to the design-builder at an early stage of the project, it is very appropriate to have the corresponding quality responsibilities shift as well, which is analogous to the oversight QAO. In order for the design-builder to most effectively manage the quality of the work, the majority of the quality responsibilities need to be shifted to the design-builder as well. Thus, the oversight QAO is very appropriate. The acceptance QAO is considered less than appropriate because the agency still has involvement in the ongoing quality of the project. Deterministic and assurance QAOs do not shift the amount of quality responsibility equivalent to the design-builder's project responsibility, and as such, can potentially compromise the ability of the design-builder to successfully manage the project. However, the assurance QAO has been used on DB projects because of the discomfort some agencies have with transferring so much of the project and quality responsibility to one design-builder. This usually stems from an agency's inexperience in DB and/or alternative project QAO.

The CMGC delivery method involves the contractor during the design phase at varying degrees, which directly impacts the level of collaboration on the project as well as the amount of project responsibility shift. Because of the varying degrees at which CMGC can be applied, all but one of the QAOs is appropriate. The deterministic QAO is less than appropriate for CMGC because it is based on a noncollaborative environment for project delivery. That is, the agency retains all quality responsibilities.

Agency Factors

Holistically, SHA's differ from state to state because of elements such as political environment, leadership of the agency, types of projects, needs of the constituency, budget, state demographics, weather, local industry, and topography. Agency factors impacting project quality relate to the characteristics and abilities of SHAs to manage projects. The four agency factors are culture, staffing availability, staffing experience, and the amount of quality responsibility the agency wants to shift to another project participant.

The culture of the agency is defined in this research as the agency's attitude toward the implementation of change in project management techniques. The agency is the leadership for the

Table 8. Agency Culture Factor Appropriateness Ratings

Agency culture	Deterministic	Assurance	Variable	Oversight	Acceptance
Traditional	++	+	−	−	−
Moderate	+	+	+	+	+
Progressive	−	+	+	++	++

project. The agency culture ultimately dictates the culture of the project. The agency culture is not determined by a few of the project staff, but rather by the shared behaviors and norms of the leadership, management, and staff within the SHA. If the project team is progressive but the executive level of the agency is traditional, it will be difficult for a project team to implement any nontraditional ideas such as an alternative QAO.

The three categories of agency culture are: traditional, moderate, and progressive. A traditional culture is one that is averse to change and is comfortable continuing managing projects as they do today. A moderate culture is an agency that is willing to attempt change that has already been proven in another agency. A progressive culture is an agency that is willing to be the pioneer for change, essentially be the test case. The agency culture appropriateness ratings are presented in Table 8.

Agency culture is not a fatal flaw for any QAOs. Based on the appropriateness rating, the more alternative a project QAO (as compared with the traditional deterministic QAO), the greater the amount of change the agency must be willing to accept. A traditional culture is less than appropriate for variable, oversight, and acceptance because each of these requires change from the traditional way of managing quality on a project. A moderate culture still embraces the traditional and can brave change, as is reflected by the moderate culture receiving appropriate ratings for all QAOs. A progressive culture is very appropriate for oversight and acceptance QAOs because these QAOs require the most amount of change within the agency and have been implemented somewhat sparingly.

Agency staffing availability refers to the amount of agency staff that can be committed to a project as compared with the traditional levels of agency staffing for comparable projects. Because of SHA downsizing across the nation, personnel are expected to do more with less (Smith 1998). As a result, the number of agency resources available is decreasing directly and impacting the ability of an agency to manage a project, including quality. The availability of agency project staff factor consists of three categories: fully staffed, moderately staffed, and minimally staffed (as compared with traditional levels of project staffing within the SHA). Table 9 presents the appropriateness ratings for the availability of agency project staff factor.

The availability of agency staff appropriateness ratings reflect the level of staffing each QAO requires. Deterministic is best suited for fully staffed agency projects, whereas acceptance is more appropriate for minimally staffed projects. In other words, the optimal staffing for deterministic and acceptance QAOs are at the opposite end of the agency project staff availability spectrum. Implementing a QAO without the appropriate levels of SHA project staff can influence the success of the quality assurance of the project. Either quality tasks will go undone, because of a lack of staff, or staff will be underutilized, because of a lack of work.

If a full staff is available for the project, as compared with typical past projects, the deterministic is very appropriate because it requires a large staff to manage the day-to-day quality needs of the project: inspection, observation, materials testing, and so on. Acceptance QAO received a fatal flaw rating where a full staff is available. The acceptance QAO shifts the bulk of the quality responsibilities away from the agency, which results in these resources being underutilized. Assurance, variable, and oversight are all rated appropriate for a fully staffed project.

