Spring 1-1-2013

Alternative Quality Assurance Organizations for Highway Design and Construction Projects

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ALTERNATIVE QUALITY ASSURANCE ORGANIZATIONS FOR HIGHWAY DESIGN AND CONSTRUCTION PROJECTS

By

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A thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirement for the degree of

Doctor of Philosophy

Civil, Architectural, and Environmental Engineering

2012

This thesis entitled:

Alternative Quality Assurance Organizations for Highway Design and Construction Projects

written by Elizabeth Rosanne Kraft

has been approved for the Civil, Architectural, and Environmental Engineering Department

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IRB protocol # ___11-0232_____

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Alternative Quality Assurance Organizations for Highway Design and Construction Projects

Thesis directed by Professor Keith R. Molenaar

Abstract

Historically, highway project quality has consisted of quality assurance (QA) and quality control (QC) for design and construction as well as project quality assurance (PQA), independent assurance (IA), and acceptance. A project quality assurance organization (QAO) consists of these roles and their relationships; analogous to a company organizational chart which assigns the roles and responsibilities within the company and identifies the relationships between these roles and responsibilities. Traditionally all quality roles have been the responsibility of the agency making a formalized identification of the QAO unnecessary. However, the highway industry has been experiencing growth in the implementation of alternative project delivery methods and, at the same time, a reduction in state highway agency (SHA) staffing levels; causing a shift of quality roles from the agency to either the designer, contractor, design builder, concessionaire or construction manager. There is little research pertaining to highway project QAOs; rather, the research has focused on organizational quality management, inspection, observation, specifications, pay factors and warranties. Additionally there is little research within the area of alternative project delivery speaking to the specifics of the assignment of project quality roles. As a result of time constraints and a lack of guidance and research the SHA has had to take an ad hoc approach to the assignment of quality roles. The goal of this research is to bridge the research gap and provide guidance to the SHA in the assignment of the project quality roles and responsibilities by linking the factors influencing the assignment of project

quality roles to established QAOs. Outcomes of the research are five fundamental QAOs: Deterministic, Assurance, Variable, Oversight and Acceptance, the identification of ten different factors influencing the selection of a project QAO and the determination of the appropriateness of the QAOs for each selection factor. Another outcome of the research is the development of a project QAO decision support tool for the industry.

Proposal format

The proposal supports a three paper dissertation format. The first section presents the observed problem, the point of departure and the research question. In order to answer the overarching research question, the research has been broken down into two distinct phases. The first phase of the research identifies the fundamental project QAOs within the industry through literature review, industry survey, content analysis and case studies. The second phase focuses on the project factors influential in the selection of a project QAO through nominal group techniques and the Delphi methods. Section two of this proposal presents the first phase of the research through the first of the three papers which includes a discussion of the problem, the methodology, results and conclusions. The second phase of the research has yet to be completed. Section three focuses on the second phase of the research through a detailed research plan including the research goals, approach and methodology. The appendices present the research protocols for this second phase of the research are included in the appendices

Dedication

To my parents, Dr. Donald and Linda Kraft. Without their love, support, encouragement and nagging this dissertation never would have been completed.

Acknowledgements

Thanks to my advising professor, Dr. Keith Molenaar. Because of your wisdom, patience, guidance and humor we both were able to see the completion of this dissertation. You were able to extract the best work out of me by not only understanding my strengths and weaknesses but working within those confines. Also, you are more than just an advising professor; you are a valued mentor. Your mentoring not only was critical to the completion of this dissertation, but also in ensuring that I had the right credentials, outside the PhD, for my future career.

Thanks to my committee: Dr. Jim Diekmann, Dr. Doug Gransberg, Dr. Matthew Hallowell and Dr. Paul Goodrum. Each of you brought unique insight, wisdom and perspective to not only my dissertation but to my PhD experience. What I learned from each of you through not only made me a better researched, but also made my research the best it could.

Thanks to my cousin Stephanie Kiley, who became my copy editor for much of this document. I'm not sure she really knew what she was getting into when she agreed to help out with the copy editing, but I am very thankful that after she did know what she signed up for she didn't run the other way. This dissertation greatly benefited from her knowledge, guidance, patience and expertise.

This experience has been a long journey. I would like to thank my parents who have had to endure the ups and downs of this entire process. Their encouragement and impromptu therapy sessions were exactly what was required to keep me moving toward the final end goal. They also spent endless hours proof reading various elements of this document. They have been my rock throughout the entire process and life.

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1.0 Observed problem and point of departure

The purpose of this section is to explain the observed problem and the point of departure for the research. First is a discussion and definition of terms for highway quality management. The next section provides further detail as to the history of quality within the highway industry. The third section focuses on recent changes within the highway industry. The section closes with a discussion of past research in highway quality and the point of departure for this research.

1.1.1 Highway quality management

The purpose of a highway quality management system can be concisely defined by four questions:

1. What do we want?
2. How do we order it?
3. Did we get what we ordered?
4. What do we do if we don't get what we ordered? (NCHRP 1979)

Within the NCHRP synthesis 65 (NCHRP 1979), the questions are also answered based on the conditions and knowledge at that time. The planning and design stage establishes what is wanted. The plans and specifications are how the product is ordered. Inspection, testing and acceptance ensure that the product the agency receives is what was ordered. Several different methods are used to resolve products that aren't what was ordered, such as pay factors, replacement of product, and acceptance of materials that are good enough.

Highway quality management has evolved since the publication of this synthesis. Today the answers to those questions have become part of industry vernacular. However, the vocabulary of this vernacular tends to get confused because the terms are frequently intermingled. A highway quality system consists of quality assurance, quality control,

acceptance, independent assurance and project quality assurance. Within the system is a project quality assurance organization (QAO) that defines which project stakeholder, agency, contractor, consultant, or designer, is responsible for the different roles and responsibilities within the project quality system. In order to clarify each of the elements within the quality system the following definitions are provided.

- Acceptance – The process of deciding, through inspection, whether to accept or reject a product, including what pay factor to apply (TRB 2009).
- Independent assurance (IA) – 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 (TRB 2009).
- Project quality assurance – All those actions necessary for the owner to ensure that the non-agency performed QA activities give a true representation of the quality of the completed project (Gransberg et al. 2008).
- Quality assurance (QA) - All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service (TRB 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" (TRB 2009).

- Quality management – The totality of the system used to manage the ultimate quality of the design as well as the construction encompassing the quality functions described previously as QA, QC, IA and verification (Gransberg et al. 2008).
- Quality assurance organization (QAO) – The assignment of the roles and responsibilities associated with the quality management of a project from concept through completion. (Note: QAO is a new term defined in this research.)
- Verification – The process of confirming the soundness or effectiveness of a product (such as a model, a program, or specifications) thereby indicating official sanction. [The validation of a product often includes the verification of test results] (TRB 2009).

1.1.2 **History**

Quality assurance (QA) was introduced to the highway industry through statistical process methods, alternative specifications and introduction of independent assurance (IA) as a result of the American Association of State Highway Officials (AASHO) road test in the late 1950's (NCHRP 1979; Gransberg et al. 2008; Hughes et al. 2005). The AASHO road test is considered by some to be the greatest controlled civil engineering experiment ever undertaken. (Hudson et al. July 2007). The AASHO road test was conducted in Ottawa Illinois between 1958 and 1961, and was focused primarily on pavement design. The objective of the test was to determine relationships between pavement performance and design variables. Prior to this test there was limited knowledge of pavement design and the bulk of specifications were materials and methods specifications. The analysis of the test results showed higher than expected variability in materials and construction properties (Smith and Skok July 2007).

"Early road building was a 'cut and try' operation, with success depending greatly on the skill and ingenuity of the engineer. Successes generally led to specifications aimed at duplicating them in other projects" (NCHRP 1979). These specifications are called method specifications. The method specifications dictate to the contractor the materials, equipment, and procedures used for construction under normal conditions. Deviations were expected, but whether or not they were a cause for rejection was a matter of engineering judgment (NCHRP 1979). Ultimately the supervising agency is obligated to closely monitor every aspect of the contractor's field operation; resulting in the owner being responsible for the outcome (Smith et al. 1998). After the AASHO road test state agencies and FHWA revised their specifications to include the terms "doctrine of reasonably close conformity" or "substantial compliance" to acknowledge that normal conditions do not always exist and this was the method chosen to respond to deviations (NCHRP 1979). The final decision as to whether a product is in substantial compliance is based on the judgment of the agency engineer; however, this decision process is not only hard to define but also hard to defend (NCHRP 1979).

There were two developments in the area of alternative specifications in the 1960s: end result specifications and performance specifications. Each of these built upon the increasing knowledge of the science and engineering involved in building roads. End result specifications are defined as "specifications that require the contractor to take the entire responsibility for supplying a product or an item of construction. The highway agency's responsibility is to either accept or reject the final product or to apply a pay adjustment commensurate with the degree of compliance with the specifications" (TRB 2009). End result specifications are statistically based and provide the limits within which the final product must fall. They essentially try to limit the role of engineering judgment involved in acceptance (NCHRP 1979). End result specifications

also started the shift to having the contractor test the final product, or rather be responsible for construction QC. Performance specifications "define how the finished product should perform over time" (TRB 2009), and are not used as widely as method or end result specifications.

As a result of the AASHO road test many agencies began measuring the variability of typical material and construction processes. This eventually led to statistical specifications, frequently incorporated into end result specifications. One of the advantages of the introduction of statistical quality measures is that the engineering judgment and the amount of variability allowed become documented in the specifications. "When this is properly done, engineering judgment becomes a known and constant factor" (NCHRP 1979).

Last, Independent Assurance (IA) sampling and testing on FHWA funded projects became required after the AASHO road test. "Depending on the definition used, the purpose of IA is to provide an independent assessment of either (1) the testing process or (2) of the product and/or the reliability of test results" (Hughes et al. 2005). The emphasis is on independent assessment.

1.1.3 **The shifting highway industry**

The Federal Highway Administration (FHWA) implemented Special Experimental Project No. 14 (SEP 14) in 1990. Special Experimental Project No. 14 allowed for the use of innovative contracting methods, including alternative project delivery, for highway projects by state agencies with the approval of FHWA (FHWA 4/4/2011). Additionally, in 1995, Title 23 of the Code of Federal Regulation 637 subpart B – Quality Assurance Procedures (23 CFR 637B) was adopted into the Federal-Aid Policy guide. This allows contractor test results to be used in acceptance programs performed by the agency, requires a QA program to be documented by each agency, and provides requirements for the certification of testing laboratories and

technicians (FHWA 1995). These events and regulations ultimately allowed for increased acceptance of alternative project delivery and the associated shift of quality responsibilities.

Over the past decade, there has been increased acceptance of alternative project delivery methods within the highway industry. In fact, in 2002, 23 CFR 636 was approved, providing that standard contracting regulations be in place for design-build (FHWA 5/23/2011). In addition, the FWHA Every Day Counts (EDC), and the American Recovery and Reinvestment Act (ARRA) programs have goals or requirements associated with delivering projects faster and using alternative delivery methods (FHWA 4/27/2011; FHWA 12/16/2011). While the federal government has legalized alternative project delivery through either SEP 14 and 23 CFR 636, states still play a large role through laws and regulations regarding alternative project delivery. Ghavamifar et al (Ghavamifar and Touran 2008) found that design-build is legal in 37 states, CM at risk is legal in 19 states and public-private-partnership is legal in 24 states. This shows that over half of the states have at least one alternative project delivery method legally available to them. A trend was also found which allows states more flexibility in choosing a contractor (Ghavamifar and Touran 2008).

Last, there has been a trend in the reduction of state highway agencies (SHA) staffing levels, which has resulted in a need to utilize alternative delivery techniques. In the 1990s, many SHA's experienced downsizing, which not only reduced the number of people able to manage increasing workloads but also impacted the expertise level within the SHA (Smith et al. 1998). No department within the SHA, including design, testing and inspection, was exempt from the downsizing. As a result, the QC testing and inspection that had previously been the responsibility of the agency started to shift to the contractor and the agency took on a role of acceptance. "Personnel losses have been a major factor in the changes influencing the materials

and construction acceptance process (Smith et al. 1998). In response, 23 CFR 637B was revised in 1995 to allow contractor QC test results to be used by the agency for acceptance.

While the FWHA issued a final rule effective in 2003 allowing recipients in the federal-highway aid program to use the design-build contracting method as they would use the design-bid-build method, the industry as a whole is taking a bit more time to gain confidence with alternative delivery methods. One reason for this is the lack of understanding as to the ramifications that alternative delivery methods have on the quality and quality management of the project. "There are two key issues that are of great concern to all public transportation agencies: project quality management and project delivery method. With the growth of alternative project delivery methods in the past few decades, the issues have become interrelated" (Gransberg et al. 2010).

Previously it was understood that all quality activities and roles were the responsibility of the agency except for construction QC. In design-bid-build, the contractor is handed completed drawings and submits a bid per the design and bid documents. In alternative project delivery, the contractor can be contracted to participate in or be responsible for the design of the project, creating a need to develop new and innovative strategies used by agencies to assure quality construction (Smith et al. 1998). QA/QC programs effectiveness requires clear allocation of roles and responsibilities to the involved parties. While the activities and roles required for highway quality remain the same, the project participants responsible for the activities and roles are changing as a result of all of the above events (Gransberg et al. 2008). Smith states that "the changing environment has created a need to highlight new and innovative strategies used by agencies to assure quality construction …. However, an overall view from the management perspective of the quality assurance process or construction quality management has not been

published" (Smith et al. 1998). "There are two key issues that are of great concern to all public transportation agencies: project quality management and project delivery method. With the growth of alternative project delivery methods in the past few decades, the issues have become interrelated" (Gransberg et al. 2010).

1.1.4 **Highway quality research**

Exiting research on highway project quality focuses primarily on construction; however, "quality is most influenced in procurement and at the beginning of design but rapidly falls off during the later stages of design, construction and maintenance" (Gransberg et al. 2008). In alternative delivery methods the contractor is frequently included or responsible for the design of the project, which shifts the design liability to the contractor, requiring a shift in the traditional project QAO from the agency to the contractor. Ultimately the design determines the quality of the final product, and as a result design QA and QC cannot be excluded from project quality management (NCHRP 1979; Gransberg et al. 2008).

The bulk of the research regarding highway quality is focused on construction QC, such as inspections, materials, testing, observation, assurance, and specifications (Hughes et al. 2005; Smith et al. 1998; Minchin et al. 2008; Miron et al. 2008; Erickson 1989). Additionally, in the early 1990s there was a research focus within all of construction on the implementation of the quality revolution taking place within the manufacturing industry, including such topics as TQM, ISO 9000, and the Baldridge award (Chini and Valdez 2003; Dikmen et al. 2005; Kasi 1995; Elliot 1991; Schmitt et al. 2000). However, this research was focused on improving the quality of independent organizations, not on improving the project QAOs (Kasi 1995; Burati Jr. 1992; Burati Jr. et al. 1992; Oswald and Burati Jr. 1992; Deffenbaugh 1993). Included within Gransberg et al (Gransberg et al. 2008) is the identification of highway quality project

management roles and tasks as well as the associated relationships. Additionally, Gransberg et al. (Gransberg et al. 2010) briefly comment on the assignment of quality management roles within a CM at risk project.

1.1.5 Point of departure

Because of the lack of adequate guidance or research on the topic of QAOs, agencies have been left to assign project quality tasks and roles in an ad hoc manner. The goal of this research is to expand the knowledge base and to provide additional guidance to SHAs in the assignment of project quality management activities and responsibilities with a focus on alternative quality management systems. Ultimately the goal of the research is to provide a knowledge base which leads to a consistent assignment of quality management roles and responsibilities in all project delivery methods.

1.2 Research questions and conceptual overview

The primary research question explored to achieve the overarching research goals is:

How do project factors impact the selection of project QAOs for highway design and construction projects?

In order to answer the primary research question, two tasks were undertaken: the identification of fundamental project QAOs and the influence of project factors on the selection of the project QAO. These two tasks equate to the two phases of the research. The first phase of the research identifies the fundamental project QAOs that are currently employed within the highway design and construction industry by answering the following research question:

What are the fundamental characteristics of project QAOs within the highway design and construction industry?

In order to answer this question, the project QAOs used in the industry were identified through a literature review, industry survey, case studies and content analysis. Once the list of industry project QAOs was identified, it was further refined to include those fundamental QAOs for the highway design and construction industry which are relevant to the agency's roles and responsibilities. The methodology for phase I of the research is depicted in Figure 1.

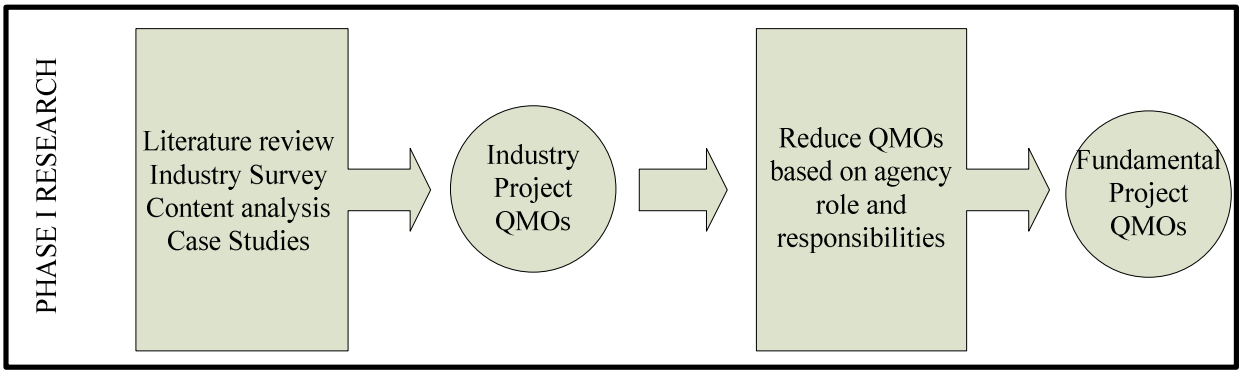

Figure 1 – Phase I research methodology

The second phase of the research determined the project factors that are influential in the selection of a project QAO. This was a two-pronged research effort; the first identified the influential project factors and the second determined their level of influence. As a result two research questions guided this phase of the research and they are the following:

1. *What are the project factors that influence the selection of the fundamental project QAOs?*
2. *To what level do the project factors influence the selection of a project QAO?*

Each question required a separate research approach. The first identified the influential project factors through exploratory research. The second validates the previously identified project factors and the calibration of their influence on the selection of the project QAO. The research used interviews with state highway agency project staff experienced in quality management across the nation for the exploratory element and the Delphi method for the calibration and validation phases as shown in Figure 2.

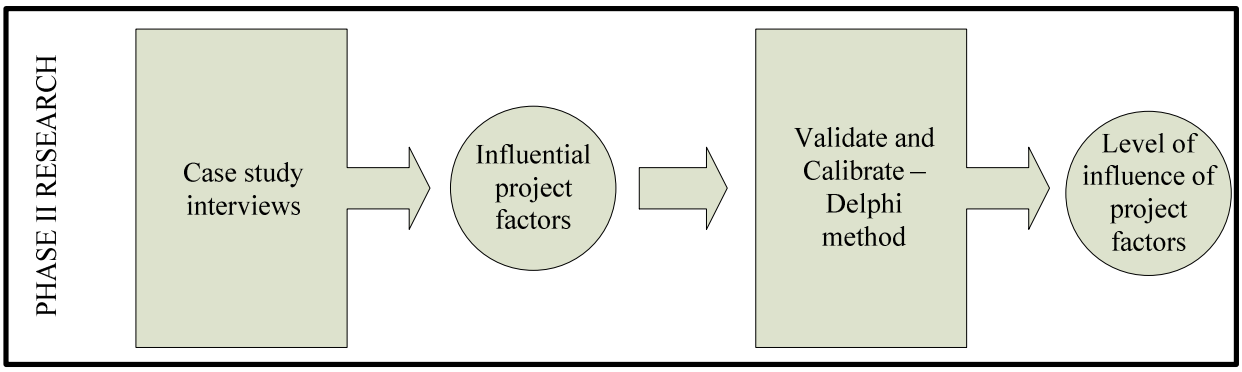

Figure 2 – Phase II research methodology

The remaining sections of this proposal will expand on the tasks, contributions and methodologies associated with each of the above research questions.

1.3 Claimed contributions of the research

Previous research conducted on highway design and construction project quality has been focused on a more micro level of highway construction quality such as technology, materials, observations, inspections, and specifications (Chini and Valdez 2003; Dikmen et al. 2005; Kasi 1995; Elliot 1991; Schmitt et al. 2000). There has also been some broader research conducted on the impact of alternative project delivery on highway project quality (Gransberg et al. 2008; Gransberg et al. 2010; Gransberg and Molenaar 2004). The present research will contribute to the highway quality management knowledge base by building upon the quality assurance and alternative delivery methods work in the following ways:

- Identifying the fundamental project QAOs for the highway industry, thus providing a better understanding of the roles and responsibilities of team members in various project delivery systems;
- Describing the barriers, benefits and implications of implementing an alternative QAO; and
- Defining and quantifying the project factors that influence the selection of a project QAO.

1.4 Predicted impact of the research

The highway industry is currently experiencing some dramatic changes as a result of increasing implementation of alternative project delivery and reductions in SHA staffing levels. Both of these changes have a direct impact on the management of quality. This research is predicted to impact the highway industry in the following ways. It should:

- Provide all project participants with a better understanding of the different possible QAOs;
- Define a structure for selecting QAOs that will allow for benchmarking and continuous improvement in highway design and construction;
- Reduce the risks associated with implementing an alternative QAO by providing guidance as to how to select an appropriate project QAO as well as implications associated with the selection of an alternative QAO; and
- Ultimately contribute to the improvement of quality within the highway design and construction industry.

2.0 Fundamental Quality Assurance Organizations

This section presents the first phase of the research, the identification of the fundamental project QAOs for the highway industry. A brief overview of highway project QAOs is presented in the first section. This is followed by a statement of the research goals, the claimed contributions and the predicted impact of the research. Finally, the first paper, *Fundamental Project Quality Assurance Organizations in Highway Design and Construction,* is presented. This paper includes details regarding the research methodology, the fundamental project QAOs and future research. Also, this paper has been accepted by the American Society of Civil Engineer for publication in the Journal of Management in Engineering.

2.1 Overview

The first phase of this research identifies the fundamental QAOs that are employed within the highway design and construction industry. A highway quality system consists of quality assurance, quality control, acceptance, and independent assurance. Within the system is a project QAO that defines which project stakeholder, agency, contractor, consultant, or designer, is responsible for the different roles and responsibilities within the project quality system. Traditionally there has been only one QAO within the industry, but as delivery methods have changed, reductions in agency staff have been realized, and agencies have completed projects faster, alternative QAOs have emerged. The primary difference among the fundamental QAOs is the agency's role within the QAO. A combination of an industry survey, a literature review, and a content analysis, is used to identify the fundamental QAOs used throughout the industry. The first of three papers comprising this dissertation is presented in this section. It provides further details on the background, methodology, results, and conclusions concerning the fundamental QAO definition.

2.2 Research goal

The goal for this phase of the research was to identify the fundamental project QAOs within the highway design and construction industry. The QAOs have not previously been defined in the literature. An understanding of the fundamental QAOs will provide a basic understanding of alternative quality systems and provide a foundation for the next phases of this research, which will help highway agencies choose appropriate QAOs in a structured and repeatable format.

2.3 Research approach and methods

Through a literature review, a national industry survey, and a content analysis, 14 project QAOs were identified within the highway industry. The fundamental project QAOs were identified based on the agency's roles and responsibilities within each QAO. The research approach and methods utilized in this phase of the research are further detailed in the paper titled *Fundamental Project Quality Assurance Organizations in Highway Design and Construction.*

2.4 Claimed contributions of the research

While there is research regarding the different tasks and responsibilities that make up project quality management, no research provides a definition of the fundamental project QAOs. This research builds on the existing research in quality management to define fundamental project QAOs. The identification of the fundamental project QAO's provides the foundation for future research regarding alternative quality management. Additionally this research continues to build on previous research by defining the fundamental project QAOs to include both design and construction. A graphical summary of the five fundamental QAOs is provided in Fundamental QAO quick guide.

2.5 Predicted impact

The highway industry is experiencing increasing acceptance of alternative project delivery methods and decreasing staffing levels. Both of these have a direct impact on the assignment of the responsibilities associated with quality management. By identifying the fundamental project QAOs, agencies will have a formal structure to support decision making. This formal structure provides expanded knowledge and thus leads to improvement in the selection of alternative management systems. This research provides a basic understanding of the implications of employing each of the fundamental project QAOs and also provides guidance as to which project delivery method(s) apply to each QAO. By understanding these implications the agency is more equipped to include the appropriate requirements and/or qualifications within the RFP and ultimately the design and construction contracts.

2.6 Paper 1 - Fundamental Project Quality Assurance Organizations in Highway Design and Construction

2.6.1 Abstract

Alternative project delivery methods and reductions in state highway agency staffing are changing project quality assurance organizations (QAO) or the assignment of project quality management roles and responsibilities in the industry. Although fundamental quality roles and responsibilities remain the same, the assignment of these roles and responsibilities is shifting away from agencies and is doing so in an ad hoc manner because of project time constraints and lack of research and guidance on the topic. Most research that pertains to highway project quality has focused on quality control levels, material specifications, inspections, and observations; there is a gap in the research about overall project quality organizations. This paper addresses that gap by providing a better understanding of highway project QAOs and guidance about assignments of quality management roles and responsibilities. The research identified five fundamental highway project QAOs through a national survey of industry, a literature review, and an analysis of the content of documents from 66 projects. The resulting five fundamental highway project QAOs are Deterministic, Assurance, Variable, Oversight and Acceptance.

Keywords: Project management, highway construction, highway design, quality management, quality assurance, quality control

2.6.2 Introduction and background

Project quality assurance organizations (QAO) are the assignment of responsibilities and the relationships of the quality roles for highway projects, both design and construction. QAOs are analogous to company organizational charts that assign roles and responsibilities in the

company and identify the relationships between those roles and responsibilities. Historically, all project QAO roles and responsibilities have been held by state highway agencies (SHA). However, quality roles and responsibilities are shifting away from SHAs because of increased acceptance of alternative project delivery methods such as design-build (DB) and design-bid-build (DBB) and reductions in SHA staffing.

Before 1960, highway quality assurance (QA) in the highway industry was limited to inspection, sampling, and testing to determine whether projects were meeting the specification limits (Hughes et al. 2005). Two events changed the course of QA programs for the highway industry, the AASHO Road Test (1956–1958) and the establishment of the House Committee on Oversights and Investigations (1961), known as the Blatnik Committee (NCHRP 1979; Hughes et al. 2005). Hughes et al. reported that, "the outcome of these studies and investigations was the requirement to conduct independent assurance (IA) sampling and testing on FHWA funded projects and was the beginning of formal quality control (QC) initiatives" (Hughes et al. 2005). QA in the highway industry has evolved since the 1960s and has moved from prescriptive quality specifications through developments in materials inspections and testing to implementation of statistical process control, and ultimately towards performance-based QA (NCHRP 1979; Hughes et al. 2005; Smith et al. 1998).

Over the past decade, acceptance of alternative project delivery methods in the highway industry has increased. In 2002, 23 CFR 636 was approved and required that standard contracting regulations must be in place for design-build projects (FHWA 5/23/2011). Although the federal government legalized alternative project delivery through SEP 14 and 23 CFR 636, state laws and regulations still influence alternative project delivery methods. Ghavamifar et al (Ghavamifar and Touran 2008) reported that design-build is authorized in 37 states, construction

manager (CM) at risk is authorized in 19 states, and public-private-partnership (PPP) is authorized in 24 states, which means that more than half of all states have at least 1 alternative project delivery method legally available. Ghavamifar and Touran also identified a trend toward allowing states more flexibility in choosing contractors (Ghavamifar and Touran 2008).

Project delivery methods define the roles and responsibilities of the parties involved in a project (Oyetunji and Anderson 2006; Molenaar and et al. 2008; Touran et al. 2009), and project delivery methods have an impact on QA roles and responsibilities. Gransberg et al. state that issues of alternative project delivery methods and project QA have become interrelated (Gransberg et al. 2010). Further, the increased use of consultants by SHAs for activities such as testing, inspection, and design is changing traditional quality roles and responsibilities (Hughes et al. 2005; Smith et al. 1998).

Alternative project delivery is going to continue to grow in the highway industry because of financial and personnel constraints and increasing needs to deliver projects in a more timely fashion (FHWA 12/16/2011; Miron et al. 2008). Growth in using alternative project delivery methods has resulted in a constant development of hybrid alternative delivery methods, and a lack of available project guidance has meant that QAOs have been adjusted to the needs of different delivery methods on an ad hoc, project-by-project basis. A significant amount of investment and risk is involved when SHAs create project-by-project QAOs because if they are not clearly thought out and communicated in requests for proposals (RFP), then agencies do not necessarily get the best possible proposals. In short, quality responsibilities for RFP responders must be clearly identified so consultants or contractors to appropriately and accurately respond to RFPs.

Since the 1990s a trend toward reductions in staff in all SHA departments, including design, and testing and inspection, has not only reduced the number of people available to manage increasing workloads and had significant impacts on the levels of experience and expertise within SHAs (Smith et al. 1998), but also has resulted in increasing needs for alternative delivery techniques. Smith reported "personnel losses have been a major factor in the changes influencing the materials and construction acceptance process" (Smith et al. 1998). In fact, 23 CFR 637B was revised in 1995 to allow QC tests conducted by contractors to be used by agencies for acceptance. As a result, the QC testing and inspection that had previously been SHA responsibilities began to shift to contractors while agencies increasingly took on acceptance roles.

However research did not kept pace with developments in quality assurance in highway design and construction industry. Most of the research about highway quality has focused on construction QC, such as inspections, materials, testing, observation, assurance, and specifications (Hughes et al. 2005; Smith et al. 1998; Minchin et al. 2008; Miron et al. 2008; Erickson 1989). Also, in the early 1990s, research in all of areas of construction focused on the quality revolution taking place in the manufacturing sector, including such topics as TQM, ISO 9000, and the Baldridge award (Minchin et al. 2008; Chini and Valdez 2003; Dikmen et al. 2005; Kasi 1995; Elliot 1991; Schmitt et al. 2000; Burati Jr. et al. 1992; Burati Jr. 1991; Arditi and Lee 2004; Arditi and Gunaydin 1997; Minchin Jr. et al. 2010; Minchin et al. 2005). Further, this research focused on improving the quality of independent organizations, not on improving project QAOs (Kasi 1995; Burati Jr. 1992; Burati Jr. et al. 1992; Oswald and Burati Jr. 1992; Deffenbaugh 1993). Gransberg et al. (Gransberg et al. 2008) identified highway quality project

management roles and tasks as well as the associated relationships and briefly commented on the assignment of QA roles in a CM at risk project.

This paper builds from these gaps in the research and on Gransberg et al. (2008) and begins to provide guidance needed for systematic QAOs by identifying and defining the fundamental QAOs in the highway industry. Although the five fundamental QAOs are derived from the highway industry, they apply to other civil and construction industries that employ alternative delivery methods and where owner agencies have traditionally been involved in QA functions.

2.6.3 **Methodology**

Identifying and defining the five fundamental QAOs was accomplished in four research phases, reviewing the literature and conducting a national industry survey, analyzing the content of 66 documents, reducing the findings to five fundamental QAOs, and validating the findings. This process resulted in information that forms the basis of a consistent and efficient approach to QAO planning for highway projects.

Literature review and national survey

A thorough literature review and national survey were conducted to identify the 14 different QAOs that could potentially constitute a theoretical QAO framework. The literature review focused on design, construction, and quality in the highway industry, and the national survey was completed by SHAs, other public transportation agencies, design-builders, and DB design and construction consultants. A total of 63 complete responses and 13 partial responses were received from 47 states. The resulting primary roles in highway design and construction QAO are project acceptance, design acceptance, design QA, design QC, construction acceptance, construction QA and construction QC. The project QAO results from assignments of these

quality roles to agencies, designers, contractors, design builders, construction managers, or concessionaires.

Although the quality assurance roles and tasks remain the same on all projects, different delivery methods have direct impacts on associated contract liabilities (Gransberg et al. 2008). As a result the most thorough approach to identifying the different QAOs being used in the industry was to conduct an investigation based on different delivery methods: design-bid-build (DBB), design-build (DB), construction manager general contractor (CMGC) and public-private-partnership (PPP). The literature review identified the QAOs used in the DBB delivery method that are well understood and accepted in the industry.

Document content analysis

Because the contracting relationships in CMGC are closely related to DBB the applicable QAOs are the same as DBB, as identified in the literature review (Gransberg et al. 2010). Next to DBB, DB is the most prevalent project delivery method in the industry and has the most opportunity for change to the quality roles resulting from the amount of shifts in overall project responsibilities. DB is also the most well-documented alternative delivery method in terms of specified QAOs, so the content analysis focused on DB RFPs and policy documents. The content analysis benefited because the most current industry trends with projects in design, in construction, or recently completed projects were consulted. The content analysis involved gathering and reviewing documents for the QA and QC program requirements in project solicitation documents (RFPs) and policy documents. The content analysis documents were from 66 different projects from 26 transportation agencies from 23 states, the District of Columbia, the U.S. DOT Eastern Federal Lands Highway Division, and one Canadian Province, reflecting a total of $11.5 billion in contracted work.

Neuendorf (Neuendorf 2002) indicated that the content analysis method can be used to develop "valid inferences from a message, written or visual, using a set of procedures". Weber (Weber 1985) reported that using the frequency of a word's appearance in the content of a document can be inferred based on the assumption that there is a set of carefully developed standard categories into which the words in the document could be placed. In this research, the documents were reviewed for specific words (e.g., quality, quality management, assurance, verification), and the contexts and frequencies of the appearances of these words were recorded. Whenever it was possible, the contexts were used to identify which contracted party was responsible for the different quality management roles. The content analysis revealed that 9 of the 14 QAOs identified in the survey and literature review were identified as existing in the industry.

Consolidating the QAOs

The nine QAOs utilized in the industry were analyzed based on an agency's quality roles and responsibilities in each QAO. If the agency shared a role, directly contracted the role out to an independent firm, or had sole responsibility for the role, the agency was it was considered an agency project quality role and responsibility. Because of differences in how agencies perform quality roles or whether non-agency quality roles and responsibilities were contracted to a single party or multiple parties, many of the 14 originally identified QAOs were considered variations of the 5 fundamental QAOs that were identified for highway design and construction projects.

Validating findings

The final step of the research was to validate the five fundamental QAOs. A different panel of six industry experts, each with a minimum of 15 years of industry experience, reviewed

the 5 fundamental QAOs. The panel was asked to validate that there currently are only five fundamental QAOs in the industry and that the QAOs identified in this research accurately reflect those fundamental industry QAOs. There was consensus among the panel members that the five fundamental QAOs identified by this research constitute an exhaustive list that accurately reflects project QAOs currently in use in the highway industry. As a result, a QAO framework was developed.

2.6.4 **QAO framework**

(Gransberg et al. 2008) presented a graphical representation of a theoretical QAO framework that forms the basis for the graphical representations in the discussions of each of the five fundamental QAOs identified in this research (Figure 3). This theoretical QAO framework, which is analogous to a corporate organizational chart, accounts for all of a highway project's quality roles, their relationships, and surrounding project quality activities. Extended definitions of project quality roles and other terms are provided in the Appendix B. In Figure 1 and the figures that illustrate each of the five fundamental QAOs, dotted lines indicate who—whether the agency, contractor, designer, concessionaire or design builder—is responsible for each project quality role. Items above a dotted line are agency responsibilities. The vertical dotted lines distinguish the responsibilities of designers and contractors.

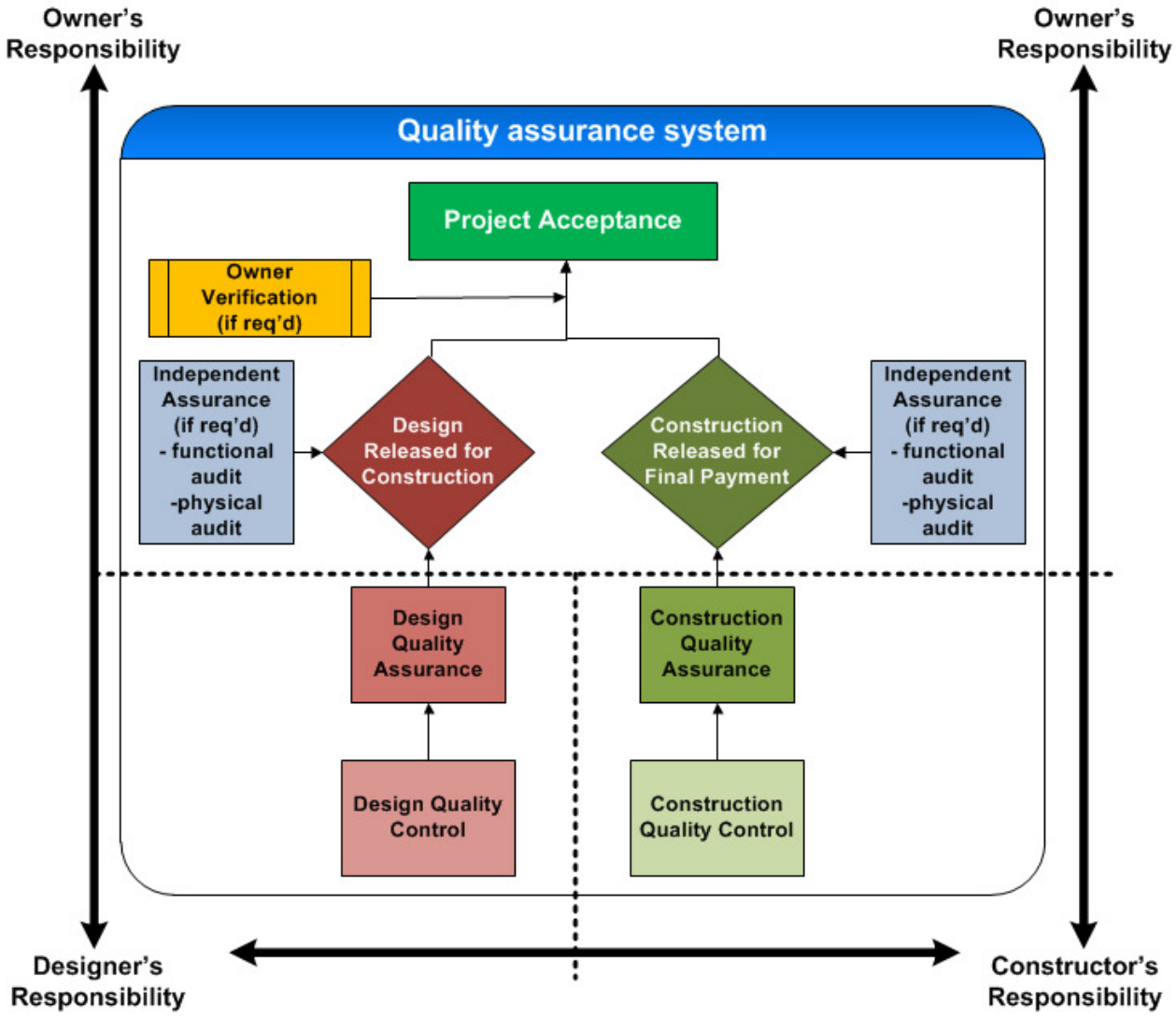

Figure 3 - Theoretical QAO Framework (modified from Gransberg et al. 2008)

The framework includes both design and construction. Although design quality is not traditionally included in highway QA discussions, it is included in the QAO framework because "the literature clearly shows that the design phase is the time when the quality of the constructed product is defined" (Gransberg et al. 2008). For highways the responsibility for quality management begins with the design engineer because "a contractor cannot cast a high-quality pavement following a poorly conceived design or antiquated specifications" (Diekmann and Nelson 1985). Diekmann and Nelson reported that on federally funded projects, 46% of contract claims resulted from design errors. Minchin et al. (Minchin Jr. et al. 2010) determined that one of

the five largest problems in the transportation industry is design drawings and specifications that result in excessive changes, requests for information (RFIs), and claims. Burati Jr. et al. further reported that 78% of quality deviations—that is, a product or result does not conform to the specification requirements—are design deviations (Burati Jr. 1992). This indicates that design must be an integral part of discussions of highway project quality.

2.6.5 **The Five Fundamental Highway QAOs**

This research identified five fundamental QAOs for project design and construction in the highway industry, and that they can be referred to as the Deterministic, Assurance, Variable, Oversight and Acceptance QAOs. Definitions for each fundamental QAO follow, and Table 1 summarizes the parties that are responsible for each project quality role for each QAO.

- Deterministic – The traditional approach to quality in the highway industry. The owner agency retains all control for all quality on the project.
- Assurance – The owner agency is responsible for all aspects of the quality assurance except for QC.
- Variable – Design and construction take different approaches to quality. One will either have a proactive approach by assigning both QA and QC to the party contracted to perform the scope of work, while the other will be a reactive approach by only having responsibility for QC. The version of this seen in industry is when all design QC/QA and construction QC is assigned to a design-builder.
- Oversight – the owner agency takes 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.

- Acceptance – Currently only used in a PPP arrangement, the owner agency is responsible for verification testing, and final acceptance. All other quality roles and responsibilities are assigned to the concessionaire.

Table 1 - Roles and Responsibilities of the five fundamental QAOs

QAO	Design QA	Design QC	Construction QA	Construction QC	PQA (agency)
Deterministic	Agency	Agency	Agency	Contractor	N/A
Assurance	Agency	Designer	Agency	Contractor	N/A
Variable	Designer	Designer	Agency	Contractor	Design
Oversight	Designer	Designer	Contractor	Contractor	Design and const.
Acceptance	*Concess	*Concess	*Concess	*Concess	Design and const.
*Concess = Concessionaire					

There are two distinct approaches to quality: reactive and proactive. The reactive approach is aimed at detecting and correcting problems that already exist. (Desai and Mital 2009) said, "in other words, the designer of a product/process/service incorporates a system of checks and measures that serves to isolate and catch defects as and when they occur. By their very nature, reactive quality assurance strategies are better suited to identify problems and resolve them and as such are clearly defensive in nature" (2009). The reactive approach inspects quality into the final products. Conversely the proactive approach to quality is aimed at preventing problems, defects and/or errors before they occur. The proactive approach provides project teams with the ability to build quality into the final product beginning at the design stage instead of inspecting the project at a later stage (Desai and Mital 2009). Figure 2 summarizes the five QAOs with respect to both the level of agency control and the approach to quality management

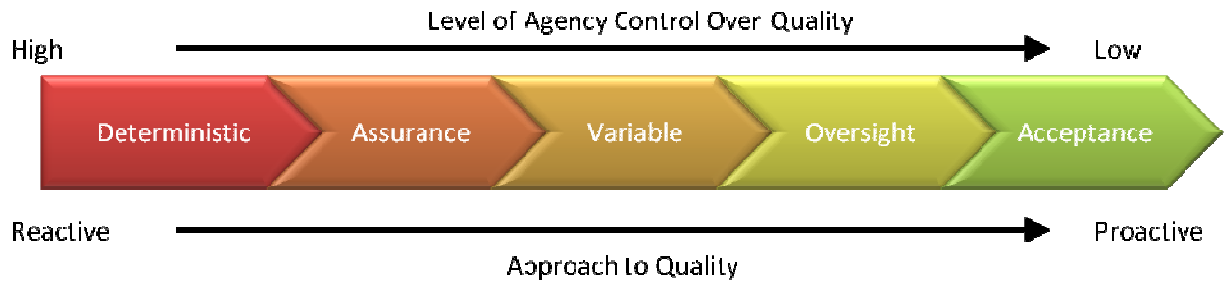

Figure 4 - Summary of the five fundamental highway industry QAOs based on agency control and approach to quality

The sections that follow present each of the five fundamental QAOs in these ways. The description of the assignment of quality roles and responsibilities identifies the team member responsible for each quality task and discusses the level of owner control for the QAO. The approach to quality indicates whether the QAO is more reactive or proactive. The project delivery method discussion identifies the project delivery methods where the QAO has been implemented in the industry and discusses the feasibility of the application of the QAO to other project delivery methods. Finally, variations of the QAO are identified.

Deterministic QAO

The Deterministic QAO (Figure 5) is the traditional QAO for highway construction projects and is well understood by the primary parties involved with projects: the agency, contractor, and designer. The agency's roles in the Deterministic QAO include design QA, design QC, construction QA, and construction QC. The agency can use third party consultants to perform any of these roles, but the agency is ultimately responsible for ensuring these roles are successfully completed on the project. The SHA provides the QC requirements for necessary tests and inspections that are appropriate for the project, but typically the contractor is the party that conducts many of the tests. The agency is responsible for inspection, observations, ensuring the contractor's testing procedures and equipment are adequate, and the resolution of any quality

control issues that develop over the course of the project. Project QA is not required because the agency is responsible for both design and construction QA on the project. The Deterministic QAO represents the baseline for alternative QAO discussions and comparisons for the remainder of this paper.

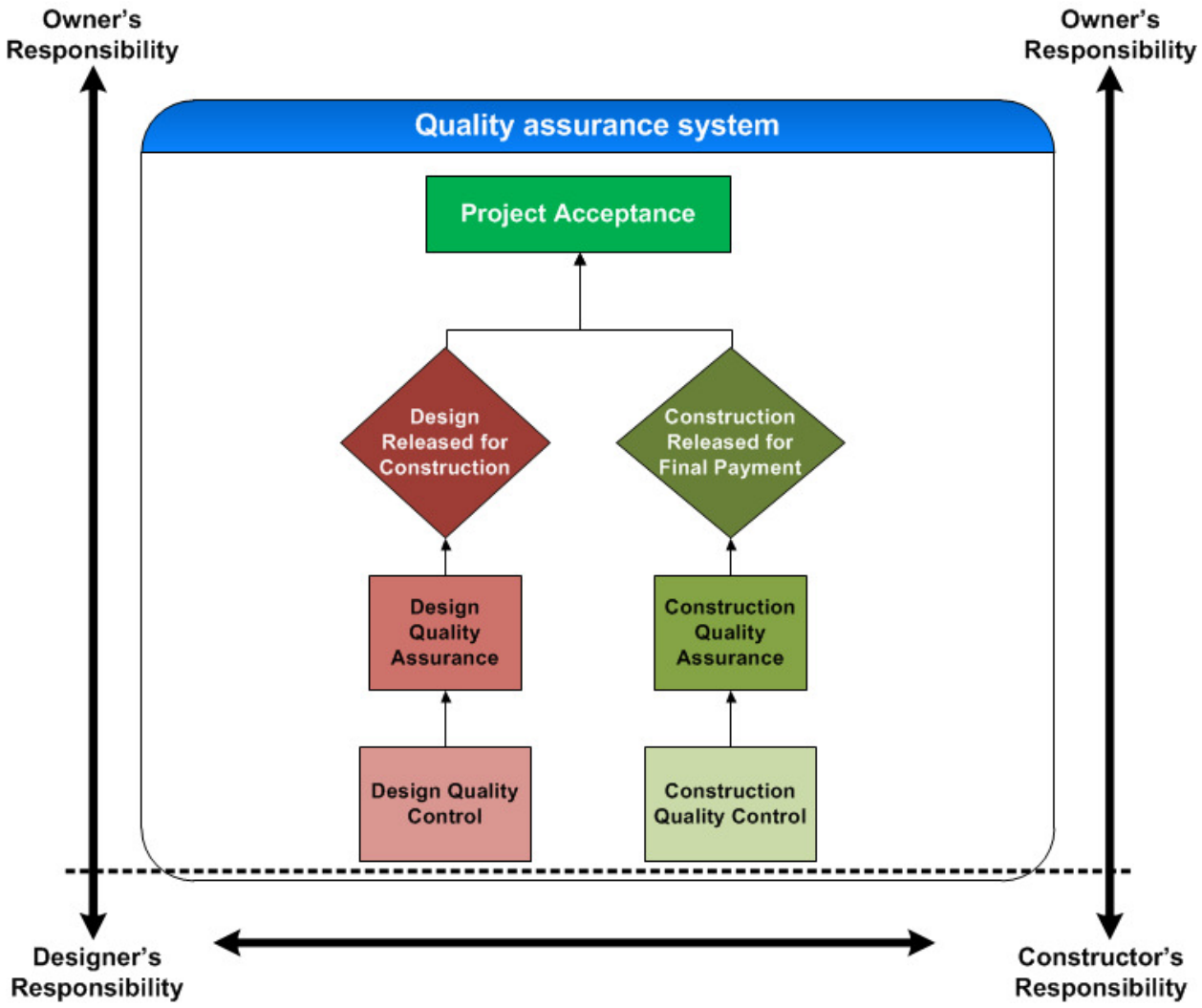

Figure 5 - Deterministic QAO

Because of the controlling role of the owner, the Deterministic QAO is considered a reactive approach to quality (Postma et al. 2002). In this QAO, the agency develops the designs, specifies the materials to be used, and watches over the construction (Gransberg et al. 2008). In the Deterministic QAO, "the contractor works within a very controlled environment like that in a

method specification project. Assurance using method specifications is based on the owner having complete control of the process and enumeration of contractor means and methods. Detailed owner-directed inspection is the primary control process and final acceptance of the work is essentially automatic" (Smith et al. 1998).

The lack of any sort of collaboration in the Deterministic approach contributes to the frequently contentious relationship between the owner and the contractor. This adversarial relationship is so pronounced that the Deterministic QAO is sometimes referred to as the "catch and punish" method (Postma et al. 2002). There is no place for collaboration because the contractor and the designer have no input in the QA of their own products; they are merely responding to what the agency dictates in the RFP, plans, specifications, and bidding documents. Difficulties can arise when there are conflicts because the quality expectations are not explicitly called out in the bidding documents and/or when contract change orders are needed.

The Deterministic QAO is most often implemented on DBB projects, especially when the design is performed in the agency, rather than outsourced to a design consultant. Gransberg et al. concluded that the quality systems used in DBB pertains to CMGC because the owner still occupies the same contractual position with respect to the designer and builder (Gransberg et al. 2010). The Deterministic QAO would be most appropriately applied to CMGC if the scope of preconstruction work for the contractor were limited to items not directly relating to the design, such as cost estimates and project scheduling.

One of the benefits of the DB delivery method is that the agency can transfer some of the risks associated with the quality of design and construction, which requires a shift in authority for each of these tasks. As a result the Deterministic QAO is not well suited for DB projects because applying the Deterministic QAO would mean the agency would retain the quality

authority for design and construction which would no longer allow the design builder to manage and assume the risks associated with those tasks (Gransberg et al. 2008).

Assurance QAO

In the Assurance QAO, the agency has the responsibility for QA in design and construction and the decisions to release the design for construction and to release construction for final payment. These responsibilities can be performed in house or by an independent consultant/engineer.

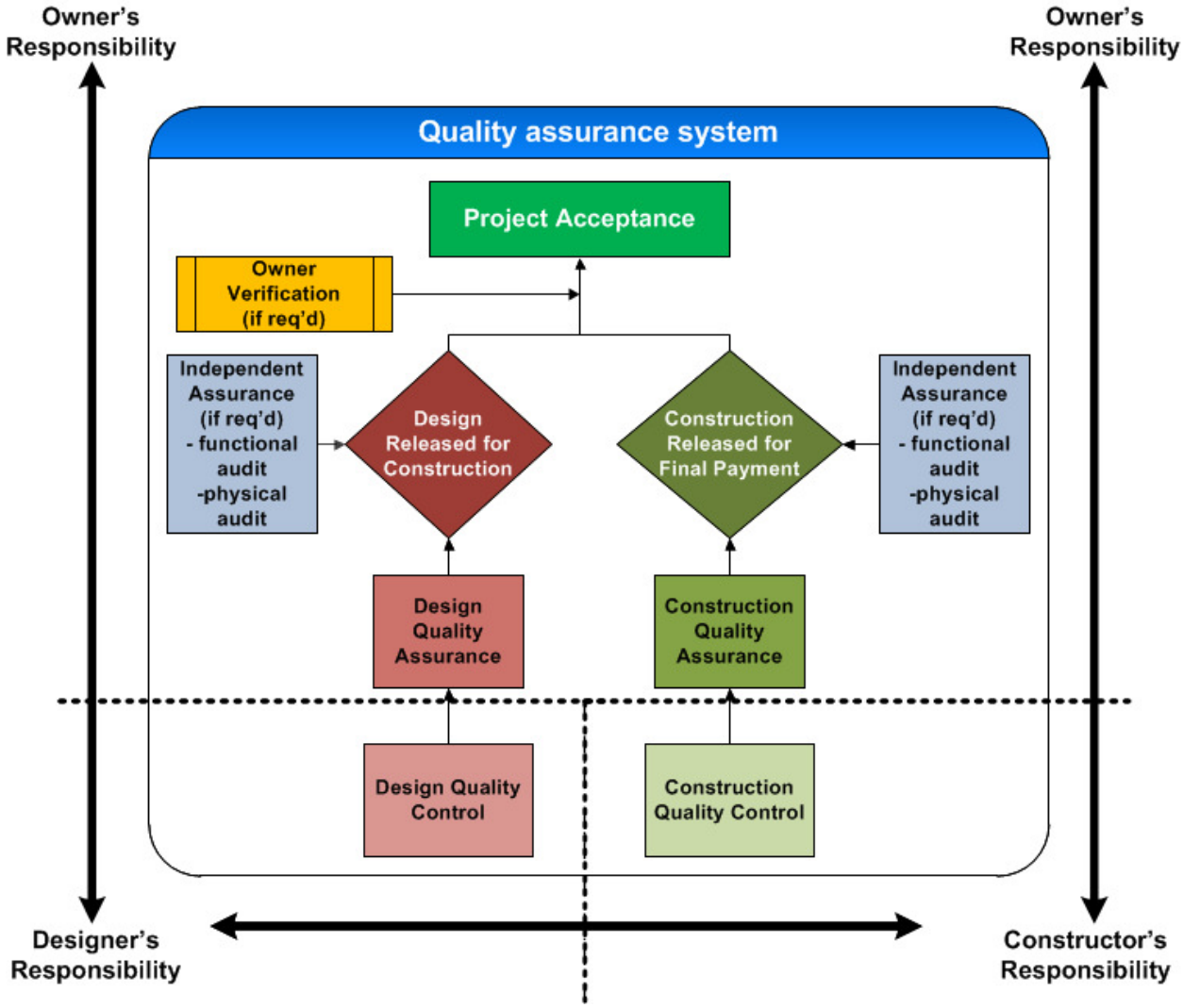

Figure 6 depicts the Assurance QAO as applied to a dual contract (i.e., separate contracts for the designer and the contractor) project. The designer and the contractor are responsible for performing QC in their respective fields. Because the agency still holds responsibility for all QA on the project, project QA is not necessary. While the contractor and the designer perform their own QC, typically the agency will perform independent assurance and testing to verify the QC tests results (Gransberg et al. 2008).