Moderately staffed projects are less than appropriate for deterministic and acceptance QAOs because of their extreme staffing needs, full and minimal respectively. A moderately staffed project, as compared with a typical project, is best suited to assurance, variable, and oversight QAOs. Selecting which of these three to implement in a moderately staffed project is dependent on the goals and other requirements of the project.

Acceptance and oversight are both rated very appropriate for a project that has minimal staff, while deterministic is a fatal flaw. A minimally staffed project doesn't allow for agency project staff to have the time to manage the day-to-day quality needs associated with the deterministic QAO, but does provide enough staff to manage the reduced agency quality responsibilities associated with oversight and acceptance. Assurance is rated less than appropriate for a minimally staffed project because the agency retains the majority of the quality responsibility for the project.

Agency staffing experience is the average number of years of experience of the agency staff committed to the project. Experience is considered to be project and field related. The four categories of agency staffing experience are: less than 5 years, 5 to 10 years, 10 to 20 years, and more than 20 years. Table 10 presents the appropriateness ratings for agency project staff experience.

Less than five years of experience is less than appropriate for the oversight and acceptance models because both of these organizations require the agency staff to be well-versed on quality for all elements of the project, which can only be achieved through time in the field. It is surprising that an average of less than five years experience for a project team is considered appropriate for any of the QAOs, much less the ones that assign the majority of project quality to the agency. Otherwise, all categories of project experience are at a minimum appropriate for all QAOs. However, 10 to 20 years of experience is very appropriate for all QAOs, which reflects a variety of experience levels within the project team.

The amount of quality risk shift away from the agency has to do with the agency having a project goal of shifting responsibility for quality to another project participant. The term *shift* refers to the amount of liability for the management of the project's quality that an agency wants to relinquish to another project partner (e.g., contractor, designer, engineer, design-builder, CMGC, or concessionaire). The categories and associated appropriateness ratings are summarized in Table 11.

The five categories for the amount of quality risk shift away from the agency closely align with the definitions of the fundamental QAOs. For example, deterministic keeps all control with the

Table 9. Availability of Agency Project Staff Factor Appropriateness Ratings

Availability of agency project staff	Deterministic	Assurance	Variable	Oversight	Acceptance
Fully staffed	++	+	+	+	X
Moderately staffed	−	+	+	+	−
Minimally staffed	X	−	+	++	++

Table 10. Agency Project Staff Experience Factor Appropriateness Ratings

Agency project staff experience	Deterministic	Assurance	Variable	Oversight	Acceptance
<5 years	+	+	+	–	–[a]
5–10 years	+	+	+	+	+
10–20 years	++[a]	++	++	++	++
>20 years	+	+	++	++	++

[a]Should not be the determining factor and should be considered in conjunction with the other factors.

agency and is equivalent to shifting none of the quality risk away from the agency. The appropriateness ratings all corroborate the definitions of the fundamental QAOs. Deterministic, assurance, and variable still have the agency managing aspects of the day-to-day quality needs of the project. As a result, each of them is a fatal flaw if the agency desires to shift all quality risk. Assurance and variable shift, at a minimum, some of the project quality risk away from the agency; therefore, if the agency has a goal to retain all quality responsibility, then assurance and variable are less than appropriate. Oversight and acceptance QAOs shift at a minimum the day-to-day management of quality away from the agency; therefore, for an agency that desires to shift none of the quality risk to other project team members, each of these QAOs is a fatal flaw.

Industry Factors

Industry factors are characteristics or abilities of the local design, engineering, contracting, and consulting communities. The two industry factors are the industry's ability to manage their own quality and the level of trust established between the industry and the agency.

The industry's ability to manage their own quality refers to the local communities' levels of competence in managing their own quality. If any level of responsibility for quality is shifted away from the agency, it is critical that the party receiving the responsibility has the competence to successfully assume it; competence to successfully meet the responsibility can be attained through education, training, experience, certification, industry culture, and/or a combination of these. The three categories of the industry's ability to manage their own quality are: low, medium, and high. Table 12 summarizes the associated appropriateness ratings.

The industry's ability to manage their own quality could be considered an indirect requirement of each of the QAOs. If the industry is not able to manage their own quality to a level that meets the needs of the QAO, then the success of the project is compromised from the very beginning. The appropriateness ratings indicate that as the amount of quality responsibility is relinquished from the agency, deterministic to acceptance, the industry's ability to manage their own quality increases, low to high.

The level of trust between the industry and agency is important because as agency control over a project is reduced, the collaborative needs of the project increase, due to the fact that additional entities are responsible for quality. Effective collaboration depends on an agency's level of confidence that project decisions made by industry partners will be based on achieving the best results for the project, rather than on the partners' interests; this is reflected in the level of trust the industry has been able to build with the agency. The three categories of trust are low, medium, and high. The corresponding appropriateness ratings are shown in Table 13.

Trust amongst all parties is positive for a project regardless of the QAO, which is why the QAO that requires little to no collaboration, deterministic, has at least an appropriate rating for all levels of trust. However, a low level of trust is a fatal flaw for acceptance and less than appropriate for oversight, reflecting

Table 11. Shift in Agency Quality Risk Factor Appropriateness Ratings

Amount of quality risk shift away from the agency	Deterministic	Assurance	Variable	Oversight	Acceptance
All	X	X	X	++	++
Some QA and some QC	–	–	++	++	+
Some QA	–[a]	–	+	++	+[a]
Some QC	+[a]	+	+	++	X
None	++	–	–	X	X

[a]Should not be the determining factor and should be considered in conjunction with the other factors.

Table 12. Industry Ability to Manage Their Own Quality Factor Appropriateness Ratings

Industry ability to manage their own quality	Deterministic	Assurance	Variable	Oversight	Acceptance
Low	++	+	+	–	X
Medium	+	+	+	+	+
High	–[a]	+	+	++	++

[a]Should not be the determining factor and should be considered in conjunction with the other factors.

Table 13. Trust between Agency and Industry Factor Appropriateness Ratings

Trust between agency and industry	Deterministic	Assurance	Variable	Oversight	Acceptance
Low	++	+	+	–	X
Moderate	+	+	+	+	+
High	+	++	++	++	++

the collaborative needs of each of these QAOs that, in turn, require trust. A moderate level of trust is appropriate for all QAOs. Whereas a high level of trust is very appropriate for all QAOs where at least some of the quality responsibilities have been shifted away from the agency, and is rated appropriate for deterministic, which shifts none of the quality responsibility.

Summary and Conclusions

This research identified 10 factors that influence the selection of a project QAO and the appropriateness of the fundamental QAOs to each selection factor. There is no literature regarding any factors as they relate to project quality management selection, but Gransberg et al. (2008) commented that project quality management and project delivery methods have become interrelated. This research corroborates the previous statement based on the fact that the project delivery method is a project QAO selection factor. The importance of the project delivery method in project QAO selection is verified by the fact that the project delivery method factor has the most diversity in appropriateness ratings across the QAOs. Selection factors with less diversity in appropriateness ratings across the different QAOs do not differentiate between the QAOs, and have less impact on the QAO selection. Conversely, the appropriateness rating diversity of the project delivery method factor indicates that it heavily impacts the QAO selection.

Six out of the 10 selection factors included fatal flaw ratings and higher levels of diversity in their ratings, meaning that they have more influence over the final QAO selection. These selection factors are: project delivery method, project size, availability of agency project staff, quality risk shift away from the agency, industry ability to manage their own quality, and trust between agency and industry. It is interesting that both of the industry factors are included in this list, indicating the importance of industry participation and buy-in for alternative QAOs. The remaining four factors without fatal flaws are very well defined and specific to the project itself, essentially defining the uniqueness of the project. It logically follows that the factors defining the uniqueness of the project also have influence in the selection of the project QAO. One might question if the four factors with little diversity in their overall appropriateness ratings should be considered in the selection of a project QAO. This question was presented to the Delphi panel when presenting them with the final results. They confirmed that these factors still needed to be considered during the selection of a QAO.

This research does not evaluate or weight the level of influence of any of the selection factors. It is speculated that a weighting of the factors would vary based on the individual SHA and project. However, it would be useful to have future research conducted to determine if this is true or if the weightings could be consistently weighted. While this research evaluates the appropriateness of fundamental QAOs to each selection factor, it does not evaluate the level of quality resulting from the selection or provide guidance as to how to incorporate the selection factors into a consistent and transparent process for the selection of a QAO.

During the interviews, it was further reinforced by the SHA that this is a topic of interest and that guidance is needed as to how to assign project quality roles and responsibilities. The results of this research provide SHAs with some much-needed guidance regarding QAO selection. The SHA can now select a QAO based on the factors that impact the decision and an understanding of the factor relationships with each of the fundamental QAOs. Also, a better understanding of the personality of each of the fundamental QAOs is gained, allowing the SHA to proactively accommodate for the nuances of the selected QAO.

Appendix. Glossary

Acceptance: "The process of deciding, through inspection, whether to accept or reject a product, including what pay factor to apply" (Transportation Research Board 2009).