Figure 6 - Assurance QAO, dual contracts

The Assurance QAO is a small step beyond the Deterministic QAO. Because the agency is still responsible for all QA on the project without input from either the designer or contractor, the owner still has a very controlling role in the project. The quality responsibilities have not shifted very far from the Deterministic method, and there is still a focus on inspections and materials testing as the way to assure quality, rather than an emphasis on building quality into the project. Additionally, because the owner is so heavily involved in dictating the quality of the project, the designer and the contractor assume less ownership for the quality of the project. The high level of agency control over project quality also prohibits collaboration between the agency and the designer and contractor regarding quality. This lack of collaboration along with the strong emphasis on assuring quality through inspection of the final product makes the Assurance QAO a reactive approach to quality.

The Assurance QAO has been applied to both DBB and DB projects. When applied to DBB projects as shown in

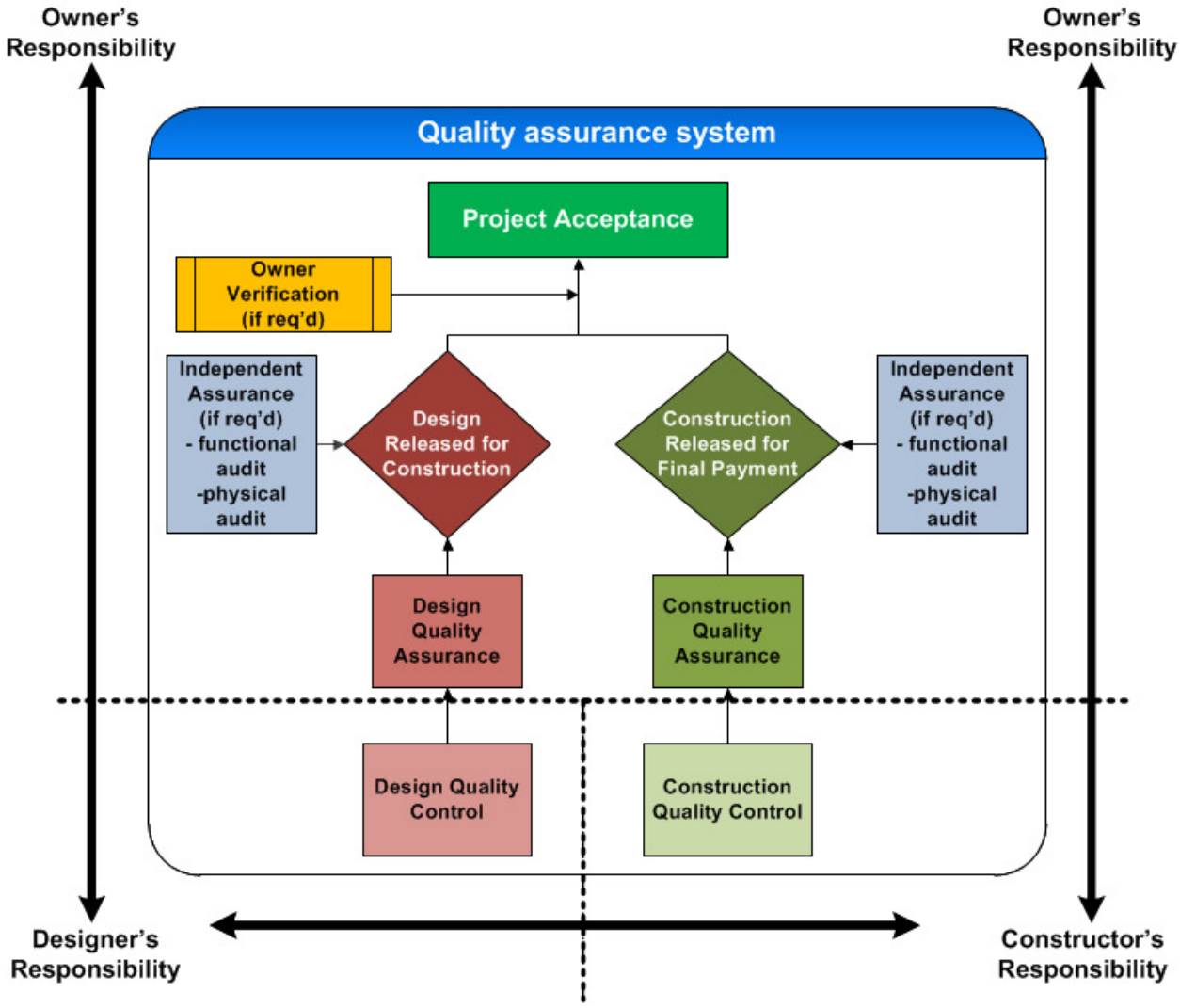

Figure 6, everything above the dotted line is the agency's responsibility and the vertical dotted line represents the separate design and construction contracts. When applied to the DB delivery method with a single contract for design and construction, all QC activities are the responsibilities of the design builder (Figure 7). Gransberg et al. (Gransberg et al. 2008) suggested that agencies that have limited experience with the DB method have implemented the Assurance QAO because the quality management policies and procedures are still evolving from

the DBB method in which the contractor controls construction QC and the SHA has control over all QA functions and over design QC

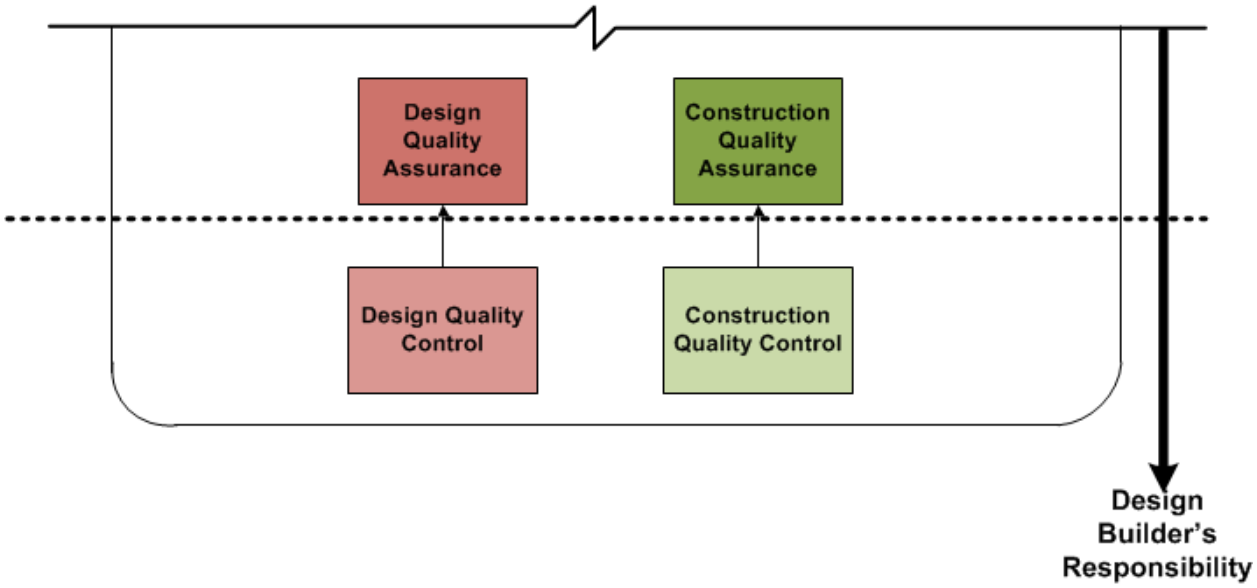

Figure 7 - Assurance QAO, single contract

Another variation on the Assurance QAO used on DB projects is the shared variation. This variation shares the responsibilities for design QA and construction QA between the owner and the design builder (Figure 8). This variation is still considered to fall into the Assurance QAO because the owner still has a role in the QA on the project so no project QA is necessary. It is critical that when stakeholders share roles on a project, all roles in the shared task must be clearly and specifically addressed and assigned to prevent confusion. This shared variation of the Assurance QAO could also be applied to the CMGC delivery method with the contractor being responsible for construction QA and the designer for design QA.

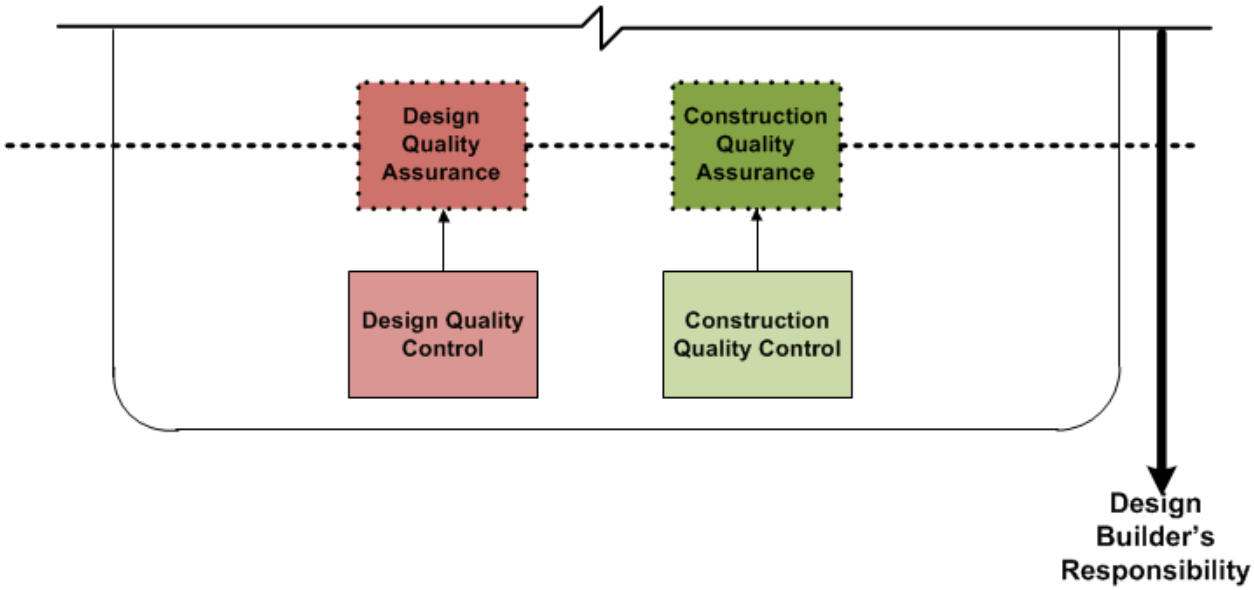

Figure 8 - Assurance QAO, shared assurance variation

Variable QAO

The Variable QAO differs from the four others because it is described by the function of the model rather than by the role of the agency. The defining characteristic of the Variable QAO is that the approach to quality between design and construction is different as reflected by the Variable QAO found in the industry, shown in Figure 9. Specifically the Variable QAO found in the industry assigns construction QA to the agency and construction QC to the contractor or the design builder resulting in a reactive approach to construction quality; while design QA and QC shifts to the designer or design builder, resulting in a proactive approach to design quality. Because the agency is no longer responsible for design QA, the agency must perform project QA on the design side of the project (Gransberg et al. 2008). This results in implementing two different approaches to quality across the agency and the project complicating attempts at creating continuity across the project.

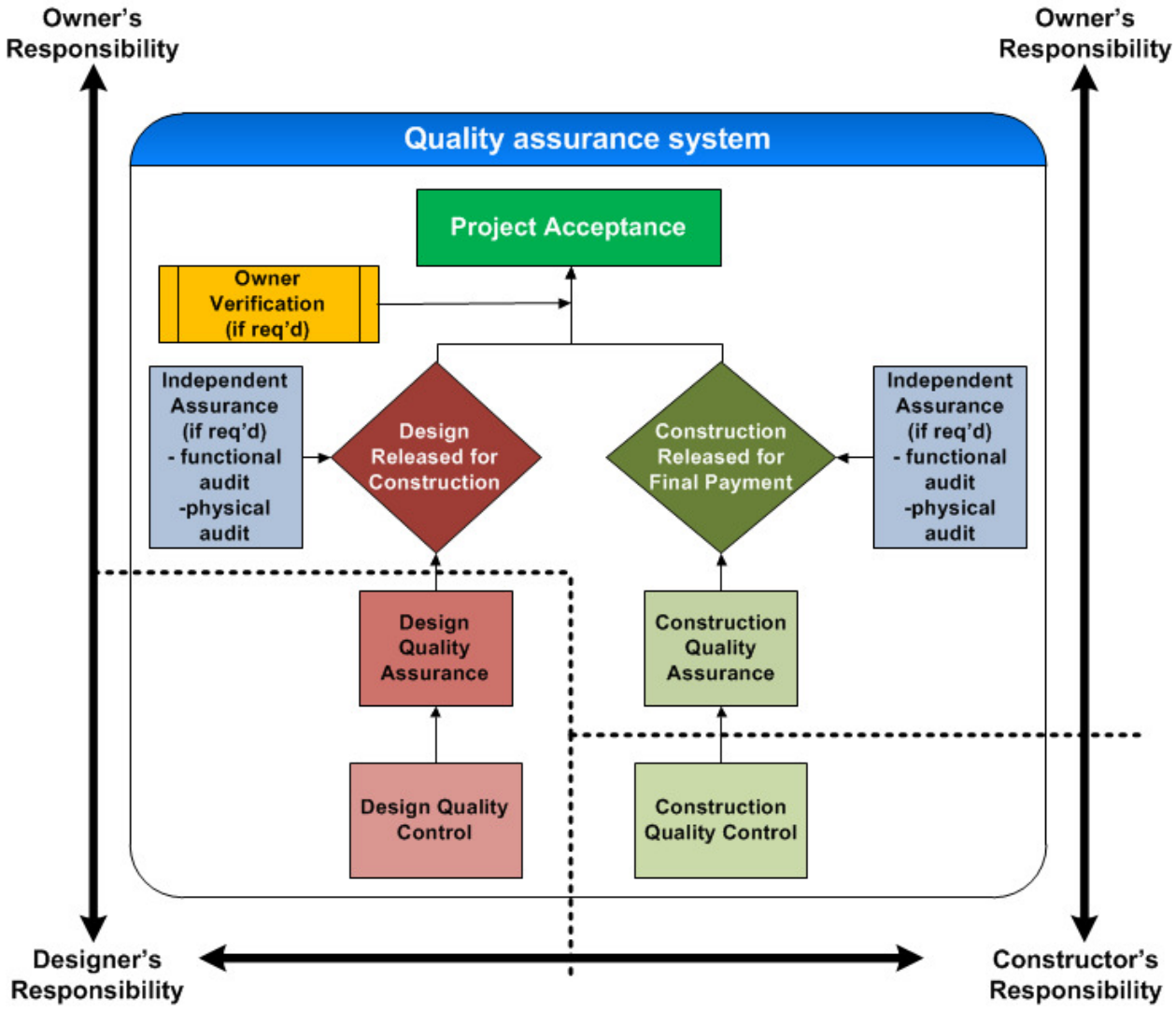

Figure 9 - Variable QAO dual contract

A critical element of a proactive approach to quality and successfully shedding the QA responsibility from the agency is the agency's identification of the quality requirements to be included in the RFP. Agencies must provide enough guidance so that respondents can include the appropriate services and approach to quality in their proposals (Gransberg et al. 2008). While this arrangement requires fewer agency resources over the duration of the project, the resources must be focused on the quality requirements in the contract not on the detailed technical details of the project. The Variable QAO can be difficult for an agency to manage because the project

team must have the skill sets to manage both proactive and reactive quality approaches in one team.

It is possible that the Variable QAO could assign the agency the design quality assurance while all the construction QA and QC is assigned to either the contractor or design builder. This variation still utilizes both the proactive and reactive approaches to quality in one project, but this time the design phase is reactive and the construction phase is proactive. However this was not found in industry. It is speculated that the reason this variation was not found in industry is because the agency traditionally prefers to retain more control over construction quality than design quality.

The Variable QAO has been implemented on DB projects and the DB variation is shown in Figure 10 . The Variable QAO was not found in DBB, CMGC or PPP projects; however, there is nothing in the variation itself which would prevent it from being implemented on a dual contract (DBB or CMGC) project.

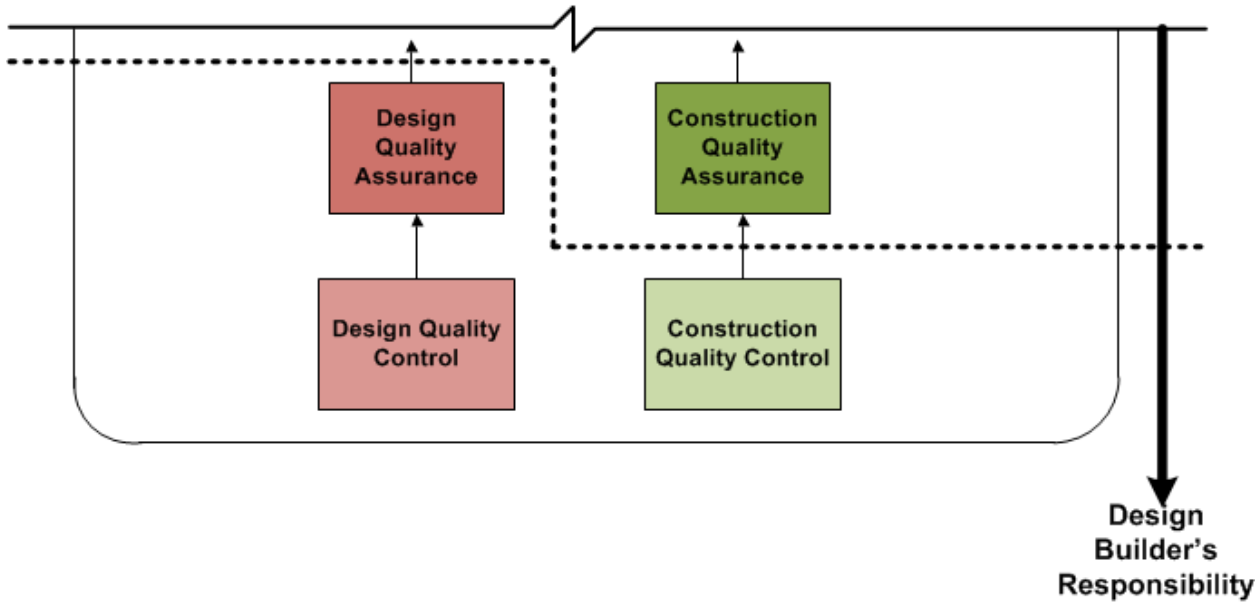

Figure 10 - Variable QAO single contract variation

Oversight QAO

The Oversight QAO, shown in Figure 11, assigns the agency the responsibility for the decisions to release the designs for construction and to release construction for final payment and project quality assurance. The designer is responsible for design QA and design QC, while the contractor is responsible for construction QA and construction QC. Because the agency does not have any responsibility for the design QA or construction QA, it is responsible for performing project QA. In the Oversight QAO the agency no longer has direct control over the day-to-day quality management of the project and is no longer dictating how to produce the quality required by the project; rather the agency's role is to ensure that both the designer and contractor quality assurance plans are effective at meeting the agency's quality requirements stipulated in the contract and that the plans are being implemented.

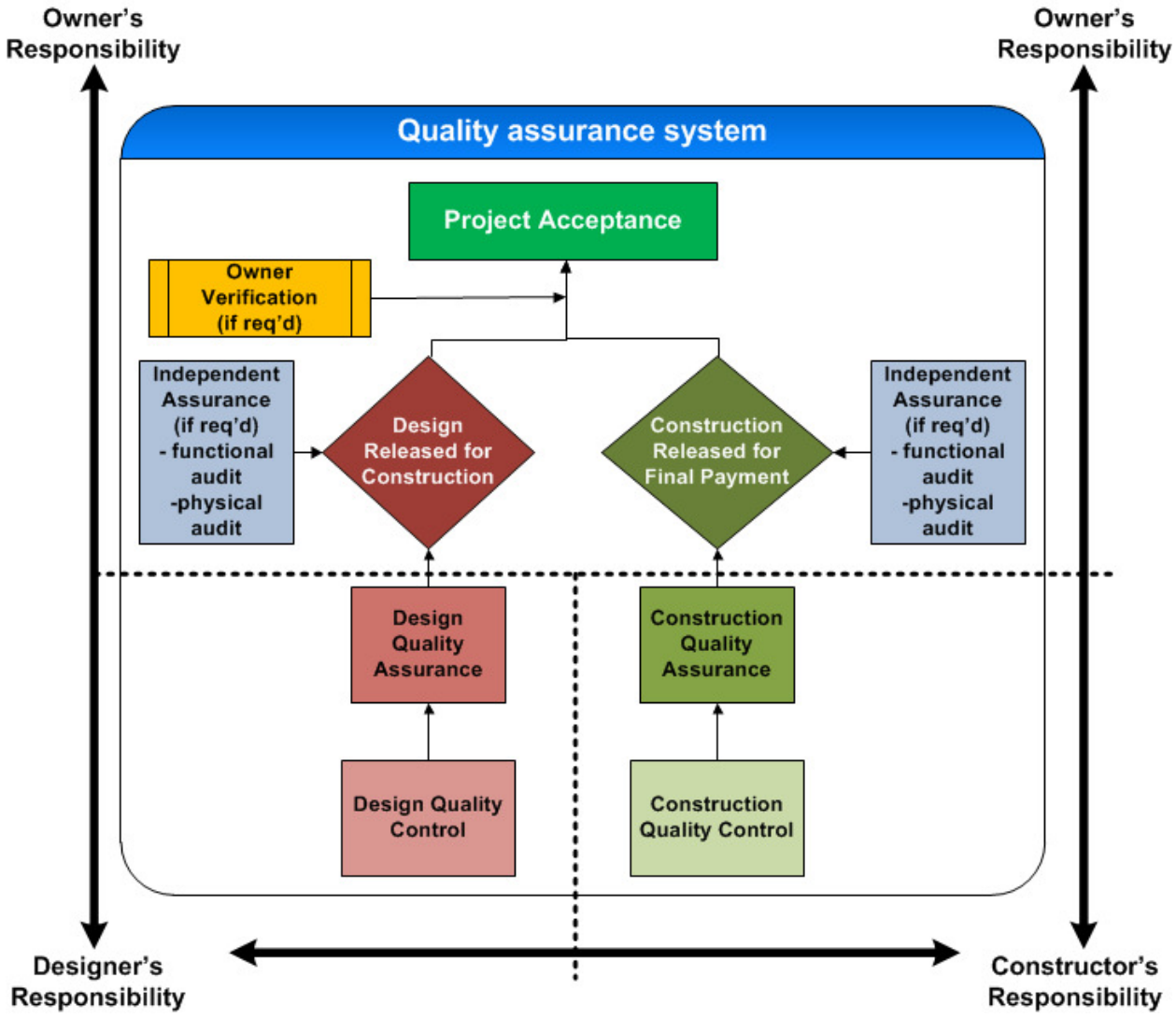

Figure 11 - Oversight QAO

The Oversight QAO is a proactive approach to quality, at least as far as the agency's role in quality is concerned. The producers, the designer and the contractor, are responsible for all aspects of the quality for the products that they produce for the agency. The Agency's primary responsibility in the Oversight organization is oversight of implementation of the QA and QC processes that influence the quality of the project, which is conducted through project QA. The agency can conduct project QA either with in-house staff or with an independent quality firm contracted directly to the agency. To effectively perform the project QA role in-house, the

agency will have to educate its staff regarding the different skills set required to be successful. The designer's and contractor's approach to quality does not have to be proactive, unless required by the agency's contract. The designer and/or contractor can create a QA plan in which their approach to quality is reactive (focused on inspecting final product rather than finding the defects before they are implemented). Either way, designers and contractors have not historically had much responsibility for the QA aspects of a project and may need specific QA training to learn how to perform this function.

While the agency always ultimately has the risk for quality on a project, in the Oversight QAO, risk is shifted to the designer and the contractor. Shifting the risk results in both the designer and contractor having to "buy-in" to the quality management of the project because they are each responsible for creating their respective QA plans which ensure that the quality goals and requirements of the project are met. Because the Oversight QAO shifts the responsibility for QA to the designer and the contractor, the level of integration between the agency, designer and contractor increases and requires a higher level of collaboration amongst the three in order to meet the quality requirements for all parties. In the Oversight QAO, all parties are involved in the quality management of the project and the designer and contractor also have contractual accountability for not only the quality of the final product that they deliver to the agency, but also the actual processes of delivering that product.

Due to the high level of collaboration required by the Oversight QAO, it would be difficult to implement on a project with a linear approach where the designer and the contractor operate in independent isolated silos over the course of the project such as a DBB project. However, in project delivery methods when the designer and contractor are brought in early to work together on a project, such as DB and CMGC, the Oversight organization would be

complimentary to the collaborative nature of these methods. In a design-build project, all QA and QC for the project would fall to the design-builder, as shown in Figure 12.