Independent assurance: "A management tool that requires a third party, not directly responsible for process control or acceptance, to provide an independent assessment of the product or the reliability of test results, or both, obtained from process control and acceptance. The results of independent assurance tests are not to be used as a basis of product acceptance" (Transportation Research Board 2009).

Quality assurance (QA): "All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service" (Transportation Research Board 2009).

Quality control (QC): "Also called process control. Those QA actions and considerations necessary to assess and adjust production and construction processes so as to control the level of quality being produced in the end product" (Transportation Research Board 2009).

References

Burati, J. L., Jr. (1992). "Causes of quality deviations in design and construction." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(1992)118:1(34), 34–49.

Burati, J. L., Jr., Matthews, M. F., and Kalidindi, S. N. (1992). "Quality management organizations and techniques." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(1992)118:1(112), 112–128.

Chini, A. R., and Valdez, H. E. (2003). "ISO 9000 and the U.S. construction industry." *J. Manage. Eng.*, 10.1061/(ASCE)0742-597X(2003)19:2(69), 69–77.

Claxton, J. D., Ritchie, J. R. B., and Zaichkowsky, J. (1980). "The nominal group technique: Its potential for consumer research." *J. Consum. Res.*, 7(3), 308–313.

Deffenbaugh, R. L. (1993). "Total quality management at construction jobsites." *J. Manage. Eng.*, 10.1061/(ASCE)9742-597X(1993)9:4(382), 382–389.

Dikmen, I., Talat Birgonul, M., Kiziltas, S. (2005). "Strategic use of quality function deployment (QFD) in the construction industry." *Build. Environ.*, 40(2), 245–255.

Elliot, R. P. (1991). "Quality assurance: Top management's tool for construction quality." *Transportation Research Record 1310, Construction Innovations 1991*, Transportation Research Board, Washington, DC, 17–19.

Erickson, J. (1989). "Meeting the quality management issue on highway construction." *J. Prof. Issues Eng.*, 10.1061/(ASCE)1052-3928(1989)115:2(162), 162–167.

Gransberg, D. D., Datin, J., and Molenaar, K. (2008). "Quality assurance in design-build projects." Transportation Research Board, Washington, DC.

Gransberg, D. D., and Shane, J. S. (2010). "NCHRP synthesis highway practice 402: Construction manager-at-risk project delivery for highway programs." Transportation Research Board, Washington, DC.

Hallowell, M. R., and Gambatese, J. A. (2010). "Qualitative research: Application of the delphi method to CEM research." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)CO.1943-7862.0000137, 99–107.

Hughes, C. S. (2005). "NCHRP synthesis of highway practice 346: State construction quality assurance programs." Transportation Research Board, Washington, DC.

Kasi, M. (1995). "TQM on a transportation project." *J. Manage. Eng.*, 10.1061/(ASCE)0742-597X(1995)11:3(21), 21–23.

Kraft, E. (2013). "Alternative quality assurance organizations for highway design and construction projects." Doctoral thesis, Univ. of Colorado, Boulder, CO.

Kraft, E., and Molenaar, K. (2013). "Project quality assurance organization selection for highway design and construction projects." *Transportation*

Research Board 93rd Annual Meeting, Transportation Research Board, Washington, DC, 29–36.
Minchin, R. E., Hammons, M. I., and Ahn, J. (2008). "A construction quality index for highway construction." *Constr. Manage. Econ.*, 26(12), 1313–1324.
Miron, A., Rogers, R. B., and Kopac, P. A. (2008). "Applying AQS in the highway industry." *Public Roads*, 72(2), 20–27.
Oswald, T. H., and Burati, J. L., Jr. (1992). "Can total quality management work in the public construction arena?" *Transportation Research Record, 1340*, Transportation Research Board, Washington, DC, 40–47.
Rowe, G., and Wright, G. (1999). "The delphi technique as a forecasting tool: Issues and analysis." *Int. J. Forecast.*, 15(4), 353–375.
Schmitt, R. L., Hanna, A. S., Russell, J. S., and Nordheim, E. V. (2000). "Contractor quality control testing levels for highway construction." *Construction Congress VI: Building Together for a Better Tomorrow in an Increasingly Complex World*, ASCE, Orlando, FL, 353–362.
Smith, G. R. (1998). *State DOT management techniques for materials and construction acceptance*, National Academy Press, Washington, DC.
Touran, A., Gransberg, D. D., Molenaar, K. R., and Ghavamifar, K. (2011). "Selection of project delivery method in transit: Drivers and objectives." *J. Manage. Eng.*, 10.1061/(ASCE)ME.1943-5479.0000027, 21–27.
Transportation Research Board. (2009). "Glossary of highway quality assurance terms." *Transportation Research Circular E-C137*, Washington, DC.