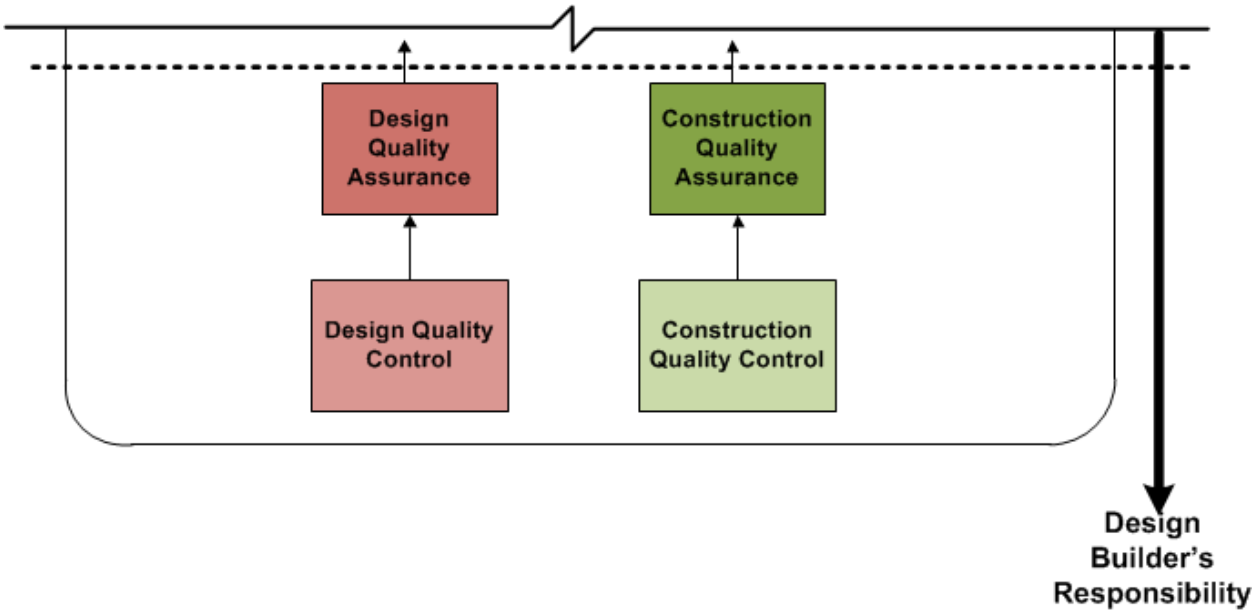

Figure 12 - Oversight QAO single contract variation

Acceptance QAO

The Acceptance QAO is specific to PPP projects. In this QAO, the owner only has responsibility for final project acceptance and owner verification testing while the private partner contracted to complete the project, the concessionaire, is responsible for all other quality responsibilities on the project (Figure 13). The concessionaire can establish a separate QAO within its own project team to manage its quality responsibilities; however the overall project QAO is the Acceptance QAO. Because the agency is no longer providing 100% of the financing for design, construction, operations, and maintenance, this shift in financial liabilities also pertains to the shift in the quality responsibilities (Gransberg et al. 2008). Because the PPP delivery method is not fully embraced or authorized in the United States, there were limited projects to include in this research. The Acceptance QAO is based on several Texas DOT projects that are using the PPP delivery method. There are some variations of the PPP method

across the globe, but because they are not implemented in the business environment of the United States they were not included in the document content analysis or survey responses.

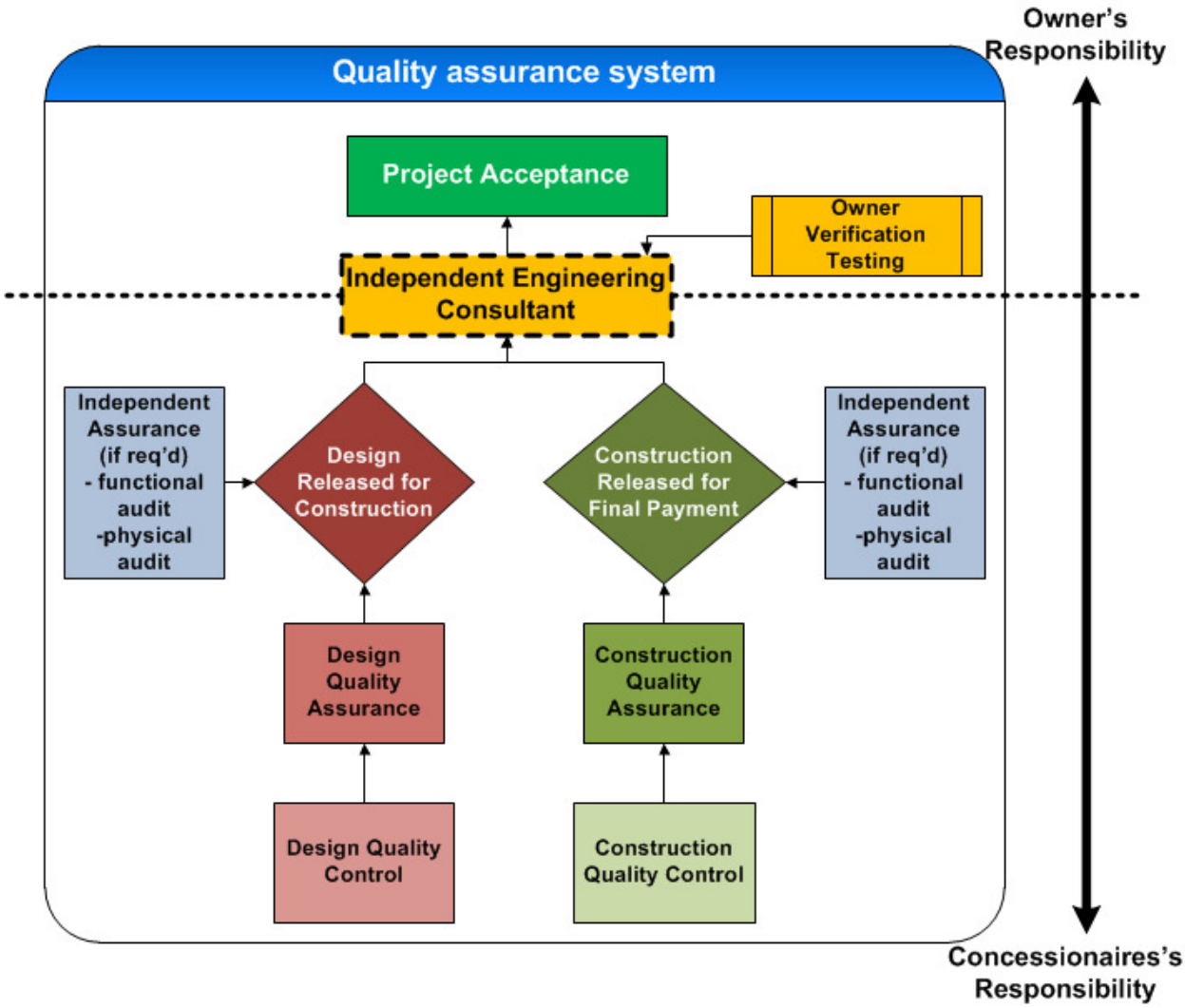

Figure 13 - Acceptance QAO

In the Acceptance QAO, the agency has the least amount of direct control over the quality management of the project. The agency's primary focus, as required by FHWA Technical Advisory 6120.3, is to perform design and construction quality oversight to satisfy their legal responsibilities to the public (Gransberg et al. 2008). This requires the agency to perform owner verification testing that is commonly performed by an independent engineer. Although the

agency pays for 100% of owner verification testing, the independent engineer is hired jointly by the concessionaire and the agency to perform not only owner verification testing but also independent assurance and any other QA activities that are now part of the concessionaire's responsibility. Note that even the acceptance of the design for construction, the acceptance of construction for final payment, and final payments are the responsibility of the concessionaire because the concessionaire carries the financial liability for correcting any design or construction deficiencies during the operations and maintenance period (Gransberg et al. 2008).

Because the agency's involvement in the quality of the project is establishing the quality requirements, approving submitted quality assurance plans and ensuring that quality plans are being implemented, the Acceptance QAO is a proactive approach to quality management. The agency will have some oversight responsibilities to meet the due diligence requirements for federal funding, but these responsibilities are not considered to dominate the overall quality management of the project. Any oversight that is the responsibility of the agency is usually conducted through verification by either in-house staff or an independent engineering consultant contracted to the agency. The concessionaire submits the quality plans required by the contract and as long as they meet the requirements of the contract they are approved by the agency. In the Acceptance QAO, the primary responsibility of the agency for creating successful quality on the project means succinctly stating the quality requirements in the contract with the concessionaire.

Collaboration in the Acceptance QAO is low because after the quality requirements are stated in the contract documents with the concessionaire, the agency is minimally involved in the project. As a result, concessionaires are responsible for assuring and controlling the quality of the project so that the project meets the agency quality requirements, while the agency performs

enough of an oversight role to ensure that they are meeting the federal requirements for due diligence and making sure the concessionaire is following their own project QA plan.

Summary of results

The quality roles and responsibilities on highway design and construction projects are shifting due to the implementation of different project delivery methods, the needs of the industry for faster and better projects, and the growing acceptance of the utilization of consultants by SHAs for traditional SHA tasks. A QAO assigns project quality roles, responsibilities, and relationships. This research has identified five fundamental QAOs for the highway design and construction industry that range from the agency having sole responsibility for all quality functions, to the agency only being responsible for final acceptance and meeting federal requirements.

Further discussion of each of the fundamental QAOs clarifies the approach to quality, the level of owner control, and the delivery methods for which it is applicable. The approach to quality is expressed as reactive (i.e., heavily focused on final product inspections) or proactive (i.e., building quality into the process). The level of owner control was expressed as high, medium, or low, and as the level of owner control moved from high to low, the approach to quality moved from reactive to proactive. Finally, the applicable delivery methods were identified through actual examples in the industry or whether the QAO could align with the project delivery method based on the timing of the parties' involvement, the level of collaboration involved in the QAO, and the level of owner control. A summary of these results is shown in Table 2.

Table 2 - Characteristics of the five fundamental QAOs

QAOs	Quality	Level of	Identified	Potential	Example States using QAO

	approach	owner control	delivery methods	delivery methods	
Deterministic	Reactive	High	DBB, CMGC	None	ALL
Assurance	Reactive	High	DB	CMGC, DBB	NM, SD, LA, MS, NC, AK, FL
Variable	Mixed	Medium	DB	CMGC	NC,FL,MN,VA,UT,ME,CA
Oversight	Proactive	Low	DB	CMGC	CA, CO, MN, MO, NV, OR, TX, UT, VA, WA, Wash DC
Acceptance	Proactive	Low	PPP	None	TX

Four project QAO characteristics apply to all five QAOs:

1. Project quality assurance is always performed by the agency.
2. Final project acceptance is always performed by the agency.
3. The contract verbiage regarding the roles and responsibilities for quality should be concisely documented for success.
4. Decisions about which QAO to use for particular projects should be made prior to the RFP for design, and construction. Quality management responsibilities should be clearly defined in RFPs so designers or contractors can appropriately provide the QA activities commensurate with the amount of risk for project quality they will assume.

Conclusion

Project QAO research in the highway industry is evolving. By identifying and discussing the five fundamental QAOs in the industry, this research builds upon work done by Arditi, Burati and Minchin by providing a preliminary framework for future research seeking clear definitions of alternative project quality assurance systems. However this research does not provide in-depth understandings for the reasons agencies should select one QAO over another nor does it evaluate the level of quality that results from any of the fundamental QAOs.

Although this research identifies critical characteristics of each of these QAOs, research into other QAO characteristics might include partnering, training, upper management leadership, and culture change, which would greatly expand our understandings and implementations of project QAOs. Also research that develops strategies for developing the goals, objectives, and scopes of quality roles and responsibilities in QAOs is needed. Further, as QAOs move toward the relinquishment of agency control, quality management plans will begin to have more governing roles in projects that must be approved by the agencies. Finally, more research should be conducted to identify the critical elements that must be included in quality management plans that are created outside the agency and that must be included in contract documents.

3.0 Factors influencing quality assurance assignments

This section presents research that builds upon the fundamental QAOs through the identification of factors that influence the selection of a QAO and the determination of the relationships between these factors and the fundamental QAOs using appropriateness ratings. The first section presents a brief overview of the research. This is followed by a statement of the research goals, research approach and methods, the claimed contributions and the predicted impact of the research. Finally, the second paper, *Quality Assurance Organization Selection Factors for the Highway Design and Construction Projects,* is presented. This paper includes details regarding the research methodology, the selection factors, appropriateness ratings for the fundamental QAOs and future research.

3.1 Overview

Currently SHAs assign quality roles and responsibilities based on regulations and requirements designed for DBB, the selected project delivery method, or on the experiences of project staff. This phase of the research provides further understanding of QAOs through the identification of the factors that influence the selection of a QAO and the relationship of these factors to the fundamental QAOs. Ten selection factors were identified in three different categories: agency, industry and project. The relationships between the QAOs and the selection factors are defined, effectively linking the two phases of research. This research provides the industry with knowledge needed to make a more informed QAO decision for each unique project and provides further understanding as to the impact of each selection factor on each fundamental QAO; once a project QAO is selected the SHA has the added knowledge needed to justify the selected QAO. The second of three papers comprising this dissertation is presented in this

section. It provides further details on the background, methodology, results and conclusions concerning the selection factors and their relationships with the fundamental QAOs.

3.2 Research goal

The goal for this phase of the research was to answer the following research questions:

1. What are the factors that influence the selection of the fundamental project QAOs?
2. To what level do the project factors influence the selection of a project QAO?

This phase builds on the fundamental QAOs by establishing the relationship between the QAOs and the selection factors using appropriateness ratings. Neither the identification of QAO selection factors nor the relationship between QAOs and selection factors has been explored in previous research.

3.3 Research approach and methods

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Through a literature review, structured interviews, and a Delphi study, ten factors that influence the selection of a QAO were identified and rated as to their appropriateness for each fundamental QAO. The ten factors identified through the structured interviews were grouped into three categories, project, agency and industry. The appropriateness of each of the fundamental QAOs for each of the ten factors was determined through a three round Delphi study using a four point appropriateness rating scale: fatal flaw, least appropriate, appropriate, and most appropriate. A detailed description of the research approach and methods used in this phase are included in the paper entitled *Quality Assurance Organization Selection Factors for the Highway Design and Construction Projects.* The protocol for the structured interviews is presented in Appendix C and a sample of the questionnaire used for each of the three rounds of the Delphi study is included in Appendix D, E, and F respectively.

3.4 Claimed contributions of the research

While there is a large amount of research regarding critical success factors or key factors influencing various parts of a construction project there is no research that identifies factors that influence the selection of a QAO. There is some research regarding success factors for various quality concepts, however none of this research is focused at the highway project level. This research bridges this gap through the identification of the factors that influence QAOs as well as linking the factors and the fundamental QAOs using the following appropriateness rating scale: fatal flaw, least appropriate, appropriate and most appropriate. Through the understanding of how the project factors influence the selection of each project QAO, not only is guidance provided for the selection of a highway project QAO, but further insight for each QAO is also gained. The influential project factors for each project QAO and their respective levels of influence continue to build the character of each QAO.

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3.5 Predicted impact

Every highway project is unique, no matter how routine, because of many reasons such as location, design requirements, financing, delivery method, construction methods, and/or schedule. While confirming that more than just project delivery method influences the selection of the QAO for a specific project, this research also provides practitioners with an understanding of the unique factors surrounding a project that have an impact on the QAO. This research provides further understanding of the implications of the selection factors for each of the fundamental QAOs through the determination the relationship between the selection factors and the fundamental QAOs. As a result the industry will be able to make a fully educated decision on the selection of the QAOs and be able to account for the impacts the QAO selection may have on the project and project management.

3.6 Paper 2 - Quality Assurance Organization Selection Factors for Highway Design and Construction Projects

3.6.1 Abstract

Project quality assurance organizations (QAO) define the assignment of project quality roles and responsibilities. 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 practice in the industry. 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 due to time constraints, limited staff knowledge and experience, and a lack of guidance from the research community. Highway 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 makes a contribution to the body of knowledge in civil engineering quality management by identifying factors that influence the selection of QAOs and rating the appropriateness of the QAOs for each selection factor. Due to 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 ten factors are: 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 impacts that each selection factor

has on the fundamental QAOs. This fundamental knowledge will allow SHAs to make more informed QAO selections.

Keywords: Project management, highway construction, highway design, quality management, quality assurance, quality control

3.6.2 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). Due to 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). While the quality activities required for highway projects remain the same, the project participants responsible for the activities are shifting (Gransberg et al. 2008). A project quality assurance organization (QAO) is the assignment of the responsibility for project quality roles and activities for design and construction.

SHAs have been left to assign responsibility for project quality roles and activities in an informal manner due to 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 (Hughes et al. 2005; Smith et al. 1998; Minchin et al. 2008; Miron et al. 2008; Erickson 1989). 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 (Gransberg et al. 2008) identify highway quality project management roles and tasks on and their relationships on design-build projects and Gransberg et al. (Gransberg et al. 2010) briefly comment on the assignment of quality management roles construction manager at risk 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 (Molenaar et al. 2013). Kraft and Molenaar (2013) identify a novel set of five fundamental QAOs in the highway industry and is used for this basis of this research to identify QAO selection factors.

This research builds upon the body of knowledge in civil engineering quality management and advances our 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 QAO 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.

3.6.3 **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,

independent assurance and project quality assurance for both design and construction. For clarity, each of these roles and responsibilities is defined in Appendix B. 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 and are summarized in Table 1.

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.

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 currently only used in the Public Private Partnership (PPP) project delivery method. All quality roles and responsibilities are the responsibility of the

concessionaire, 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.

3.6.4 **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 due to 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 towards 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).

3.6.5 **Selection factor identification methodology**

When the quality roles on a project differ from the traditional roles, 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 have the appropriate knowledge regarding the assignment of project QAO roles. Highway quality terminology is sometimes overlapping and inconsistent between states (TRB 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 wasn't one project manager from project concept through completion, multiple SHA staff from one project was 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 3. 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. The information provided by the questionnaires enabled the interviews to stay on topic and go more smoothly. The questionnaire is included in Appendix C

Table 3 - Characteristics of projects participating in selection factor interviews

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 Million - $500 Million	44%
$500 Million - $1 Billion	6%
>$1 Billion	17%
Project Duration	
< 24 Months	39%
24 Months – 36 Months	17%
36 Months – 48 Months	17%
>48 Months	28%
Project QAO	
Deterministic	5%
Assurance	47%
Variable	0%
Oversight	37%
Acceptance	11%

Characteristics of projects participating in selection factor interviews

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

3.6.6 **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 ten 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 keys 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 (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's (2010) suggestion that a Delphi study needs at least three rounds to ensure understanding of any possible outliers.

A panel of 12 experts rated the appropriateness of each QAO to each category of selection factor during the three rounds of the Delphi method. 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 ten 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.

3.6.7 Quality Assurance Organization Selection Factors

The structured interviews resulted in a list of ten factors that influence the selection of a project QAO, as listed above. The Delphi study further validated the ten selection factors by not adding or eliminating any factors. The ten factors are organized into three groups for ease of discussion: project, agency, and industry as shown in Table 4. Any selection factors pertaining to specific contractor qualifications or personnel qualifications were excluded because this information is not available until after the QAO is selected.

Table 4 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
	Staffing availability
	Amount of quality shift away from agency
Industry	Ability to manage their own quality
	Trust between industry and agency

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 marked with "*" in the summary tables for each selection factor in the following sections.

The following three sections present each of the selection factor groups, 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.

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Project Factors

Because every highway design and construction project is unique, it was anticipated that there would be project factors that would influence in 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. These make up the project factors group.

Project size is determined by the budget of the project including both design and construction and is divided into five different categories. Table 5 presents the appropriateness ratings of the fundamental QAOs for each project size factor category.

Table 5 – Project Size Factor Appropriateness Ratings

Project Size	Determin.	Assure.	Var.	Over.	Accept.
<$10M	++	++	+	+*	--
$10M - $50M	++	++	+	+	+
$50M-$500M	-	+	+	++	++ *
$500M - $2B	X	-	+	++*	++
>$2B	X	-	+	++*	++

* Should not be the determining factor and should be considered in conjunction with the other factors.

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 meet time constraints. The appropriateness ratings reflect these needs. As the project size increases, the appropriate QAO shifts from Deterministic towards 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 $500M and $2B. These "fatal flaw" ratings were received by the Deterministic QAO and eliminate it as a QAO candidate for projects larger than $500M. 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 $500M. Additionally, the Deterministic QAO would require an immense number of agency resources for a project larger than $500M that, in most cases, no longer exist within the agency. Acceptance received a "very appropriate" rating for projects larger than $500M for two reasons: first, the Acceptance QAO shifts the most risk away from the agency; second, it supplies the

largest number of outside resources. 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 $10M 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 $10M 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 typical project is based on the experience in the locality of the project. One county may consider a particular type of bridge design to be typical while the same design could be considered new and complex in another county 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 6.

Table 6 – Project Complexity Factor Appropriateness Ratings

Project Complexity	Determin.	Assure.	Var.	Over.	Accept.
Low	++	+	+	+	+
Medium	+	+	+	+*	+
High	-	+	++	++	++

Project Complexity	Determin.	Assure.	Var.	Over.	Accept.
* 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", while 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 due to 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 7.

Table 7 – Schedule Sensitivity Factor Appropriateness Ratings

Schedule Sensitivity	Determin.	Assure.	Var.	Over.	Accept.
Low	+	+	+	+	+
Medium	-	+	+	+	+

Schedule Sensitivity	Determin.	Assure.	Var.	Over.	Accept.
High	-	+	+	++	++
* Should not be the determining factor and should be considered in conjunction with the other factors.					

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 due to the complete 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), design-build (DB), construction manager general contractor (CMGC), and public-private-partnership (PPP). The project delivery method appropriateness ratings are summarized in Table 8.

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Table 8 – Project Delivery Method Factor Appropriateness Ratings

Project Delivery Method	Determin.	Assure.	Var.	Over.	Accept.
Design-bid-build	++	+	+	+*	-
Design-build	-	-	+	++	-
CMGC/CMAR	-	+	+	++	+
PPP/DBOM	X	-	-	+	++
* Should not be the determining factor and should be considered in conjunction with the other factors.					

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 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 equivalent 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 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. Due to 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 non-collaborative environment for project delivery. That is, the agency retains all quality responsibilities.

Agency Factors

Holistically, SHA's differ from state to state due to 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 the agency's attitude toward the implementation of change in project management techniques. The agency is the leadership for the 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 non-traditional ideas such as an alternative QAO.

The three categories of agency culture are: traditional, moderate, and progressive. A traditional culture is one that is adverse 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 9.

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Table 9 – Agency Culture Factor Appropriateness Ratings

Agency Culture	Determin.	Assure.	Var.	Over.	Accept.
Traditional	++	+	-	-	-
Moderate	+	+	+	+	+
Progressive	-	+	+	++	++
* Should not be the determining factor and should be considered in conjunction with the other factors.					

Agency culture is not a "fatal flaw" for any QAOs. Based on the appropriateness rating, the more alternative a project QAO (as compared to the traditional Deterministic QAO), the greater the amount of change the agency has to 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 to the traditional levels of agency staffing for comparable projects. Due to SHA downsizing across the nation, SHAs are expected to do more with less (Smith et al. 1998). As a result, the number of agency resources available is decreasing directly 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 to traditional levels of project staffing within the SHA). Table 10 presents the appropriateness ratings for the availability of agency project staff factor.

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Table 10 – Availability of Agency Project Staff Factor Appropriateness Ratings

Availability of Agency Project Staff	**Determin.**	**Assure.**	**Var.**	**Over.**	**Accept.**
Fully staffed	++	+	+	+	X
Moderately staffed	-	+	+	+	-
Minimally staffed	X	-	+	++	++
*needs to be considered in conjunction with the other factors.					

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, due to a lack of staff, or staff will be underutilized, due to a lack of work.

If a full staff is available for the project, as compared to 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, etc. 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 to 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.

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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 Deterministic, 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 five years, five to ten years, ten to twenty

years, and more than twenty years. Table 11 presents the appropriateness ratings for agency project staff experience.

Table 11 - Agency Project Staff Experience Factor Appropriateness Ratings

Agency Project Staff Experience	Determin.	Assure.	Var.	Over.	Accept.
<5 years	+	+	+	-	- *
5 years - 10years	+	+	+	+	+
10 years - 20 years	++*	++	++	++	++
>20 years	+	+	++	++	++
* Should not be the determining factor and should be considered in conjunction with the other factors.					

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, ten to twenty years of experience is "very appropriate" for all QAOs which reflects a variety of experience levels within the project team.

The amount of quality 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, concessionaire). The categories and associated appropriateness ratings are summarized in Table 12.

Table 12 –Shift in Agency Quality Risk Factor Appropriateness Ratings

Shift the Quality Risk Away from the Agency	**Determin.**	**Assure.**	**Var.**	**Over.**	**Accept.**
All	X	X	X	++	++
Some QA and some QC	-	-	++	++	+
Some QA	- *	-	+	++	+*
Some QC	+ *	+	+	++	X
None	++	-	-	X	X
* Should not be the determining factor and should be considered in conjunction with the other factors.					

The five categories for the amount of quality shift away from the agency closely align with the definitions of the fundamental QAOs. For example, Deterministic keeps all control with the 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 responsibility. Assurance and Variable shift at a minimum some of the project quality responsibility 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 responsibility to other project team members, each of these QAOs is a "fatal flaw."

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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 13 summarizes the associated appropriateness ratings.

Table 13 – Industry Ability to Manage their Own Quality Factor Appropriateness Ratings

Industry Ability to Manage their Own Quality	**Determin.**	**Assure.**	**Var.**	**Over.**	**Accept.**
Low	++	+	+	-	X
Medium	+	+	+	+	+
High	-*	+	+	++	++
* Should not be the determining factor and should be considered in conjunction with the other factors.					

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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 the 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 14.

Table 14 – Trust between Agency and Industry Factor Appropriateness Ratings

Trust Between Agency and Industry	**Determin.**	**Assure.**	**Var.**	**Over.**	**Accept.**
Low	++	+	+	-	X
Moderate	+	+	+	+	+
High	+	++	++	++	++
* Should not be the determining factor and should be considered in conjunction with the other factors.					

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 the collaborative needs of each of these QAOs that, in turn, require trust. A moderate level of trust is "appropriate" for all QAOs. While 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.

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3.6.8 **Summary and Conclusions**

This research identified ten 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 for 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 an important selection factor. Its importance is verified by the fact that the project delivery method has the most diversity in appropriateness ratings and thereby has the most impact on the QAO selection.

Some factors' effects on the selection of a QAO were particularly interesting. Specifically, public interest factors were not found to be influential in the selection of a QAO. This finding is easily explained because the public does not necessarily get involved in the production or management of quality. The public wants a quality project, but is not responsible for overseeing quality. The agency culture selection factor was originally expected to have appropriateness ratings closely aligned to the amount of change each of the QAOs required of the SHA. However, the appropriateness ratings were not diverse, indicating that culture is not as influential in the selection of a QAO as originally anticipated.

Six out of the ten 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, shift quality risk 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 with "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 more influence in the selection of the project QAO. One might question 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 not. 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 the SHA 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.

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4.0 Quality Assurance Organization Selection Tool

This section presents the culmination of all of the research, the QAO decision support tool. The first section presents a brief overview of highway project QAOs. This is followed by a statement of the research goals, the claimed contributions and the predicted impact of the research. Finally, the third paper, *Project Quality Assurance Organization Selection for Highway Design and Construction Projects,* is presented. This paper includes details regarding the research methodology, an introduction to the decision support tool, an example of the use of the decision support tool and future research. The QAO decision support tool is included in Appendix G and the blank forms and ratings required to implement the decision support tool can be found in Appendix G.2.

4.1 Overview

While understanding that today's highway industry requires alternative QAOs to be implemented due to alternative project delivery methods, and reduction of SHA staffing levels, SHAs have not yet developed a consistent, transparent, and justifiable method for the selection of QAO on a project by project basis. The quality roles and responsibilities are traditionally defined for design bid build projects through requirements and regulations. Once an alternative delivery method is implemented, DB, CMGC or PPP, a few agencies have defined the quality roles and regulations for projects based solely on the project delivery method and others leave it up to the project staff or past experiences. The QAO decision support tool is applicable for all project delivery methods and provides a consistent, transparent and justifiable process for the selection of the most appropriate QAO based on more than just the project delivery method or limited past experiences of project staff. Additionally the QAO decision support tool provides further understanding as to the impacts the selection factors have on the different QAOs. The

third of three papers comprising this dissertation is presented in this section. It presents the QAO decision support tool as well as the background and methodology used to develop the tool.

4.2 Research goals

The goal of this final phase of the research was to provide the industry with a tool to guide the QAO selection process. The tool needed to not only aid in the selection of an appropriate QAO but also act as a catalyst to discuss the impact and implications of each of the fundamental QAOs for the project at hand. Additionally the tool needed to provide the industry with a consistent, transparent, and justifiable process for QAO selection. The tool accomplishes all of the above needs.

4.3 Research approach and methods

The QAO decision support tool was developed based on the results of the research from the previous section and includes the following:

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1. Identification of the fundamental QAOs
2. Identification of the factors that influence the selection of a QAO
3. Determination of the relationships between the fundamental QAOs and the selection factors.

A process flow chart for the tool was developed to ensure the goal and needs of the research were being addressed. The research results were used to convert the process flow chart to a tool consisting of standardized analysis forms for completion by the SHAs using the provided appropriateness ratings and rating explanations. The QAO decision support tool allows the SHA to make an informed, consistent, transparent and justifiable QAO selection. Additionally, the process provides guidance as to the implications of each of the selection factors on the project QAO. The details of the research approach utilized in the development of the QAO decision

support tool is further discussed in the paper entitled *Project Quality Assurance Organization Selection for Highway Design and Construction Projects*. Also the entire QAO decision support tool is included in Appendix G.

4.4 Claimed contributions of the research

SHAs have been using informal methods, or have been attempting to adapt previous in house requirements and regulations to determine the project QAO. The results of this research provide the SHAs with a consistent, transparent and justifiable process to select a QAO for a specific project; which is needed because the QAO selection can have implications as to the required qualifications of the contractor able to bid on the project (level of contractor ability to manage their own quality). The QAO decision support tool also aids the agency in the selection of a project QAO through the evaluation of each of the fundamental project QAOs for each selection factor to determine the most appropriate ones and eliminate ones that have fatal flaws.

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4.5 Predicted impact

The construction industry has been attempting to adapt the traditional approach to project quality management in response to alternative project delivery methods and reductions of staff. However, their only method available to the agency to gain understanding of the impacts of how alternative project QAOs impact a project is through trial and error. The decision support tool provides the SHA with an ability to make an informed decision for the selection of a project QAO and the industry an understanding as to why the selection was made and the implications of the selection. The QAO decision support tools will also limit the trial and error factor which will provide improved efficiency within the project quality organization. Ultimately, project success should be improved by the selection of the appropriate project QAO.

4.6 Paper 3 - Project Quality Assurance Organization Selection for Highway Design and Construction Projects

4.6.1 Abstract

The assignment of project quality roles and responsibilities in the highway industry makes up a project quality assurance organization (QAO). Historically all project quality roles and responsibilities have been assigned to the state highway agency (SHA), an accepted and well-understood practice in the industry. However, increasing use of alternative project delivery methods and reductions in SHA staffing are having an impact on traditional QAO practices. In response, SHAs are increasingly selecting QAOs in an informal manner due to time constraints, limited staff knowledge and experience, and a lack of guidance from the research community. Most highway quality research focuses on inspections, observations, corporate quality, warranties, and materials testing, resulting in a gap in the research about shifts in roles and responsibilities in project QAOs. This research begins to bridge this gap by investigating and identifying fundamental QAOs in the industry, identifying factors that influence the selection of QAOs, exploring relationships between QAOs and selection factors, and presenting a systematic process to assist SHAs in selecting QAOs. The process presented here provides a consistent, efficient, justifiable, and defensible approach for selecting project QAOs. The QAO selection process also provides SHAs with opportunities for identifying, discussing, and understanding potential impacts of different QAOs on different projects.

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4.6.2 Introduction

The highway industry has been experiencing growth in the implementation of alternative project delivery methods and, at the same time, reductions in state highway agency (SHA) staffing levels. Each of these changes has a direct impact on the assignment of roles and

responsibilities for project quality assurance, and state highway agencies (SHAs) have reacted to these changes in an informal manner. A project quality assurance organization (QAO) is defined in this research as the assignment of responsibilities and the relationships of quality roles in a highway project, both for design and construction. A QAO is analogous to a company organizational chart that assigns the roles and responsibilities within the company and identifies the relationships between these roles and responsibilities. In the highway industry, project quality roles and responsibilities include the following: project acceptance, design acceptance, construction acceptance, design quality assurance, construction quality assurance, design quality control, and construction quality control. Historically all project quality roles and responsibilities have been assigned to the state highway agency (SHA), an accepted and well-understood practice in the industry.

However, increasing use of alternative project delivery methods and reductions in SHA staffing are having an impact on traditional QAO practices, which means that project quality roles and responsibilities are shifting the point in time when someone other than the SHA is required to take on some quality assurance/quality control (QA/QC) roles for both design and construction. When shifts in project QAOs are required, agencies typically assign quality roles and responsibilities in an informal manner because of both knowledge and time constraints. This informal process can result in a lack of understanding of the impacts of shifting quality roles and responsibilities and does not provide a QAO selection that is justifiable and defensible. Additionally, there is little research pertaining to highway project QAOs to aid in the QAO selection process; rather, research has focused on organizational quality management, inspection, observation, specifications, pay factors, and warranties.

The purpose of this paper is to present a research-based process tool that accounts for selection factors that are specific to individual projects and that provide guidance in the selection of an appropriate QAO. This paper first briefly describes the research that identified five fundamental QAOs in the highway industry and the factors that influence the selection of a QAO, then describes the relationships between the appropriateness levels of the five QAOs and the selection factors. Next the paper uses a case study to demonstrate the tool that is designed to provide a consistent, justifiable and defensible process for selecting appropriate project QAOs in the highway industry and explores additional understandings of the impacts of the selection of an alternative project QAO.

4.6.3 **Background**

Project delivery methods define the roles and responsibilities of the parties involved in a project (Oyetunji and Anderson 2006; Molenaar and et al. 2008; Touran et al. 2009). QA is one role and responsibility area that is impacted by the project delivery method. Gransberg et al. state that the issues of alternative project delivery method and project quality assurance have become interrelated (Gransberg et al. 2010). Alternative project delivery is going to continue to grow in the highway industry because of the financial and personnel constraints on the industry as well as the need to deliver projects in a more timely fashion (FHWA 12/16/2011; Miron et al. 2008). Further, the traditional roles and responsibilities for QA/QC are changing because SHAs are increasingly using consultants for activities such as testing, inspection, and design (Hughes et al. 2005; Smith et al. 1998).

QAOs have been adjusting to the needs of the alternative delivery methods on a project-by-project basis because of a lack of available guidance. For consultants, concessionaires (private company or venture of companies in a public private partnership), or contractors to

appropriately and accurately respond to requests for proposals (RFP) and requests for qualifications (RFQ), clear identification of the quality roles and responsibilities of responders is required. There is a significant amount of investment and risk in SHAs creating project-by-project QAOs, and if they are not clearly thought out and communicated within RFPs, then the agency does not get the best possible proposals.

There has also been a trend in the reduction of SHA staffing, which has resulted in the need to use alternative delivery techniques. In *State DOT Management Techniques for Materials and Construction Acceptance*, Smith asserts that "personnel losses have been a major factor in the changes influencing the materials and construction acceptance process" (Smith et al. 1998). In the 1990s, many SHAs experienced downsizing, which not only reduced the number of people able to manage increasing workloads but also had an impact on the expertise within SHAs. No SHA departments, including design, testing and inspection, were exempt from downsizing. As a result, QC testing and inspection that had previously been the responsibility of the agency started to shift to contractors and the agencies took on a role of acceptance. (Smith et al. 1998). In response, in 1995, 23 CFR 637B was revised to allow contractor QC test results to be used by agencies for acceptance.

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However, research in the highway design and construction industry has not kept pace with these quality management developments as most of the research about highway quality has focused on construction QC, such as inspections, materials, testing, observation, assurance, and specifications (Hughes et al. 2005; Smith et al. 1998; Minchin et al. 2008; Miron et al. 2008; Erickson 1989). Additionally, in the early 1990s quality research in all of construction focused on the implementation of the quality revolution, such as TQM, ISO 9000, and the Baldridge award, taking place in the manufacturing sector (Minchin et al. 2008; Chini and Valdez 2003;

Dikmen et al. 2005; Kasi 1995; Elliot 1991; Schmitt et al. 2000; Burati Jr. et al. 1992; Burati Jr. 1991; Arditi and Lee 2004; Arditi and Gunaydin 1997; Minchin Jr. et al. 2010; Minchin et al. 2005). However, the focus of this research was on improving the quality of independent organizations, not on improving project QAOs (Kasi 1995; Burati Jr. 1992; Burati Jr. et al. 1992; Oswald and Burati Jr. 1992; Deffenbaugh 1993). However, Gransberg et al. identified highway quality project assurance roles and tasks as well as the associated relationships and briefly commented on the assignment of quality assurance roles within a CM at risk project (Gransberg et al. 2008).

The project selection tool is intended to assist the agency in selecting the most appropriate QAOs for a project through a justifiable and defensible process. Also the selection tool allows for the impacts of alternative QAO to be identified, discussed and addressed prior to implementation.

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4.6.4 **Research Approach**

The following sections discuss the three activities and outcomes—identifying fundamental QAOs and QAO selection factors and establishing relationships between the QAOs and the factors—that were used to design and test the new QAO selection process tool.

Identifying Fundamental Project QAOs

Five fundamental QAOs were identified in four distinct research phases (Kraft and Molenaar 2013). A thorough literature review and national survey were conducted, and a theoretical framework with 14 different QAOs was identified. Second, a content analysis and review of documents from 66 projects across the United States identified 9 of the 14 QAOs in the framework that are currently in use in the highway industry. The third phase reduced the nine

current industry QAOs to five fundamental QAOs based on an assessment of roles and responsibilities of SHAs. The five fundamental QAOs are: Deterministic, Assurance, Variable, Oversight, and Acceptance. Table 1 summarizes the assignment of the roles and responsibilities for each QAO and each are defined below.

The *Deterministic QAO* is the traditional approach to quality in the highway industry. The agency retains all control for all quality on the project. In the *Assurance QAO*, the agency is responsible for all aspects of the quality assurance 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 DB project, the design phase may take a proactive approach by assigning both QA and QC responsibilities to the party contracted to perform the scope of work, while the construction phase may take a reactive approach by assigning QC responsibility only to the party contracted to perform the scope of work.

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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 currently only used in PPP arrangements, and the agencies are responsible for verification testing and final acceptance. All other quality roles and responsibilities are assigned to the concessionaire.

After the five fundamental QAOs were identified in phase three, a panel of six industry experts reviewed those findings. Experts on the panel had cumulative total of 163 years of industry experience, with each individual having a minimum of 15 years of experience. The panel validated that the five fundamental QAOs accurately reflected and were all encompassing of current industry practices.

The identification of the five fundamental QAOs forms the foundation for identifying project QAO selection factors, was the basis for constructing the QAO selection process tool, and provides a consistent and efficient approach to QAO planning. The fundamental QAOs also help SHAs understand what it means to select a particular QAO.

Identifying QAO Selection Factors

The factors that influence the selection of an appropriate QAO for a project must be identified and the relationships between the selection factors must be accounted for. Identifying the factors involved interviews with agency project staff from 23 projects in 13 states. The interview process had two goals, first to identify the factors and second, to confirm that there is not a process currently in place for an agency to select a project QAO when the default QAO is not appropriate for projects. This was confirmed, and the interviewees reported that most often when an alternative QAO is needed (i.e., the Deterministic QAO is not appropriate) for a project, the selection is left up to the project team without guidance or a standardized, transparent decision process.

Ten factors that influence the selection of a project QAO were identified through interviews. The ten factors fell into three categories: project, agency, and industry (**Error! Reference source not found.**). Any factors that were a condition of circumstances occurring after the RFP process, such as the experience of the contractor's project management staff, were excluded because this information is unknown at the time QAO selection for a project takes place.

Project Category Factors

Project factors are characteristics of specific projects. The four factors that influence the selection of a QAO are: 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. *Project complexity* is related to how similar the project is to a typical project. 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 schedule sensitivity refers to the vulnerability of the project schedule to changes due to delays, conflicts, and/or events outside of the designer and/or contractor's control, such as coordination of observations, inspections and/or testing performed by the agency. *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).

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Agency Category Factors

Agency factors are characteristics and abilities of SHAs that are responsible for 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 the agency's attitude toward the implementation of change in project management techniques. *Agency staffing availability* stems from the SHAs across the nation being downsized, and is determined by the quantity of agency staff available to commit to projects as compared to

the traditional levels of agency staffing for comparable projects. *Agency staffing experience* is the average number of years of experience of the agency staff committed to the project.

The amount of quality shift away from the agency has to do with shifting responsibility for quality to another project participant. These shifts refer to the amount of liability for the management of the project's quality that an agency wants to shift to another project partner (e.g., contractor, designer, engineer, design builder, CMGC, concessionaire).

Industry Factors

Industry factors are characteristics or abilities of 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. This competence may result from either education, training, experience, industry culture or a combination of these. *The level of trust between the industry and agency* is important because as agency control over a project is reduced, increased levels of trust are required because the project becomes more collaborative. 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.

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The next step involved is establishing relationships between each of the selection factors and each fundamental QAO to understand how the selection factors influence project QAO selection.

4.6.5 **Establishing Relationships Between Selection Factors and QAOs**

A Delphi study was conducted to establish the relationships between the ten selection factors, and the five fundamental QAOs. A panel of 12 experts rated the appropriateness of each QAO to each category of selection factor. Each expert was required to have a minimum of 15 years of industry experience.

Four appropriateness ratings were used for the Delphi study, fatal flaw (denoted with X), least appropriate (–), appropriate (+), and most appropriate (++). After three rounds of the Delphi study 93% of the ratings had reached consensus in the Delphi study; the remaining 7% either had an outlier or were torn between two ratings that included appropriate and a rating on either side of appropriate. The selection factors that did not reach consensus require consideration in conjunction with the other factors; these factors are marked with * in the summary Table 15.

Table 15 - Selection factor appropriateness rating sheet

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Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Project delivery method					
Design bid build	++	+	+	+*	-
Design build	-	-	+	++	-
CMGC/CMAR	-	+	+	++	+
P3/DBOM	X	-	-	+	++
Project size					
<$10M	++	++	+	+*	-
$10M - $50M	++	++	+	+	+
$50M-$500M	-	+	+	++	++ *

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
$500M - $2B	X	-	+	++*	++
>$2B	X	-	+	++*	++
Availability of agency project staff					
fully staffed	++	+	+	+	X
moderately staffed	-	+	+	+	-
minimally staffed	X	-	+	++	++
Industry ability to manage their own quality					
Low	++	+	+	-	X
Medium	+	+	+	+	+
High	-*	+	+	++	++
Trust between agency and industry					
Low	++	+	+	-	X
Moderate	+	+	+	+	+
High	+	++	++	++	++
Shift the quality risk away from the agency					
All	X	X	X	++	++
Some QA and some QC	-	-	++	++	+
Some QA	- *	-	+	++	+*
Some QC	+ *	+	+	++	X
None	++	-	-	X	X

8

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Project complexity					
Low	++	+	+	+	+
Medium	+	+	+	+*	+
High	-	+	++	++	++
Schedule sensitivity					
Low	+	+	+	+	+
Medium	-	+	+	+	+
High	-	+	+	++	++
Agency project staff experience					
<5 years	+	+	+	-	- *
5 years - 10years	+	+	+	+	+
10 years - 20 years	++*	++	++	++	++
>20 years	+	+	++	++	++
Agency culture					
Traditional	++	+	-	-	-
Moderate	+	+	+	+	+
Progressive	-	+	+	++	++

*needs to be considered in conjunction with the other factors.

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The selection factors and the appropriateness ratings presented in this section form the basis for the development of the project QAO selection process tool with the intent of providing guidance, transparency, and understanding to the process.

4.6.6 **The QAO Selection process Tool**

The goal of the QAO selection process is to help SHAs identify the most appropriate QAO for projects at hand by rating the appropriateness of the five fundamental QAOs according to the categories of selection factors that apply to the projects. We suggest that project QAOs be selected before the RFP or RFQ process for services (design, engineering, construction, and consulting) begins so project quality roles and responsibilities can be accurately accounted for in responses to project RFPs or RFQs.

The QAO selection process tool uses a three-step process for selecting the most appropriate QAOs for a particular project (Figure 14). The three steps are identifying barriers to QAO adoption, using the selection process profile form to prepare a selection factor profile, and using the QAO factor analysis form to select the most appropriate QAO. The steps are discussed in more detail in the following sections.

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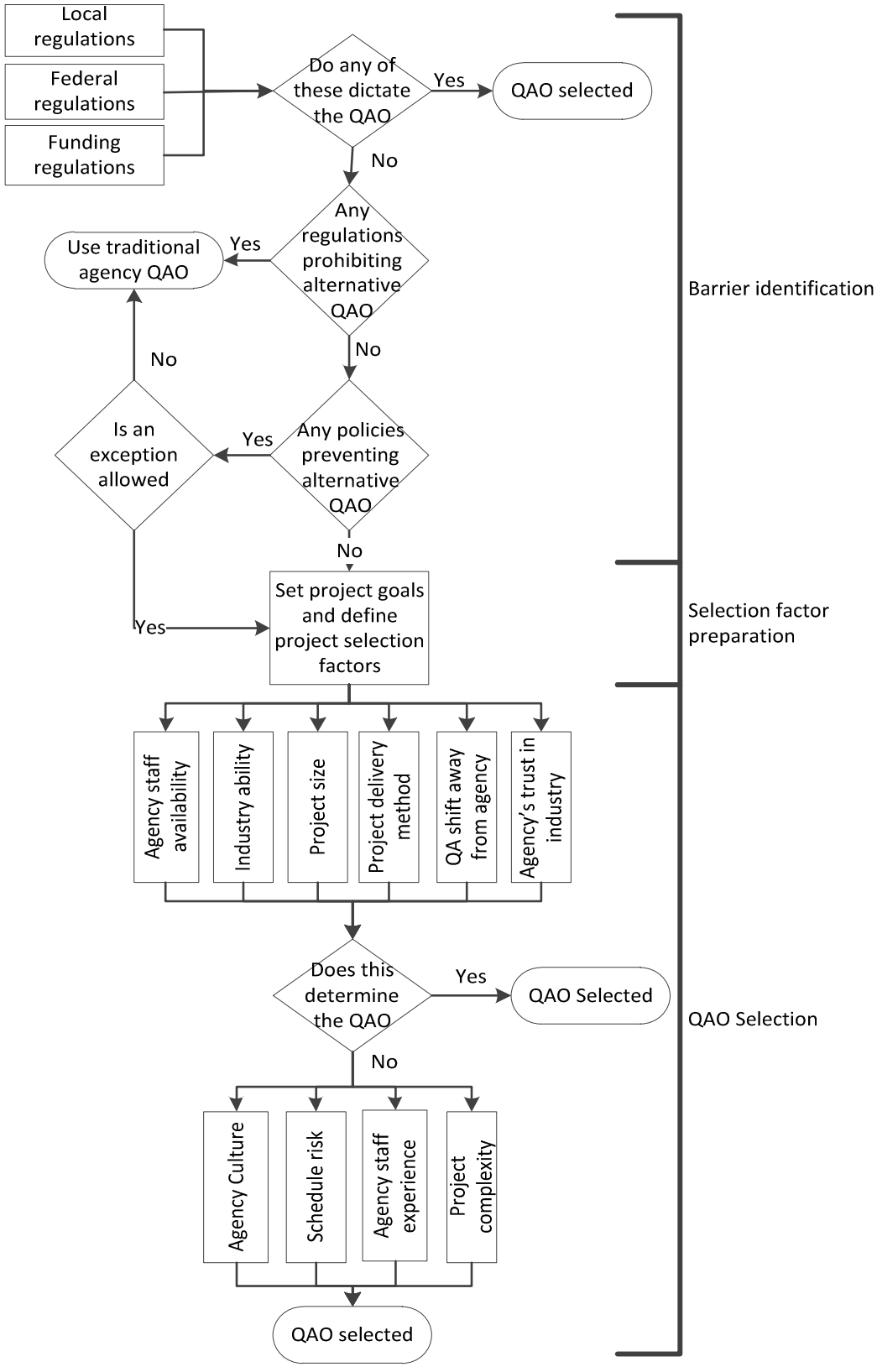

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Figure 14 - Project QAO selection process

Step 1. Identify Barriers to QAO Selection

Barriers are regulations or policies that either prevent the use of an alternative QAO or dictate that a specific QAO be used on the project. Possible barriers include, but are not limited to, federal, local, or funding regulations; political issues; and agency policies. It is important to identify these barriers at the beginning of QAO selection process because it is very likely that if barriers exist, the QAO selection process will begin and end at this step. For example, when a specific QAO is required, that QAO must be selected.

Step 2. Preparing the Selection Factor Profile

The goal of the second step is to prepare the project QAO selection factor profile. The selection factor profile identifies which category of each selection factor applies to the project being analyzed.

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The information in the selection factor profile will be used in step three to identify the appropriateness ratings for each selection factor that applies to the project. For some selection factors it is easy to identify which category applies to the project, such as project budget or project delivery method; however, identifying the correct category for selection factors such as the amount of quality responsibility the agency wants to shift to other project participants, requires the project goals to be established and understood so that the correct selection factor category is determined. Also the project goals should provide the user with further understanding of the motivation of the project on a whole as to why the project is diverging from the standard default project QAO for the agency, ensuring that the agency is making a fully educated decision. Once the goals are established the user can complete the project QAO selection factor profile form.

Step 3. Using the QAO Analysis Form to Select an Appropriate QAO

The final step of the QAO selection process is selecting the appropriate QAOs based on a comprehensive understanding of the appropriateness ratings for each QAO that correspond to the category of each of the project selection factors. In this step, the user transcribes the appropriateness ratings for the category of each selection recorded in the project QAO selection factor profile form from step two into the project QAO analysis form.

The four appropriateness ratings that were used for the Delphi study, fatal flaw (denoted with X), least appropriate (–), appropriate (+), and most appropriate (++) are also used in the forms to establish the appropriateness ratings of the factors. 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 least appropriate rating (–) indicates that for the particular selection factor category the QAO can work but is not the best option and if this QAO is implemented there may be extra measures needed to accommodate this particular selection factor. An appropriate rating (+) indicates that the QAO can work for that particular selection factor category meaning it neither harms nor improves the success of the project. Finally the most applicable rating (++) indicates that a project falling into that particular category can be improved by the implementation of the associated QAO.

What follows is an example of how appropriateness ratings for the QAOs are established for the project delivery method selection factor in the project category in Table 8.

Table 8. As the amount of project responsibility shifts away from the agency, design bid build (DBB) to public private partnership (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. One fatal flaw rating corresponds to the implementation of the Deterministic QAO on a PPP project, which also makes sense because the Deterministic QAO requires the agency to retain all control of the quality assurance, but in PPP projects almost all quality control over the project shifts away from the agency to the concessionaire.

Because the Deterministic QAO and the PPP delivery methods are opposite in terms of the involvement of the agency in the management of the project, the fatal flaw rating is accurate. Acceptance is rated least applicable for both DBB and DB because the agency still has some minimal responsibility for the day to day management of the project which does not equate to the very limited amount of quality responsibility the agency retains with the Acceptance QAO.

The project QAO analysis form splits the selection factors are into two groups based on whether a selection factor has a fatal flaw rating in any category. Primary selection factors are those factors that have at least one fatal flaw rating and secondary selection factors are those factors that do not have any fatal flaw ratings. The reason for the two steps is to quickly eliminate any of the QAOs that have a fatal flaw so that they are not incorrectly considered over the course of the selection process.

The first step in the QAO selection step is to transcribe the appropriateness ratings for the category of each of the primary selection factors that corresponds to the project from the appropriateness ratings sheet into the project QAO analysis form. If any of the primary selection factors have a fatal flaw rating then the respective QAO is eliminated as an appropriate QAO option for the project being analyzed. If the potential QAOs are not narrowed down to two or less options at the completion of the primary selection factors then the same process is used for

the secondary selection factors. If the potential QAOs are narrowed down to two or less the user can continue on to the secondary selection factors to further understand the potential QAOs, investigate the details of each project selection factor ratings and/or make a final selection of the project QAO.

This section has presented the three steps of the project QAO selection tool: barrier identification, selection factor preparation and QAO selection. The following section demonstrates the use of the tool and validates the tool by testing the tool with an actual industry project.

4.6.7 **Demonstration and validation project**

A highway project in a state in the mid section of the United States was selected to demonstrate and validate the project QAO selection process tool; the exact location is not identified to protect the identity of persons who participated in the research. The scope of the project was to construct a landmark river bridge(s); rehabilitate or replace approximately four miles of interstate; improve traffic operations, geometrics, and safety; and add mainline capacity.

The budget for the DB project was approximately $230M. The SHA selected the DB method to reduce/compress/accelerate project delivery period; get early construction contractor involvement; encourage innovation; compete different design solutions through the proposal process; and address flexibility needs during the construction phase. This SHA has been very open to trying new delivery methods and does have a focus on shifting more quality responsibilities away from the agency. The agency and the local contracting and engineering industry have built up high levels of mutual trust as a result of increasing use of alternative delivery methods in the state. The agency has experienced staff reductions over the past decade and significant losses of expertise through retirements.

The first step of the project QAO selection tool is identifying barriers to the implementation of alternative project QAO. The demonstration project is in a state that is leading the way in shifting quality responsibility away from the agency, and no state or local barriers preventing alternative QAO selection were identified. Also no federal regulations pertain to this project that would prohibit the implementation of an alternative QAO. The agency itself is relatively progressive and encourages trying new processes and strategies that can improve projects and overall efficiencies. As such no agency polices exist that prevent alternative QAO implementation. The result of the first step is that all project QAOs are still viable for this project.

The second step of the project QAO selection tool is completing the project QAO selection factor profile form. The project goals were already established, so the selection factor profile form was completed to show the QAO appropriateness ratings for the category of each selection factor corresponding to the project. The completed selection factor form is used in step three.

The third and final step in the project QAO selection tool is using the project QAO analysis form to select the project QAO. This form is completed by transcribing the appropriateness ratings for each QAO to the category of selection factor applicable to the project. The completed project QAO analysis form for the demonstration project is presented in Figure 15. In this case the Deterministic, Assurance, and Variable QAOs had fatal flaw ratings in at least one of the primary selection factors and as such they were deemed inappropriate. This left two potential QAO options, Oversight and Acceptance. The secondary selection factors for these QAOs were analyzed to further understand the two possible QAOs so a final QAO decision could be made with confidence and the appropriate considerations.

The project delivery method for this project is DB. The appropriateness ratings for each QAO for the design build category were transcribed into the project QAO analysis form Figure 15 in the project delivery method row. Both Deterministic and Assurance are rated as least appropriate, but are not fatal flaws. However because of the amount of project responsibility that DB typically shifts to the design builder, the Deterministic and Assurance QAOs do not shift enough quality responsibility to the design builder to be in line with the intention of the delivery method. Deterministic and Assurance have been used on DB projects when the agency is minimally experienced in DB and is not comfortable with shifting too much of the quality responsibility.

The Acceptance QAO shifts too much responsibility away from the agency because for a DB project and as a result incurs a least appropriate rating. The Oversight QAO is considered the best fit because the design builder is responsible for delivering both the design and construction of the project while the agency is responsible for clearly stating the requirements for the project but is not involved in the day-to-day management of project design or construction. The Oversight QAO allows the agency to ensure that the design builder is meeting the requirements of the project.

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Primary selection factors	**Determin.**	**Assure.**	**Var.**	**Over.**	**Accept.**
Agency staff availability	X	–	+	++	++
Trust between agency and industry	+	++	++	++	++
Industry quality ability	+	+	+	+	+
Project delivery method	–	–	+	++	–
Project size	–	+	+	++	++

Quality responsibility to be shifted from agency	X	X	X	++	++
Tally of primary selection factor results	**X**	**X**	**X**	**++**	**++**
Secondary selection factors	**Determin.**	**Assure.**	**Var.**	**Over.**	**Accept.**
Project complexity	n/a	n/a	n/a	+	+
Project schedule sensitivity	n/a	n/a	n/a	++	++
Agency culture	n/a	n/a	n/a	+	+
Agency staff experience	n/a	n/a	n/a	++	++
Tally of secondary selection factor results	n/a	n/a	n/a	++	++
Rating key: X Fatal Flaw –Least Appropriate + Appropriate ++ Most Appropriate					

9 Figure 15 - Completed project QAO analysis form for the demonstration project.

The project QAO selection tool indicated that the Oversight and Acceptance QAOs are the most appropriate for the project. In cases like this, because projects and agencies are unique, it is up to the agency at this point to decide whether the Oversight or Acceptance QAO would be the best fit for the project. At the time this tool was developed, the demonstration project was already well into construction, so the tool could not be used to select the QAO for the project. However, the Oversight QAO, which is one of the options indicated by the QAO selection tool, was implemented for the demonstration project, which seems to further validate the tool.

4.6.8 **Conclusions**

A project QAO is the assignment of the quality roles and responsibilities on a project. Historically in the highway industry there was only one option for a project QAO because agencies were responsible for all quality assurance roles and responsibilities on a project.

However this is shifting due to the increasing use of alternative project delivery methods and the reduction of state highway agency staffing levels. In response, agencies have been changing the traditional project QAO by shifting the assignment of the roles and responsibilities in an informal manner because of a lack of time, knowledge, and available guidance and research on project quality assurance organization. This paper builds on work done by Arditi, Burati and Minchin and begins to close the gap on the guidance and research on project quality assurance organization through the presentation of a project QAO selection process tool. The tool is based on the identification of five fundamental project QAOs and ten project QAO selection factors that fall in three categories and accounts for relationships between the QAOs and the selection factors. The selection tool provides the industry with a consistent, transparent, justifiable, and defensible approach to the selection of a project QAO.

However, this research is only the beginning of research that more fully explores the impacts and implementations of QAOs. This research does not attempt to evaluate or judge the performance level of any of the fundamental QAOs. Also the fundamental QAOs are based on current industry practices. Although possible future circumstances were considered during the research to identify the five fundamental QAOs, future research may be called for as the highway industry evolves. Additionally further guidance is needed about how different aspects of projects (e.g., procurement, contracting, staffing levels, specifications, requirements management, payment methods, and qualifications of contractors, engineers and consultants) influence the QAO selection process.

5.0 Research Conclusions

This section presents the conclusions of the research. First is the summary of the research findings. A discussion of the practical application of the research follows. Next is a discussion of the claimed contributions, the practical application, and the predicted impact of the research. The section closes with a discussion of the limitations of the research, how future work can address them and final conclusions.

5.1 Summary of research findings

This research set out to answer the following primary research question:

How do project factors impact the selection of project QAOs for highway design and construction projects?

Three secondary questions were identified to guide the research: 1) *What are the fundamental characteristics of project QAOs within the highway design and construction industry?* 2) *What are the project factors that influence the selection of the fundamental project QAOs?* 3) *To what level do the project factors influence the selection of a project QAO?*

5.1.1 First phase of research

The first phase of the research answered the first of the secondary questions—*What are the fundamental characteristics of project QAOs within the highway design and construction industry?*—by defining the term QAO and identifying and defining the five fundamental QAOs in the highway industry. The five fundamental QAOs in the highway industry are

- Deterministic – The owner agency retains all control for all quality on the project. This is the traditional approach to quality in the highway industry.
- Assurance – The owner agency is responsible for all aspects of QA except for QC.

- Variable – The owner agency is responsible for design QC/QA and construction QA or design QA and construction QA/QC. This model has two approaches to construction and design quality: proactive and reactive.
    - In the proactive approach, the owner agency assigns responsibility for both QA and QC to the party contracted to perform the scope of work.
    - In the reactive approach, the owner agency assigns responsibility for only QC to the party contracted to perform the scope of work.
- Oversight – The owner agency is responsible for oversight on the project; the owner agency assigns the roles of design QA, design QC, construction QA and construction QC to the parties that are contracted to perform these scopes of work.
- Acceptance – The owner agency is responsible for verification testing and final acceptance. The owner agency assigns all other quality roles and responsibilities to the concessionaire. Acceptance QAO currently is only used in a PPP arrangement.

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5.1.2 **Second Phase of Research**

The second phase of the research answered the second and third secondary research questions—*What are the project factors that influence the selection of the fundamental project QAOs?* and *To what level do the project factors influence the selection of a project QAO?*—by identifying selection factors and determining the relationship between the selection factors and the fundamental QAOs. The research identified and defined ten factors that influence the selection of a project QAO. The selection factors, indentified through structured interviews with SHA project staff from across the country, were grouped into three categories: agency, industry and project. Definitions for the ten factors follow.

Agency culture (agency factor) – The agency's attitude toward the implementation of change in project management techniques.

Agency staffing ability (agency factor) – The quantity of agency project staff available to be committed to the project as compared to traditional levels.

Agency staff experience (agency factor) – The average number of years of experience of the agency staff committed to the project.

Quality responsibility to shift away from the agency (agency factor) – The amount of liability for the management of the project's quality that the agency wants to shift to another project partner (contractor, designer, engineer, design builder, CMGC, concessionaire).

Industry's ability to manage their own quality (industry factor) – The local industry's level of competence in managing their own quality. The industry includes both the design and construction communities.

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Trust between the agency and the industry (industry factor) – The level of agency confidence that project decisions will be based on achieving the best results for the project, rather than the individual or specific company.

Project delivery method (project factor) – "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 complexity (project factor) – The intricacy of project scope as compared to typical project in the same locale stemming from programming requirements, design constraints, construction methods, site conditions, budget and funding constraints, quality requirements, etc.

Project size (project factor) – The total dollar value of the project's design and construction budgets.

Schedule sensitivity (project factor) – The vulnerability of the project schedule to changes due to delays, conflicts, and/or events outside of the designer's and/or contractor's control, such as coordination of observations, inspections and/or testing performed by the agency.

The relationships between the selection factors and the fundamental QAOs were determined through appropriateness ratings using a three-round Delphi study. The appropriateness scale used for all rounds of the Delphi study is: fatal flaw (denoted with X), less than appropriate (–), appropriate (+), and very appropriate (++). 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 appropriateness rating for each fundamental QAO to each of the selection factor categories is shown in Table 15. The selection factors that did not reach consensus should not be a sole determining factor when selecting a QAO, but they can be used in conjunction with other factors.

The compilation of all of the research provides an understanding of how multiple factors—not just project factors, but also agency and industry factors—influence the selection of a QAO on a highway design and construction project. Thus, the compilation of the research results answers the primary research question.

5.2 Claimed contributions

This research extends the highway quality management research of Arditi (Arditi and Gunaydin 1997, Arditi and Lee 2004), Burati (Burati Jr. 1992; Burati Jr. 1991, Burati Jr. et al.

1992; Oswald and Burati Jr. 1992), and Minchin (Minchin et al. 2005, Minchin et al. 2008, Minchin et al 2010) by answering how project factors impact the selection of project QAOs for highway design and construction projects. The research has added the following contributions to the existing knowledge base:

- The definition of QAO;
- The identification and definition of the five fundamental QAOs for highway design and construction projects;
- The identification and definition of the ten factors influencing the selection of a QAO for highway design and construction projects;
- The determination of the relationships between all selection factors and each fundamental QAO;
- An increased understanding of the impacts that alternative QAOs have on highway design and construction projects.

The research defines the roles and responsibilities of all project stakeholders (agency, contractor, designer and consultants) in a clear and understandable manner. The research also describes each of the fundamental QAOs through a description of the stakeholder's roles and responsibilities, and the applicable project delivery methods. The results provide a better understanding of the impact that a particular QAO has on a project. With this information, an agency can better anticipate the consequences of using a particular QAO on the management of a highway project. For example, if an agency selects the Oversight QAO, the agency needs to provide additional training for all stakeholders, and the RFP has to include the quality requirements for the project.

The factors that influence the selection of a project QAO have never been previously identified. Through the understanding of the relationship between the selection factors and the fundamental QAOs, not only does this research provide guidance for the selection of a highway project QAO, but also provides further insight for each QAO and the impact of the selection factors on the management of highway project quality. Determining the relationship between the selection factors and the fundamental QAOs also bridges the gap between the fundamental QAOs and the selection factors, and comprehensively answers the primary research question. It provides researchers and practitioners with a framework and common vocabulary for advancing alternative quality management systems in the highway industry.

Finally, the application of the results of this research provides a formal project QAO decision support tool. Prior to this research, SHAs have used informal methods, or have been building upon previous processes used for the assignment of project quality roles and responsibilities. The decision support tool aids SHAs in the selection of a project QAO by determining the most appropriate organization for a specific project based on the appropriateness ratings of each selection factor category to the fundamental QAOs.

5.3 Practical application

This research provides SHAs with guidance on QAOs and their selection through a QAO decision support tool. The tool is based on rigorous and validated research. The decision tool is intended to guide a SHA to the most appropriate QAO for a project, keeping in mind that an agency may have more than one QAO option or may create variants on the five fundamental QAOs. The QAO selection decision support tool consists of three steps:

1. Identify barriers to QAO selection;
2. Prepare the selection factor profile; and

3. Select an appropriate QAO using the QAO Analysis Form.

Using the QAO decision support tool—a consistent, transparent, and justifiable selection method—an SHA will be able to make an informed and well thought out decision to select the most appropriate QAO. They will also document their decision and provide a roadmap for writing their quality management plan.

The purpose of the first step of the QAO selection decision support tool identifies any barriers that would exclude an agency from using of any of the five fundamental QAOs. A few examples of barriers include: political, legal, and funding. The second step identifies the category for each selection factor that applies to the project being analyzed. The third and final step guides an SHA in the selection of a QAO by identifying the most appropriate organization based on the appropriateness ratings that correspond to the category of each selection factor determined in step two.

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5.4 Predicted impact of the research

Due to the lack of knowledge in this area, there is a need for this research in both academia and industry. Within the highway design and construction industry, the research on quality has primarily considered the construction phase of a project and focused on specifications and construction QC topic areas. However the industry needs to better understand the impact of project quality as a whole due to the growing acceptance of alternative project delivery methods and the reduction of SHA workforces.

The research impacts academia by providing a foundation for highway quality research at the project organization level, rather than the quality component level, i.e., construction QC. This research also impacts academia by defining the project QAO. It builds upon work previously done in the areas of highway quality assurance, and alternative project delivery

methods (Hughes et al. 2005; Smith et al. 1998; Erickson 1989; Gransberg and Molenaar 2004). The results of the research construct a foundation for the management of highway design and construction project quality on which future research regarding highway project quality management can be conducted.

The construction industry has been attempting to adapt the traditional approach to project quality management in response to alternative project delivery methods and reductions of staff. However, currently, the only method available to an agency to gain understanding of the impacts of how alternative project QAOs impact a project is through trial and error. This research formalizes the five fundamental project QAOs, which will provide organizational learning and allow for the project team to better prepare for the implementation of an alternative project QAO. The research explains how quality management impacts a project through exploring the relationships between the QAO selection factors and the fundamental QAOs. Additionally, the research provides the industry with a decision support tool which will lead the agency to make an informed decision when it selections a project QAO. The QAO decision support tools should limit the trial and error factor and provide improved efficiency within the project quality organization.

5.5 Limitations

The research answered the question, "How do project factors impact the selection of project QAOs for highway design and construction projects?" However the results are limited by the emerging nature and the complexity of the topic. Because of the emerging nature of the topic, there was limited data, limited experience, and limited examples of alternative QAO implementation within the industry. As a result the fundamental QAOs identified by the research are based on QAOs that currently exist in the industry. It is possible that additional

QAOs not identified in this research may develop in the future as the industry becomes more comfortable with alternative project delivery methods and more comfortable with the contractor taking on more responsibility for quality. The development of additional fundamental QAOs implies that the industry is embracing not only alternative project delivery, project management and quality methods, but also developing relationships with contractors that are built up trust, the contractor's expertise, and a willingness to shift more quality responsibility to the contractor.

While there is historical data pertaining to material specifications and material quality in every SHA, there is a lack of data and consistent measures of quality assurance organizations within the industry. It can be speculated that the reason for this is the industry focus on "how to implement alternative quality systems" at this point, rather than evaluating the effectiveness of quality assurance organizations. The development of measures to assess the performance of QAOs is a topic for future research.

The complexity of the topic was evident by a variety of conditions within the industry. This complexity created barriers for the research. For example, there is widespread inconsistent use of quality terminology throughout the industry. The complexity of the topic has resulted in SHAs have differing opinions about the transfer of quality responsibility to the contracting community. Furthermore, during the structured interviews SHAs expressed a need for further guidance regarding quality on a highway project with shifting project roles and responsibilities.

5.6 Future research

The management of highway project quality is an emerging topic. As such, this research was constrained by the data and experiences currently available in the industry. However, there exists opportunity for future research to better evaluate the fundamental QAOs and the selection factors as more data and experience become available. The research has provided a good

foundation, but the limitations result in the need for additional work. The following topics provide some points of departure for future research.

- What level of quality performance results from each QAO? – There is not a method available for consistently measuring the performance of a QAO and whether or not it was the optimal selection for a particular project. This question will be difficult to measure due to the complexity of the topic and the fact that every project has different priorities and goals to measure against. However this question must be answered to truly determine the appropriateness of alternative QAOs.
- Do the need and/or amount of agency staff reduce as the amount of quality responsibility shifts to the industry? – One of the drivers of alternative QAOs is the reduction of SHA staffing and the assumption that alternative QAOs require fewer SHA staff to manage. However research has not shown this to be true. There are anecdotal examples in the industry where it may not necessarily be a reduction in staff that is driving the need, but a reduction in the amount of expertise required across the staff. The importance of the number of staff and the experience level of the staff are indicated by the fact that they are QAO selection factors. In order to fully understand the impact of these factors on highway projects future research is needed to determine the SHA staffing profiles for each QAO.
- How does an SHA implement alternative QAOs? – While this research provides guidance in the selection of a project QAO, that is only the first step. The next step is implementation. Each of the fundamental QAOs have unique needs that

must be considered during the planning and management of a project. This guidance does not fully exist at this time and it is needed in order to successfully implement an alternative QAO.

- Do the fundamental QAOs identified by this research change as the quality practices, project management methods and alternative QAO experience in the industry change? – This research was based on what currently exists in the industry. Because the topic is in its infancy and the industry is constantly evolving, it is possible that additional QAOs will develop. The selection factors may change and the relationships of the QAOs to the selection factors could shift.

5.7 Conclusions

The research identified five fundamental QAOs, ten QAO selection factors and the relationship between each QAO and each selection factor. The five fundamental QAOs covered the most traditional (the SHA retaining the responsibility for quality) to the most alternative (the SHA only performing federally required quality due diligence). All but the Variable QAO seem to progressively build on the previous QAO in the spectrum going from traditional to alternative. The Variable QAO could be considered a default QAO to capture the variations that didn't fit into any of the other four QAOs. Additionally this QAO was not found to be frequently applied in the industry, but remained in the fundamental QAOs due to the fact that the industry experts (both in the interviews and Delphi panel) said that it was valid in the industry and should remain in the fundamental QAOs.

The ten selection factors identified by the research were segregated into three types of selection factors: agency, project and industry. It was not surprising that the selection factors happened to fall into these three categories. What surprised this researcher was the fact that the

traditional selection factors did not focus on risk management internal to the SHA, especially considering the diversity in scope, schedule, budget, and project delivery method of the projects and project staff that participated in the structured interviews. This is most likely due to the fact that there are other factors that are currently much more influential in the selection of a QAO, such as the ability of the industry to manage their own quality. As highway project quality assurance matures, risk management will likely become a selection factor.

The project delivery method selection factor had the most diversity in appropriateness ratings, effectively causing it to have more influence on QAO selection. This finding further validates the statement, "with the growth of alternative project delivery methods in the past few decades, the issues have become interrelated" (Gransberg et al. 2010). Although the shift of quality risk away from the agency selection factor also had a high level of diversity in appropriateness ratings, this was an expected result due to the diverse spectrum of QAOs.

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Based on information collected during the structured interviews with SHA project staff, this researcher expected both agency staff experience and project complexity selection factors to have a higher level of diversity in appropriateness ratings than how they were rated in the Delphi results. During the structured interviews SHA project staff explained that because of the reduction in agency staff experience due to retirements, agency staff experience was one reasons to select an alternative QAO. However, staff with over 20 years of experience received a most appropriate rating for the Acceptance QAO, which is the most alternative QAO from the traditional Deterministic. A possible reason for this discrepancy was found during the Delphi study; the less the SHA is involved in the day-to-day quality assurance/control, the more important it is that the SHA project staff responsible for quality have an even stronger grasp and understanding for the details of the project and project quality.

In the structured interviews, SHA project staff stated that project complexity was another reason for selecting an alternative QAO. A contractor with specialized expertise would be more capable of managing the quality of a project. As a result this researcher expected the more alternative QAOs would be appropriate, if not most appropriate, for a high complexity project. However the research demonstrated that the only rating below appropriate for project complexity was the Deterministic QAO for a highly complex project. These results indicate that, while it is important to consider project complexity and its ramifications on the selection of a QAO, project complexity may not be a dominant factor in the selection when compared to other factors.

The QAO decision support tool is based on the research discussed above, and was developed to guide and educate the industry regarding the selection of an appropriate QAO for a specific project. The tool is expected to be helpful for the industry and improve not just the management of quality, but also the understanding of how the management of quality can impact the overall quality of a product through its entire lifecycle. While the tool has primary and secondary factors, it does not consider any factor more influential in the selection than another; none of the factors are weighted in the tool. SHAs can have different priorities and may have a need to place a higher importance on certain factors. While the tool doesn't necessarily include any sort of selection factor weightings, the tool can be modified by each SHA to address specific agency priorities or a specific project.

Ultimately, the research was successful in answering the primary and secondary research questions. As a result, the research has added to the body of knowledge regarding project quality within the highway industry. The research has also provided the industry with a QAO decision support tool to assist in the selection of a project QAO. This research further provides the

highway industry with a good foundation and path for the future research regarding project quality for highway design and construction projects.

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Appendix A Fundamental QAO quick guide

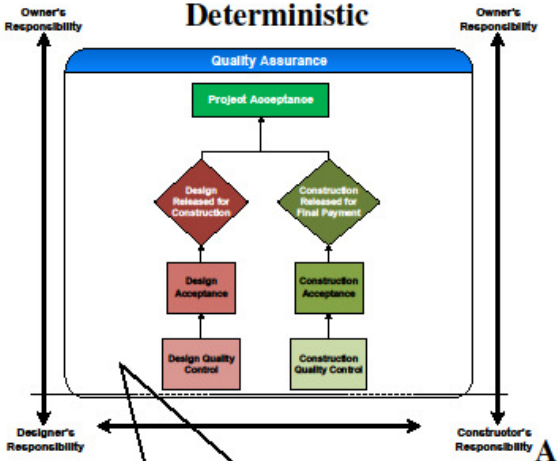
1

Five fundamental highway project quality assurance organizations quick guide

Quality assurance organization (QAO) — The assignment of the roles and responsibilities associated with the quality management of a project from concept through completion.

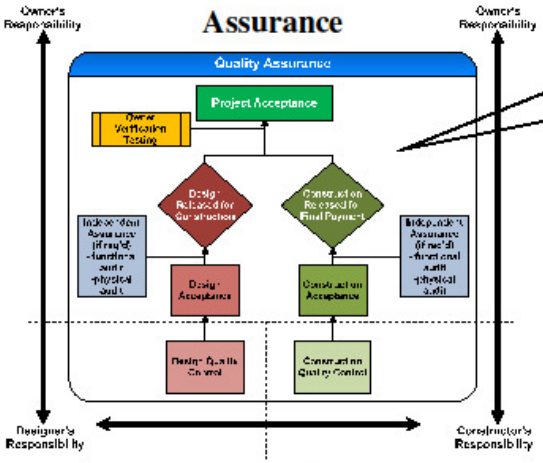
The dotted lines represent the separation of the responsibility for the different project quality roles and responsibilities.

Deterministic



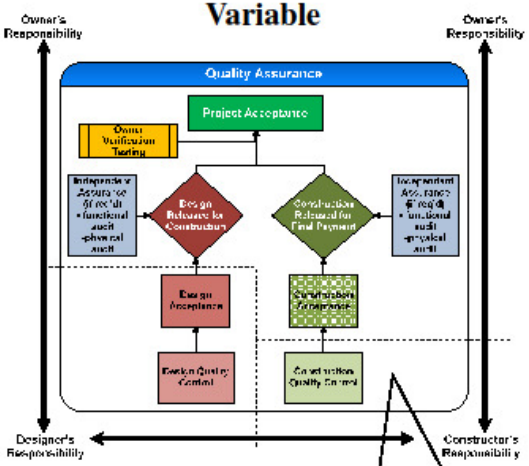
Deterministic:
- Traditional approach to project quality management;
- Owner retains majority of quality responsibilities and control

Assurance



Assurance:
Agency responsible for both design and construction quality assurance.

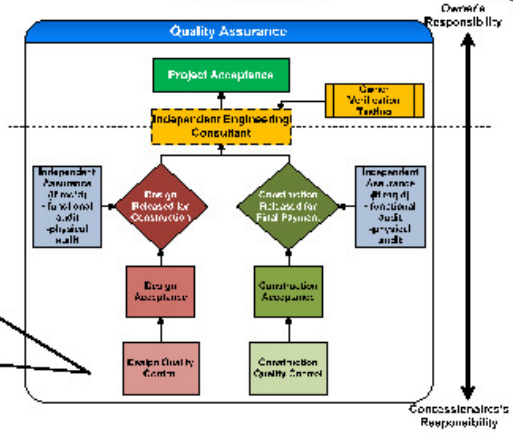
Variable



Variable:
- Agency retains control of either design OR construction assurance.
- Design and construction have different approaches to quality

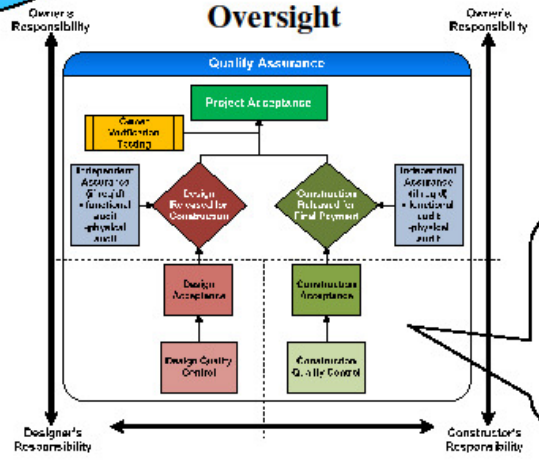
Decreasing agency control
Shifting approach to quality

Acceptance



Acceptance:
- Typically implemented on PPP projects
- QAO with the least amount of agency control

Oversight



Oversight:
- Agency responsible for ensuring contractor and design implement approved quality plans

Appendix B Quality Definitions

Project Quality Management Organization - The assignment of the responsibilities and the relationships of quality roles in a highway project, both for design and construction.

Quality Management – The totality of the system used to manage the ultimate quality of the design as well as the construction encompassing the quality functions QA, QC, IA and verification (Gransberg et al. 2008).

Project Quality Assurance – All those actions necessary for the agency to ensure that design-builder-performed QA activities give a true representation of the quality of the completed project (Gransberg et al. 2008).

Quality Assurance (QA) – All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service (TRB 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 (TRB 2009).

Acceptance – The process of deciding, through inspection, whether to accept or reject a product including what pay factor to apply (TRB 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 (TRB 2009).

Appendix C SHA Project Staff Interview Protocol to Identify QAO Selection Factors

INTRODUCTION/BACKGROUND:

The purpose of this questionnaire is to identify how and why state highway agencies (SHA) assign the quality roles and responsibilities for projects. The scope of this questionnaire includes roles for both design and construction quality. This survey serves as the basis for an interview of the respondent to further understand the process.

DEFINITIONS: The research will use TRB Circular E-C074, *Glossary of Highway Quality Assurance Terms* to standardize its terminology. The following are terms that must be carefully understood to properly complete this survey.

Acceptance: Sampling and testing, or inspection, to determine the degree of compliance with contract requirements. TRB E-C074.

Independent Assurance (IA): A management tool that requires a third party, not directly responsible for process control or acceptance, to provide an independent assessment of the product and/or the reliability of test results obtained from process control and acceptance testing. [The results of independent assurance tests are not to be used as a basis of product acceptance.] TRB E-C074

Quality: (1) The degree of excellence of a product or service. (2) The degree to which a product or service satisfies the needs of a specific customer. (3) The degree to which a product or service conforms with a given requirement.

Quality Assurance (QA): All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. [QA addresses the overall problem of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible. Within this broad context, QA involves continued

evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction, and maintenance, and the interactions of these activities.] TRB E-C074.

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. TRB E-C074.

Quality Management (QM): The overarching system of policies and procedures that govern the performance of QA and QC activities. The totality of the effort to ensure quality in design and/or construction.

Verification: The process of determining or testing the truth or accuracy of test results by examining the data and/or providing objective evidence. [Verification sampling and testing may be part of an independent assurance program (to verify contractor QC testing or agency acceptance) or part of an acceptance program (to verify contractor testing used in the agency's acceptance decision).] TRB E-C074

Design-Bid-Build (DBB): A project delivery method where the design is completed either by in-house professional engineering staff or a design consultant before the construction contract is advertised. Also called the "traditional method."

Design-Build (DB): A project delivery method where both the design and the construction of the project are simultaneously awarded to a single entity.

Construction Manager-General Contractor (CMGC): A project delivery method where the contractor is selected during the design process and makes input to the design via constructability, cost engineering, and value analysis reviews. Once the design is complete, the

same entity builds the projects as the general contractor. CMGC assumes that the contractor will self-perform a significant amount of the construction work.

Construction Manager-at-Risk (CMR): A project delivery method similar to CMGC, but where the CM does not self-perform any of the construction work.

Public Private Partnership (P3): A project delivery method where the agency contracts with a concessionaire organization to design, build, finance and operate an infrastructure facility for a defined extended period of time.

Design deliverable: A product produced by the design-builder's design team that is submitted for review to the agency (i.e. design packages, construction documents, etc.).

Construction deliverable: A product produced by the design-builder's construction team that is submitted for review to the agency (shop drawings, product submittals, etc.).

DIRECTIONS: Please answer all questions to the best of your ability.

General Agency Information

1. US state in which the respondent is employed:

2. Name of Agency:

3. Are your Quality Management systems different between Project Delivery Methods?
   ☐Yes ☐No

4. To aid in the understanding of design quality, can you approximate proportion of in-house design versus outsourced design services (use ranges if necessary)?
   In-house design services - %

   Outsourced design services - %

5. How does your agency communicate their approach to project quality assurance to all parties involved in the project?

6. Does your agency have a defined process for assigning the quality roles for each project (design QA, design QC, construction QA, construction QC, design acceptance, construction acceptance, verification, independent assurance)? ☐Yes ☐No

   Explanatory notes:

7. Who in your agency is responsible for assigning the project quality roles?
   Can the research team contact the above person regarding this research? ☐Yes ☐No If so, please provide contact information for this person (email and phone number).

Respondent Information

1. Name:

2. Position/Occupation:

3. Length of time in current position:

4. What is your role on this project?

5. Have you held any positions prior to your current position related to QM, QA, QC? If so, please briefly list that information.

6. Have you worked on projects using different project delivery methods? If so, specifically which project delivery methods do you have experience with?

7. How many years of experience do you have with projects using baseline/DBB quality systems?

Case Study Project Information and Data

1. Project Name and location:

2. Project scope of work:

3. Original Total Awarded Value of project: $

Final Total Value of project: $

4. Date preliminary design or design-build contract awarded:
   Date project advertised:

   Explanatory notes:

5. Date final design contract awarded:
   Date construction contract awarded:
   [Note: same if DB]

6. Original Project Delivery Period (including design): (Months/years)
   Final Project Delivery Period (including design): (Months/years)

   Explanatory notes:

7. What percentage of time does the agency project staff conduct quality testing, sampling, and inspection? %

8. Project delivery method used on this project:

Design-Bid-Build	**CMGC/C M-at-Risk**	**Design-Build**	**P3**
☐	☐	☐	☐

   Please explain what effect this choice had on the overall quality of the project:

9. Which of the following were reasons why your agency selected the delivery method used for this project? Check all that apply.
   - ☐ Reduce/compress/accelerate project delivery period
   - ☐ Establish project budget at an early stage of design development
   - ☐ Get early construction contractor involvement
   - ☐ Encourage innovation
   - ☐ Facilitate Value Engineering
   - ☐ Encourage price competition (bidding process)
   - ☐ Compete different design solutions through the proposal process
   - ☐ Redistribute risk
   - ☐ Complex project requirements
   - ☐ Flexibility needs during construction phase
   - ☐ Reduce life cycle costs
   - ☐ Provide mechanism for follow-on operations and/or maintenance
   - ☐ Innovative financing

☐ Other: Explain

10. Which project participant was assigned the following roles (If it was shared then select all that apply:

Project participant	Design QA	Design QC	Design acceptance	Construction QA	Construction QC	Construction acceptance
Agency	☐	☐	☐	☐	☐	☐
Designer	☐	☐	☐	☐	☐	☐
Contractor	☐	☐	☐	☐	☐	☐
Design builder	☐	☐	☐	☐	☐	☐
Consultant	☐	☐	☐	☐	☐	☐
Concessionaire	☐	☐	☐	☐	☐	☐

Explanatory Notes:

10. Was Independent Assurance implemented by the agency on this project? ☐Yes ☐No

11. Was Verification implemented by the agency on this project? ☐Yes ☐No

12. Were contractor test results used for acceptance on this project? ☐Yes ☐No

13. Which of the below best describes your agency's approach to QA on this project?
    a. Respondent: select appropriate delivery method for this project and select accordingly

DBB	**CMGC**	**DB**	**P3**
☐Design consultant primarily responsible for QA/Agency audits consultant program ☐Contractor primarily responsible for QA/Agency audits contractor program ☐Agency retains traditional QA roles ☐Agency retains an independent party to perform QA roles ☐Agency uses two or	☐Design consultant primarily responsible for QA/Agency audits consultant program ☐Contractor primarily responsible for QA/Agency audits contractor program ☐Agency retains traditional QA roles ☐Agency retains an independent party to perform QA roles ☐Agency uses two or	☐Design-builder primarily responsible for QA/Agency audits design-builder's program ☐Agency retains traditional QA roles ☐Agency retains an independent party to perform QA roles ☐Agency uses two or more of the above depending on the project ☐None of the above	☐Concessionaire primarily responsible for QA/Agency audits concessionaire's program ☐Agency retains traditional QA roles ☐Agency retains an independent party to perform QA roles ☐Agency uses two or more of the above

more of the above depending on the project ☐ None of the above	more of the above depending on the project ☐ None of the above		depending on the project ☐ None of the above

If "None of the above" was selected, please describe the approach that was used instead:

14. Please rate the following factors for their impact on the quality of this project:

Factor	Very High Impact	High Impact	Some Impact	Slight Impact	No Impact
Qualifications of agency design staff	☐	☐	☐	☐	☐
Qualifications of agency project management staff	☐	☐	☐	☐	☐
Qualifications of agency construction staff	☐	☐	☐	☐	☐
Qualifications of the design consultant's staff	☐	☐	☐	☐	☐
Design consultant's past project experience	☐	☐	☐	☐	☐
Qualifications of the construction contractor's staff	☐	☐	☐	☐	☐
Construction contractor's past project experience	☐	☐	☐	☐	☐
Submittal of Quality management plans prior to work start	☐	☐	☐	☐	☐
Level of agency involvement in the QM process	☐	☐	☐	☐	☐
Use of agency specifications and/or design details	☐	☐	☐	☐	☐
Level of detail expressed in the procurement documents (IFB/RFQ/RFP)	☐	☐	☐	☐	☐
Use of manuals, standards and specifications developed for DBB type projects	☐	☐	☐	☐	☐
Allowing flexibility in choice of design standards and construction specifications	☐	☐	☐	☐	☐
Use of performance criteria/specifications	☐	☐	☐	☐	☐
Detailed design criteria	☐	☐	☐	☐	☐
Warranty provisions	☐	☐	☐	☐	☐
Incentive/disincentive provisions	☐	☐	☐	☐	☐
Follow-on maintenance provisions	☐	☐	☐	☐	☐
Innovative financing (PPP/concession)	☐	☐	☐	☐	☐

.

Appendix D Delphi Study Round One Sample

INTRODUCTION/BACKGROUND: Traditionally, highway agencies have fulfilled all project quality management roles and responsibilities (design acceptance, design quality assurance (QA), design quality control (QC), construction acceptance, construction QA and construction QC). As a result of the increasing use of alternative delivery methods, decreasing agency staffing levels and changing federal regulations, project quality management roles are shifting to designers and constructors. However, there is currently no guidance for selecting the appropriate quality assurance organization (QAO) for a project. Within the highway industry five fundamental project QAOs have been identified through this research. The purpose of this questionnaire is to determine which QAOs are most appropriate for a project based on project, agency and industry factors.

DEFINITIONS: An understanding of a few fundamental quality terms is necessary for consistency. Please review the following definitions prior to completing the attached matrices.

QUALITY DEFINITIONS:

- **Quality Management** – The totality of the system used to manage the ultimate quality of the design as well as the construction, encompassing these quality functions: quality assurance, quality control, independent assurance and verification (Gransberg et al. 2008).

- **Quality Assurance Organization (QAO)** – The assignment of the roles and responsibilities associated with the quality management of a project from concept through completion.

- **Quality Assurance (QA)** – All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service (TRB 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 (TRB 2009).

- **Acceptance** – The process of deciding, through inspection, whether to accept or reject a product including what pay factor to apply (TRB 2009).

FIVE QUALITY ASSURANCE ORGANIZATIONS: The definition for each of the quality management organizations is provided below. Table 16 summarizes the assigned quality roles and responsibilities for each QAO and Figure 16 provides a spectrum of the QAOs and the associated level of control the agency has over the quality of the project.

Table 16 - Summary of roles and responsibility assignments for each QAO

QAO	Design acceptance	Design QA	Design QC	Construction Acceptance	Construction QA	Construction QC
Deterministic	Agency	Agency	Agency	Agency	Agency	Agency
Assurance	Agency	Agency	Designer	Agency	Agency	Contractor
Variable	Agency	Designer	Designer	Agency	Agency	Contractor
Oversight	Agency	Designer	Designer	Agency	Contractor	Contractor
Acceptance	Concess*	Concess*	Concess*	Concess*	Concess*	Concess*
*Concess = Concessionaire						

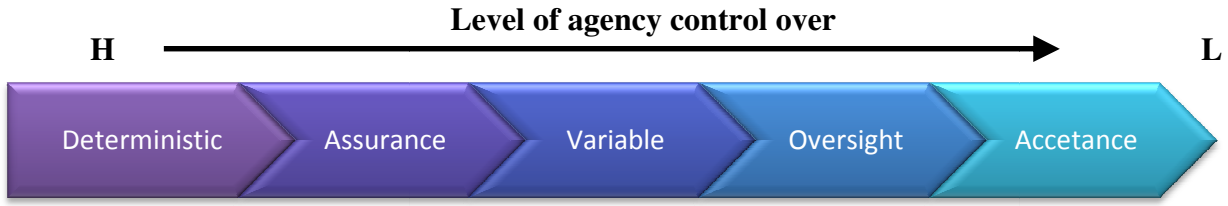


Figure 16 - Spectrum of QMOs and associated levels of project quality control retained by the agency

- **Deterministic QAO** - The traditional approach to quality within the highway industry. The owner agency retains all control over the quality management of the project

- **Assurance QAO -** The owner agency is responsible for all aspects of the quality management except for QC.

- **Variable QAO** - Design and construction take different approaches to quality. One will either have a proactive approach by assigning both QA and QC to the party contracted to perform the scope of work, while the other will be a reactive approach by only having responsibility for QC. The most frequent variation of this QAO seen in industry is the assignment of all design QC/QA and construction to a design-builder.

- **Oversight QAO** - the owner agency takes 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.

- **Acceptance QAO** - Currently only used in a PPP arrangement, the owner agency is responsible for verification testing and final acceptance. All other quality roles and responsibilities are assigned to the concessionaire.

INSTRUCTIONS:

The purpose of this questionnaire is to validate and calibrate the factors that can lead to the selection of a project QAO. Before completing this questionnaire please become familiar with the project QAOs through the above definitions and descriptions on the QAO quick guide (separate attached file). Nine factors have been identified as influential to the selection of a QAO. A matrix of QAOs has been created for each project factor. Each matrix requires the highlighted cells to be completed with a ranking as to the appropriateness of that specific factor level to the successful implementation of the respective QAO using the appropriateness rankings shown in the Table 17. Please return the completed questionnaire to Elizabeth Kraft via email (elizabeth.kraft@colorado.edu) by **Friday June 8th at 12:00PM MST**. Should you have any questions about the questionnaire feel free to call Elizabeth Kraft at 720-352-4216.

Table 17 - Appropriateness level ratings

X	Fatal Flaw
-1	Less than appropriate
0	Appropriate
1	Very appropriate

MATRICES:

Project delivery method - "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." The project delivery methods considered for this research are design-bid-build, design-build, construction manager general contractor and public private partnership (P3)/design-build-operate-maintain (DBOM). ***Within the highlighted cells, please rate the different project delivery methods as to their appropriateness for the associated QAO.***

PROJECT DELIVERY METHOD					
Delivery method	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Design bid build					
Design build					
CMGC/CMAR					
P3/DBOM					

Industry ability - The industry's level of competence to successfully manage quality. The industry includes both the design and construction communities. ***Within the highlighted cells, please rate the appropriateness of the industry ability level to the associated QAO.***

INDUSTRY ABILITY TO MANAGE THEIR OWN QUALITY					
Industry ability	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**

Low					
Medium					
High					

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

Agency resources – The agency's project staff, both the quantity of agency staff on the project and the technical experience level of the staff, resulting in two separate matrices for agency resources. The quantity of staff is in comparison to the traditional levels of a typical agency project. The technical experience level is the average level of technical experience of all the agency staff assigned to a particular project. ***Within the highlighted cells, please rate the appropriateness of the different agency project staffing levels to the associated QAOs.***

AGENCY STAFFING RESOURCES					
Staff availability	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
fully staffed					
moderately staffed					
minimally staffed					

Within the highlighted cells, please rate the appropriateness of the average project staff technical experience levels to the associated QAOs.

AGENCY STAFFING RESOURCES					
Average project staff technical experience	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
<5 years					
5 years - 10 years					
10 years - 20 years					
>20 years					

Agency culture – In this context agency culture refers to the agency's attitude toward the implementation of change in project management techniques. In the traditional culture the agency is in control of all aspects of the project and is not willing or able to implement any changes to the way similar projects have been done in the past. The progressive culture indicates that the agency is willing to be an industry pioneer and embark upon changes that will lead towards a collaborative approach to projects even if they have not been tested elsewhere. In the moderate culture the agency is willing to make changes towards a collaborative approach to project management, but will only do so if they have been proven to work elsewhere. ***Within the highlighted cells please rate the level of appropriateness of the type of agency culture to the associated QAO.***

AGENCY CULTURE					
Agency culture	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Traditional					

Moderate					
Progressive					

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

Shifting the quality risk away from the agency – The amount of liability for the management of the project's quality that the agency wants to shift to another project partner (contractor, designer, engineer, design builder, CMGC, concessionaire). ***Within the highlighted cells, please rate the appropriateness of the amount of quality risk the agency wants to shift to another party to the associated QAO.***

SHIFT THE QUALITY RISK AWAY FROM THE AGENCY					
Quality shift to others	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
All					
Some QA and some QC					
Some QA					
Some QC					
None					

Project size - The total dollar value of the project's design and construction budgets. ***Within the highlighted cells, please rate the appropriateness of the size of the project to the associated QAO.***

PROJECT SIZE					
Project budget	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
<$10M					
$10M - $50M					
$50M-$500M					
$500M - $2B					
>$2B					

Schedule sensitivity - The vulnerability of the project schedule to changes due to delays, conflicts, and/or events outside of the designer's and/or contractor's control, such as coordination of observations, inspections and/or testing performed by the agency. ***Within the highlighted cells please rate the level of appropriateness of the amount of schedule sensitivity to the associated QAO.***

SCHEDULE SENSITIVITY					
schedule sensitivity	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Low					
Medium					
High					

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

Project complexity - The intricacy of project scope stemming from design constraints, construction methods, site conditions, budget and funding constraints, quality requirements, etc. ***Within the highlighted cells please rate the appropriateness of the level of project complexity to the associated project QAO.***

PROJECT COMPLEXITY					
Project complexity	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Low					
Medium					
High					

Agency trust in the Industry – The level of Agency confidence that project decisions will be based on achieving the best results for the project, rather than the individual or specific company. This requires the industry to overcome the well situated paradigm of lack of trust between the project participants (designer, engineer, contractor, consultant, and agency). **Within the highlighted cells please rate the level of appropriateness to the associated QAO.**

TRUST BETWEEN AGENCY AND INDUSTRY					
Level of trust	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Low					
Moderate					
High					

Appendix E Delphi Study Round Two Sample

INTRODUCTION/BACKGROUND: Traditionally, highway agencies have fulfilled all project quality management roles and responsibilities (design acceptance, design quality assurance (QA), design quality control (QC), construction acceptance, construction QA and construction QC). As a result of the increasing use of alternative delivery methods, decreasing agency staffing levels and changing federal regulations, project quality management roles are shifting to designers and constructors. However, there is currently no guidance for selecting the appropriate quality assurance organization (QAO) for a project. Within the highway industry five fundamental project QAOs have been identified through this research. The purpose of this questionnaire is to determine which QAOs are most appropriate for a project based on project, agency and industry factors.

DEFINITIONS: An understanding of a few fundamental quality terms is necessary for consistency. Please review the following definitions prior to completing the attached matrices.

QUALITY DEFINITIONS:

- **Quality Management** – The totality of the system used to manage the ultimate quality of the design as well as the construction, encompassing these quality functions: quality assurance, quality control, independent assurance and verification (Gransberg et al. 2008).

- **Quality Assurance Organization (QAO)** – The assignment of the roles and responsibilities associated with the quality management of a project from concept through completion.

- **Quality Assurance (QA)** – All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service (TRB 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 (TRB 2009).

- **Acceptance** – The process of deciding, through inspection, whether to accept or reject a product including what pay factor to apply (TRB 2009).

FIVE QUALITY MANAGEMENT ORGANIZATIONS: The definition for each of the quality management organizations is provided below. Table 16 summarizes the assigned quality roles and responsibilities for each QAO and Figure 16 provides a spectrum of the QAOs and the associated level of control the agency has over the quality of the project.

Table 18 - Summary of roles and responsibility assignments for each QAO

QAO	Design acceptance	Design QA	Design QC	Construction Acceptance	Construction QA	Construction QC
Deterministic	Agency	Agency	Agency	Agency	Agency	Agency

QAO	Design acceptance	Design QA	Design QC	Construction Acceptance	Construction QA	Construction QC
Assurance	Agency	Agency	Designer	Agency	Agency	Contractor
Variable	Agency	Designer	Designer	Agency	Agency	Contractor
Oversight	Agency	Designer	Designer	Agency	Contractor	Contractor
Acceptance	Concess*	Concess*	Concess*	Concess*	Concess*	Concess*
*Concess = Concessionaire						

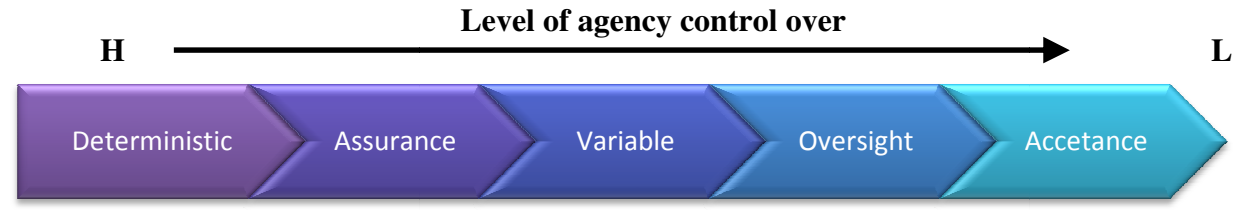


Figure 17 - Spectrum of QMOs and associated levels of project quality control retained by the agency

- **Deterministic QAO** - The traditional approach to quality within the highway industry. The owner agency retains all control over the quality management of the project

- **Assurance QAO -** The owner agency is responsible for all aspects of the quality management except for QC.

- **Variable QAO** - Design and construction take different approaches to quality. One will either have a proactive approach by assigning both QA and QC to the party contracted to perform the scope of work, while the other will be a reactive approach by only having responsibility for QC. The most frequent variation of this QAO seen in industry is the assignment of all design QC/QA and construction to a design-builder.

- **Oversight QAO** - the owner agency takes 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.

- **Acceptance QAO** - Currently only used in a PPP arrangement, the owner agency is responsible for verification testing and final acceptance. All other quality roles and responsibilities are assigned to the concessionaire.

INSTRUCTIONS:

The purpose of this questionnaire is to validate and calibrate the factors that can lead to the selection of a project QAO. Before completing this questionnaire please become familiar with the project QAOs through the above definitions and descriptions on the QAO quick guide (separate attached file). Nine factors have been identified as influential to the selection of a QAO. A matrix of QAOs has been created for each project factor.

The first round of the questionnaire resulted in cells within the matrices either reaching consensus, reducing down to two options or still inconclusive. The cells that reached consensus have the final ranking shown in their respective cells. The cells that have been reduced down to two options have the options shown in their respective cells; please select the ranking option that you feel is most accurate for that specific project factor and QAO. The cells that are still inconclusive have been left blank, of which several have been highlighted. Please complete the highlighted cells with a ranking as to the appropriateness of that specific level of factor to the successful implementation of the respective QAO using the appropriateness rankings shown in the Table 17. Some matrices may not have highlighted cells. As a note the ranking of 0 (appropriate) implies that the QAO can be selected for that specific level of factor but it is neither the best fit nor the worst fit, it will just work. Additionally there is a space under each matrix where you can elaborate on your answers should you feel it necessary to do so.

Please return the completed questionnaire to Elizabeth Kraft via email (elizabeth.kraft@colorado.edu) by **Friday June 15th at 1:00PM MST**. Should you have any questions about the questionnaire feel free to call Elizabeth Kraft at 720-352-4216.

Table 19 - Appropriateness level ratings

X	Fatal Flaw
-1	Less than appropriate
0	Appropriate
1	Very appropriate

MATRICES:

Project delivery method - "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." The project delivery methods considered for this research are design-bid-build, design-build, construction manager general contractor and public private partnership (P3)/design-build-operate-maintain (DBOM). ***Within the highlighted cells, please rate the different project delivery methods as to their appropriateness for the associated QAO.***

PROJECT DELIVERY METHOD					
Delivery method	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Design bid build	1		-1 ☐ 0 ☐		
Design build	X ☐ -1 ☐			1	
CMGC/CMAR	-1 ☐ 0 ☐	0 ☐ 1 ☐		-1 ☐ 1 ☐	

P3/DBOM	X				0 ☐ 1 ☐

Project delivery method ranking elaboration:

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

Industry ability - The industry's level of competence to successfully manage quality. The industry includes both the design and construction communities. ***Within the highlighted cells, please rate the appropriateness of the industry ability level to the associated QAO.***

INDUSTRY ABILITY TO MANAGE THEIR OWN QUALITY					
Industry ability	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Low	1	-1☐ 0☐			X☐ 1☐
Medium		0☐ 1☐		-1☐ 0☐	-1☐ 0☐
High		0	0☐ 1☐	1	

Industry ability to manage their own quality ranking elaboration:

Agency resources – The agency's project staff, both the quantity of agency staff on the project and the technical experience level of the staff, resulting in two separate matrices for agency resources. The quantity of staff is in comparison to the traditional levels of a typical agency project. The technical experience level is the average level of technical experience of all the agency staff assigned to a particular project. ***Within the highlighted cells, please rate the appropriateness of the different agency project staffing levels to the associated QAOs.***

AGENCY STAFFING RESOURCES					
Staff availability	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
fully staffed	1	-1☐ 0☐			X☐ 1☐
moderately staffed	-1	0☐ 1☐		-1☐ 0☐	-1☐ 0☐
minimally staffed	X☐ -1☐			1	

Agency staffing resources ranking elaboration:

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

Within the highlighted cells, please rate the appropriateness of the average project staff technical experience levels to the associated QAOs.

AGENCY STAFFING RESOURCES					
Average project staff technical experience	Deterministic	Assurance	Variable	Oversight	Acceptance
<5 years	-1☐ 0☐	-1☐ 0☐	-1☐ 0☐		
5 years - 10 years	0	0			0☐ 1☐
10 years - 20 years		1	1	0☐ 1☐	1
>20 years		0☐ 1☐	0☐ 1☐		

Agency Staffing resources ranking elaboration:

Agency culture – In this context agency culture refers to the agency's attitude toward the implementation of change in project management techniques. In the traditional culture the agency is in control of all aspects of the project and is not willing or able to implement any changes to the way similar projects have been done in the past. The progressive culture indicates that the agency is willing to be an industry pioneer and embark upon changes that will lead towards a collaborative approach to projects even if they have not been tested elsewhere. In the moderate culture the agency is willing to make changes towards a collaborative approach to project management, but will only do so if they have been proven to work elsewhere. ***Within the highlighted cells please rate the level of appropriateness of the type of agency culture to the associated QAO.***

AGENCY CULTURE					
Agency culture	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Traditional	1	-1☐ 0☐			
Moderate			0	0☐ 1☐	0☐ 1☐

Progressive			0	1	

Agency culture ranking elaboration:

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

Shifting the quality risk away from the agency – The amount of liability for the management of the project's quality that the agency wants to shift to another project partner (contractor, designer, engineer, design builder, CMGC, concessionaire). ***Within the highlighted cells, please rate the appropriateness of the amount of quality risk the agency wants to shift to another party to the associated QAO.***

SHIFT THE QUALITY RISK AWAY FROM THE AGENCY					
Quality shift to others	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
All		X☐ -1☐	X	1	
Some QA and some QC				1	0☐ 1☐
Some QA			0☐ 1☐	0☐ 1☐	
Some QC			0☐ 1☐		
None	0☐ 1☐	-1	-1	X	X

Shift the quality risk away from the agency ranking elaboration:

Project size - The total dollar value of the project's design and construction budgets. Within the highlighted cells, please rate the appropriateness of the size of the project to the associated QAO.

PROJECT SIZE					
Project budget	Deterministic	Assurance	Variable	Oversight	Acceptance
<$10M	1	1			-1☐ 0☐
$10M - $50M	0☐ 1☐	0☐ 1☐	0☐ 1☐	0☐ 1☐	0
$50M-$500M	-1☐ 0☐	0☐ 1☐	0☐ 1☐	1	
$500M - $2B		-1☐ 0☐			
>$2B		-1☐ 0☐			

Project size ranking elaboration:

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

Schedule sensitivity - The vulnerability of the project schedule to changes due to delays, conflicts, and/or events outside of the designer's and/or contractor's control, such as coordination of observations, inspections and/or testing performed by the agency. ***Within the highlighted cells please rate the level of appropriateness of the amount of schedule sensitivity to the associated QAO.***

SCHEDULE SENSITIVITY					
schedule sensitivity	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Low		0☐ 1☐		-1☐ 0☐	
Medium		0			0☐ 1☐
High	-1☐ 0☐	0			

Schedule sensitivity ranking elaboration:

Project complexity - The intricacy of project scope stemming from design constraints, construction methods, site conditions, budget and funding constraints, quality requirements, etc. ***Within the highlighted cells please rate the appropriateness of the level of project complexity to the associated project QAO.***

PROJECT COMPLEXITY

Project complexity	Deterministic	Assurance	Variable	Oversight	Acceptance
Low	1	-1☐ 0☐	0	-1☐ 0☐	0☐ 1☐
Medium		0☐ 1☐	0☐ 1☐	0☐ 1☐	
High	-1	0		1	1

Project complexity ranking elaboration:

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

Agency trust in the Industry – The level of Agency confidence that project decisions will be based on achieving the best results for the project, rather than the individual or specific company. This requires the industry to overcome the well situated paradigm of lack of trust between the project participants (designer, engineer, contractor, consultant, and agency). **Within the highlighted cells please rate the level of appropriateness to the associated QAO.**

TRUST BETWEEN AGENCY AND INDUSTRY					
Level of trust	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Low	1	0		X ☐ -1 ☐	X
Moderate	-1 ☐ 0 ☐				
High	0	1	1		1

Project complexity ranking elaboration:

Appendix F Delphi Study Round Three Sample

INTRODUCTION/BACKGROUND: Traditionally, highway agencies have fulfilled all project quality management roles and responsibilities (design acceptance, design quality assurance (QA), design quality control (QC), construction acceptance, construction QA and construction QC). As a result of the increasing use of alternative delivery methods, decreasing agency staffing levels and changing federal regulations, project quality management roles are shifting to designers and constructors. However, there is currently no guidance for selecting the appropriate quality assurance organization (QAO) for a project. Within the highway industry five fundamental project QAOs have been identified through this research. The purpose of this questionnaire is to determine which QAOs are most appropriate for a project based on project, agency and industry factors.

DEFINITIONS: An understanding of a few fundamental quality terms is necessary for consistency. Please review the following definitions prior to completing the attached matrices.

QUALITY DEFINITIONS:

- **Quality Management** – The totality of the system used to manage the ultimate quality of the design as well as the construction, encompassing these quality functions: quality assurance, quality control, independent assurance and verification (Gransberg et al. 2008).

- **Quality Assurance Organization (QAO)** – The assignment of the roles and responsibilities associated with the quality management of a project from concept through completion.

- **Quality Assurance (QA)** – All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service (TRB 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 (TRB 2009).

- **Acceptance** – The process of deciding, through inspection, whether to accept or reject a product including what pay factor to apply (TRB 2009).

FIVE QUALITY MANAGEMENT ORGANIZATIONS: The definition for each of the quality management organizations is provided below. Table 16 summarizes the assigned quality roles and responsibilities for each QAO and Figure 16 provides a spectrum of the QAOs and the associated level of control the agency has over the quality of the project.

Table 20 - Summary of roles and responsibility assignments for each QAO

QAO	Design acceptance	Design QA	Design QC	Construction Acceptance	Construction QA	Construction QC
Deterministic	Agency	Agency	Agency	Agency	Agency	Agency

QAO	Design acceptance	Design QA	Design QC	Construction Acceptance	Construction QA	Construction QC
Assurance	Agency	Agency	Designer	Agency	Agency	Contractor
Variable	Agency	Designer	Designer	Agency	Agency	Contractor
Oversight	Agency	Designer	Designer	Agency	Contractor	Contractor
Acceptance	Concess*	Concess*	Concess*	Concess*	Concess*	Concess*
*Concess = Concessionaire						

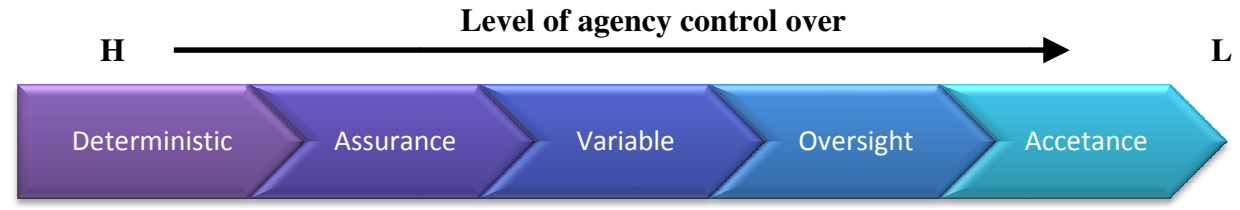


Figure 18 - Spectrum of QMOs and associated levels of project quality control retained by the agency

- **Deterministic QAO** - The traditional approach to quality within the highway industry. The owner agency retains all control over the quality management of the project

- **Assurance QAO -** The owner agency is responsible for all aspects of the quality management except for QC.

- **Variable QAO** - Design and construction take different approaches to quality. One will either have a proactive approach by assigning both QA and QC to the party contracted to perform the scope of work, while the other will be a reactive approach by only having responsibility for QC. The most frequent variation of this QAO seen in industry is the assignment of all design QC/QA and construction to a design-builder.

- **Oversight QAO** - the owner agency takes 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.

- **Acceptance QAO** - Currently only used in a PPP arrangement, the owner agency is responsible for verification testing and final acceptance. All other quality roles and responsibilities are assigned to the concessionaire.

INSTRUCTIONS:

The purpose of this questionnaire is to validate and calibrate the factors that can lead to the selection of a project QAO. Before completing this questionnaire please become familiar with the project QAOs by perusing the above definitions and descriptions on the QAO quick guide (separate attached file). Nine factors have been identified as influential in the selection of a QAO. A matrix of QAOs has been created for each project factor.

The second round of the questionnaire allowed a higher level of consensus on the matrices to be achieved. The cells that reached consensus have the final ranking shown in their respective cells. Additionally several of the questionnaire respondents provided elaboration on several of their rankings which are included above the respective matrices.

Table 21 - Appropriateness ratings

X	Fatal Flaw
-1	Less than appropriate
0	Appropriate
1	Very appropriate

The cells that are still inconclusive have been left blank and are highlighted. Please complete the highlighted cells with a ranking as to the appropriateness of that specific level of factor to the successful implementation of the respective QAO using the appropriateness rankings shown in the Table 17. If a matrix has comments from the second round of the questionnaire directly above it, please read them before providing your ranking.

Last, there is a space provided after each matrix to comment or elaborate on your rankings. Some of the matrices are more inconclusive than the others and would benefit you're your elaboration or comments regarding your rankings. You are requested to complete the highlighted ranking elaboration spaces, which can be brief.

Note that the ranking of 0 (appropriate) implies that the QAO can be selected for that specific level of factor but it is neither the best fit nor the worst fit. It will just work.

Please return the completed questionnaire to Elizabeth Kraft via email (elizabeth.kraft@colorado.edu) by **Friday June 22nd at 1:00PM MST**. Should you have any questions about the questionnaire feel free to call Elizabeth Kraft at 720-352-4216.

MATRICES:

PROJECT DELIVERY METHOD - "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." The project delivery methods considered for this research are design-bid-build, design-build, construction manager general contractor and public private partnership (P3)/design-build-operate-maintain (DBOM). ***Within the highlighted cells, please rate the different project delivery methods as to their appropriateness for the associated QAO.***

PROJECT DELIVERY METHOD					
Delivery method	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Design bid build	1	0	0		-1
Design build	-1			1	-1
CMGC/CMAR	-1	0	0	1	0
P3/DBOM	X	-1	-1		1

Project delivery method ranking elaboration:

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

INDUSTRY ABILITY - The industry's level of competence to successfully manage quality. The industry includes both the design and construction communities. ***Please read the second round questionnaire elaboration on the rankings received for this topic before ranking the highlighted cells as to the appropriateness of the industry ability level to the associated QAO.***

Elaboration on the rankings received on the second round questionnaire regarding industry ability to manage their own quality:

- The matrix was evaluated based on level of competence within the industry to manage not how the QAO affects their ability to manage.

INDUSTRY ABILITY TO MANAGE THEIR OWN QUALITY					
Industry ability	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Low	1	0			X
Medium		0	0	0	0
High		0	0	1	

Industry ability to manage their own quality ranking elaboration:

AGENCY RESOURCES – The agency's project staff, both the quantity of agency staff on the project and the technical experience level of the staff, resulting in two separate matrices for agency resources. The quantity of staff is in comparison to the traditional levels of a typical agency project. The technical experience level is the average level of technical experience of all the agency staff assigned to a particular project. ***Within the highlighted cells, please rate the appropriateness of the different agency project staffing levels to the associated QAOs.***

AGENCY STAFFING RESOURCES					
Staff availability	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
fully staffed	1	0	0	0	X
moderately staffed	-1	0	0	0	-1
minimally staffed	X		0	1	1

Agency staff availability ranking elaboration:

Please read the second round questionnaire ranking elaboration received for this topic before ranking the highlighted cells according as to the appropriateness of the average project staff technical experience levels to the associated QAOs. Because of the higher level of inconclusiveness for this matrix, please provide some elaboration on your rankings in the space provided directly below this matrix.

Elaboration of the rankings received on the second round questionnaire regarding agency staff technical experience:

- Agency staffing exceeding 20 years would indicate and older work force. Deterministic type of QAO requires heavy in-field interaction. Older state agency inspection staffs are less likely to be "into the details" and would be better to do a oversight role vs a hands-on role.

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

- The Acceptance QAO is totally dependent on the consultant's and contractor's experience while the owner's or agency's technical experience is irrelevant so all levels of agency experience are very appropriate for the acceptance QAO.

AGENCY STAFFING RESOURCES					
Average project staff technical experience	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
<5 years	0	0			
5 years - 10 years	0	0	0	0	0
10 years - 20 years		1	1		1
>20 years		0	1	1	1

Average project staff technical experience ranking elaboration:

AGENCY CULTURE – In this context agency culture refers to the agency's attitude toward the implementation of change in project management techniques. In the traditional culture the agency is in control of all aspects of the project and is not willing or able to implement any changes to the way similar projects have been done in the past. The progressive culture indicates that the agency is willing to be an industry pioneer and embark upon changes that will lead towards a collaborative approach to projects even if they have not been tested elsewhere. In the moderate culture the agency is willing to make changes towards a collaborative approach to project management, but will only do so if they have been proven to work elsewhere. ***Please read the second round questionnaire elaboration on the rankings received for this topic before ranking the highlighted cells as to the level of appropriateness of the type of agency culture to the associated QAO.***

Elaboration on the rankings received on the second round questionnaire regarding agency culture:

- A progress culture in the agency wouldn't consider using an assurance model. While it would work, the agency would be using more performance based specifications.

AGENCY CULTURE					
Agency culture	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Traditional	1	0	-1	-1	-1
Moderate	0	0	0	0	0
Progressive		0	0	1	1

Agency culture ranking elaboration:

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

SHIFTING THE QUALITY RISK AWAY FROM THE AGENCY – The amount of liability for the management of the project's quality that the agency wants to shift to another project partner (contractor, designer, engineer, design builder, CMGC, concessionaire). ***Within the highlighted cells, please rate the appropriateness of the amount of quality risk the agency wants to shift to another party to the associated QAO. Because of the higher level of inconclusiveness for this matrix, please provide some elaboration on your rankings in the space provided directly below this matrix.***

SHIFT THE QUALITY RISK AWAY FROM THE AGENCY					
Quality shift to others	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
All	X	X	X	1	
Some QA and some QC			1	1	0
Some QA		-1	0	1	
Some QC			0	1	X
None	1	-1	-1	X	X

Shift the quality risk away from the agency ranking elaboration:

PROJECT SIZE - The total dollar value of the project's design and construction budgets. ***Within the highlighted cells, please rate the appropriateness of the size of the project to the associated QAO. Because of the higher level of inconclusiveness for this matrix, please provide some elaboration on your rankings in the space provided directly below this matrix.***

PROJECT SIZE					
Project budget	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
<$10M	1	1	0		-1
$10M - $50M	1	1	0	0	0
$50M-$500M	-1	0	0	1	
$500M - $2B	X		0		1
>$2B		-1			1

Project size ranking elaboration:

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

SCHEDULE SENSITIVITY - The vulnerability of the project schedule to changes due to delays, conflicts, and/or events outside of the designer's and/or contractor's control, such as coordination of observations, inspections and/or testing performed by the agency. ***Within the highlighted cells please rate the level of appropriateness of the amount of schedule sensitivity to the associated QAO.***

SCHEDULE SENSITIVITY					
schedule sensitivity	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Low	0		0	0	0
Medium	-1	0	0	0	0
High	-1	0		1	

Schedule sensitivity ranking elaboration:

PROJECT COMPLEXITY - The intricacy of project scope stemming from design constraints, construction methods, site conditions, budget and funding constraints, quality requirements, etc. ***Within the highlighted cells please rate the appropriateness of the level of project complexity to the associated project QAO. There is a dead heat in the ranking of the highlighted, please provide elaboration on your ranking just below the matrix.***

PROJECT COMPLEXITY					
Project complexity	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Low	1	0	0	0	0
Medium	0	0	0		0
High	-1	0	1	1	1

Project complexity ranking elaboration:

X = Fatal Flaw	-1 = less than appropriate	0 = appropriate	1 = highly appropriate

AGENCY TRUST IN THE INDUSTRY – The level of Agency confidence that project decisions will be based on achieving the best results for the project, rather than the individual or specific company. This requires the industry to overcome the well situated paradigm of lack of trust between the project participants (designer, engineer, contractor, consultant, and agency). **Within the highlighted cells please rate the level of appropriateness to the associated QAO.**

TRUST BETWEEN AGENCY AND INDUSTRY					
Level of trust	**Deterministic**	**Assurance**	**Variable**	**Oversight**	**Acceptance**
Low	1	0		-1	X
Moderate	0		0	0	0
High	0	1	1	1	1

Trust between agency and industry ranking elaboration:

Appendix G QAO Decision Support Tool

OBJECTIVE

To assist state highway agencies (SHAs) in the assignment of project quality assurance roles for highway projects through the selection of the most applicable project quality assurance organization (QAO). Ideally the process will begin early in the project development process, but at the latest before the procurement process begins for design or construction contracts. This guide will provide the basic definitions needed to understand the tool, provide instructions in the use of the tool, and present a demonstration of the tool using a project from industry. Included in the appendices of this guide are the selection factor definitions, the factor appropriateness ratings and all blank forms needed to use the tool.

DEFINITIONS

An understanding of a few basic quality terms and the fundamental quality assurance organizations (QAOs) is necessary to be able to implement the selection tool accurately. Below the basic quality definitions and the fundamental QAOs are defined. Please review the following definitions prior to completing the selection of the project QAO.

Quality definitions

Quality Management – The totality of the system used to manage the ultimate quality of the design as well as the construction, encompassing these quality functions: quality assurance, quality control, independent assurance and verification (Gransberg et al. 2008).

Quality Assurance Organization (QAO) – The assignment of the roles and responsibilities associated with the quality management of a project from concept through completion.

Quality Assurance (QA) – All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service (TRB 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 (TRB 2009).

Acceptance – The process of deciding, through inspection, whether to accept or reject a product including what pay factor to apply (TRB 2009).

Fundamental quality assurance organizations

The definition for each of the quality management organizations is provided below. Table 16 summarizes the assigned quality roles and responsibilities for each QAO and Figure 16 provides a spectrum of the QAOs and the associated level of control the agency has over the quality of the project.

Deterministic QAO - The traditional approach to quality within the highway industry. The owner agency retains all control over the quality management of the project

Assurance QAO - The owner agency is responsible for all aspects of the quality management except for QC.

Variable QAO - Design and construction take different approaches to quality. One will either have a proactive approach by assigning both QA and QC to the party contracted to perform the scope of work, while the other will be a reactive approach by only having responsibility for QC. The most frequent variation of this QAO seen in industry is the assignment of all design QC/QA and construction to a design-builder.

Oversight QAO - the owner agency takes 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.

Acceptance QAO - Currently only used in a PPP arrangement, the owner agency is responsible for verification testing and final acceptance. All other quality roles and responsibilities are assigned to the concessionaire.

Table 22 - Summary of roles and responsibility assignments for each QAO

QAO	Design QA	Design QC	Construction QA	Construction QC	Project acceptance
Deterministic	Agency	Agency	Agency	Contractor	Agency
Assurance	Agency	Designer	Agency	Contractor	Agency
Variable	Designer	Designer	Agency	Contractor	Agency
Oversight	Designer	Designer	Contractor	Contractor	Agency
Acceptance	*Concess	Concess	Concess	Concess	Agency

*Concess = Concessionaire

Figure 19 - Spectrum of QAOs and associated levels of project quality control retained by the agency

PROJECT QAO SELECTION TOOL

The goal of the QAO selection tool is to help SHAs select the most appropriate QAO for projects at hand by rating the appropriateness of the five fundamental QAOs according to the categories of selection factors that apply to the projects. All ten selection factors are defined in Appendix A. It is suggest that project QAOs be selected before the RFP or RFQ process for services (design, engineering, construction, and consulting) begins so project quality roles and responsibilities can be accurately accounted for in responses to project RFPs or RFQs.

The QAO selection tool uses a three-step process for selecting the most appropriate QAOs for a particular project (Figure 20). The three steps are identifying barriers to QAO adoption, using the selection process profile form to prepare a selection factor profile, and using the QAO factor analysis form to select the most appropriate QAO. The steps are discussed in more detail in the following sections.

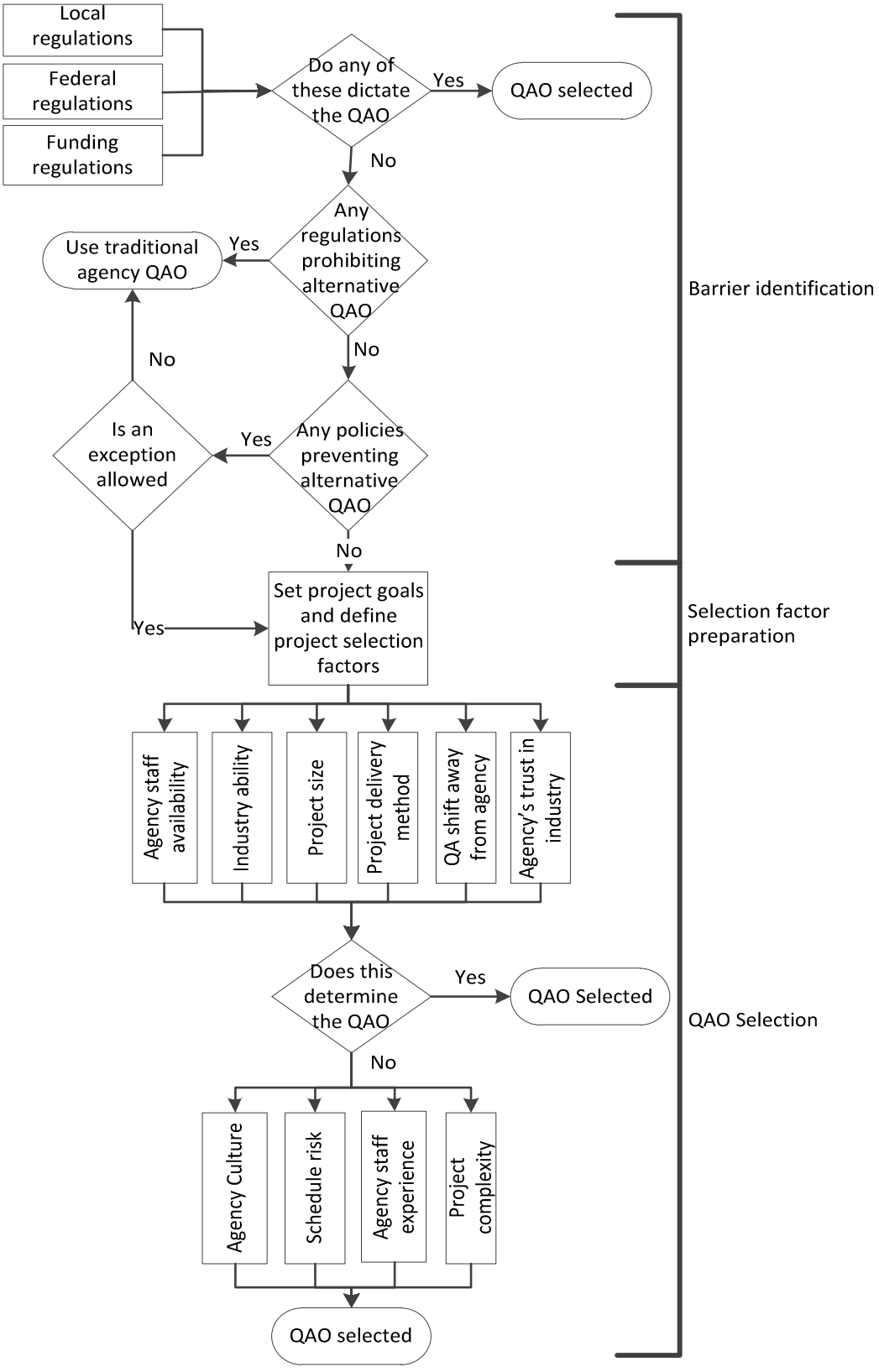


Figure 20 - Project QAO selection flow chart

Step 1. Identify Barriers to QAO Selection

Barriers are regulations or policies that either prevent the use of an alternative QAO or dictate that a specific QAO be used on the project. Possible barriers include, but are not limited to, federal, local, or funding regulations; political issues; and agency policies. It is important to identify these barriers at the beginning of QAO selection process because it is very likely that if barriers exist, the QAO selection process will begin and end at this step. For example, when a specific QAO is required, that QAO must be selected.

Step 2. Preparing the Selection Factor Profile

The goal of the second step is to prepare the project QAO selection factor profile. The selection factor profile identifies which category of each selection factor applies to the project being analyzed.

The information in the selection factor profile will be used in step three to identify the appropriateness ratings for each selection factor that applies to the project. For some selection factors it is easy to identify which category applies to the project, such as project budget or project delivery method; however, identifying the correct category for selection factors such as the amount of quality responsibility the agency wants to shift to other project participants, requires the project goals to be established and understood so that the correct selection factor category is determined. Also the project goals should provide the user with further understanding of the motivation of the project on a whole as to why the project is diverging from the standard default project QAO for the agency, ensuring that the agency is making a fully educated decision. Once the goals are established the user can complete the project QAO selection factor profile form included in Appendix C.

Step 3. Using the QAO Analysis Form to Select an Appropriate QAO

The final step of the QAO selection process is selecting the appropriate QAOs based on a comprehensive understanding of the appropriateness ratings for each QAO that correspond to the category of each of the project selection factors. In this step, the user transcribes the appropriateness ratings for the category of each selection recorded in the project QAO selection factor profile form from step two into the project QAO analysis form. Appropriateness ratings for all categories of selection factors are included in Appendix B and all forms are included in appendix C of this project QAO selection guide.

The four appropriateness ratings used in the forms to establish the appropriateness rating of the factors are, fatal flaw (denoted with X), least appropriate (–), appropriate (+), and most 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 least appropriate rating (–) indicates that for the particular selection factor category the QAO can work but is not the best option and if this QAO is implemented there may be extra measures needed to accommodate this particular selection factor. An appropriate rating (+) indicates that the QAO can work for that particular selection factor category meaning it neither harms nor improves the success of the project. Finally the most applicable rating (++) indicates that a project falling into that particular category can be improved by the implementation of the associated QAO.

The project QAO selection analysis form is split into two separate sections: primary selection factors and secondary selection factors. The primary factors are all the selection factors that have at least one fatal flaw rating; secondary factors are the remaining selection factors. If any of the primary selection factors have a fatal flaw rating then the respective QAO is eliminated as an appropriate QAO option for the project being analyzed. Due to the diversity of

the appropriateness ratings for the primary factors they have a more decisive role in the project QAO selection. If the potential QAOs are not narrowed down to two or less options at the completion of the primary selection factors then the same process is used for the secondary selection factors. If the potential QAOs are narrowed down to two or less the user can continue on to the secondary selection factors to further understand the potential QAOs, investigate the details of each project selection factor ratings and/or make a final selection of the project QAO.

This section has presented the three steps of the project QAO selection tool: barrier identification, selection factor preparation and QAO selection. The following section demonstrates the use of the tool by implementing the tool with an actual industry project.

DEMONSTRATION PROJECT

A highway project in a state in the mid section of the United States was selected to demonstrate and validate the project QAO selection process tool; the exact location is not identified to protect the identity of persons who participated in the research. The scope of the project was to construct a landmark river bridge(s); rehabilitate or replace approximately four miles of interstate; improve traffic operations, geometrics, and safety; and add mainline capacity.

The budget for the DB project was approximately $230M. The SHA selected the DB method to reduce/compress/accelerate project delivery period; get early construction contractor involvement; encourage innovation; compete different design solutions through the proposal process; and address flexibility needs during the construction phase. This SHA has been very open to trying new delivery methods and does have a focus on shifting more quality responsibilities away from the agency. The agency and the local contracting and engineering industry have built up high levels of mutual trust as a result of increasing use of alternative

delivery methods in the state. The agency has experienced staff reductions over the past decade and significant losses of expertise through retirements.

The first step of the project QAO selection tool is identifying barriers to the implementation of alternative project QAO. The demonstration project is in a state that is leading the way in shifting quality responsibility away from the agency, and no state or local barriers preventing alternative QAO selection were identified. Also no federal regulations pertain to this project that would prohibit the implementation of an alternative QAO. The agency itself is relatively progressive and encourages trying new processes and strategies that can improve projects and overall efficiencies. As such no agency polices exist that prevent alternative QAO implementation. The result of the first step is that all project QAOs are still viable for this project.

The second step of the project QAO selection tool is completing the project QAO selection factor profile form. The project goals were already established, so the selection factor profile form was completed to show the QAO appropriateness ratings for the category of each selection factor corresponding to the project. The completed selection factor form is used in step three.

The third and final step in the project QAO selection tool is using the project QAO analysis form to select the project QAO. This form is completed by transcribing the appropriateness ratings for each QAO to the category of selection factor applicable to the project. The completed project QAO analysis form for the demonstration project is presented in Figure 15. In this case the Deterministic, Assurance, and Variable QAOs had fatal flaw ratings in at least one of the primary selection factors and as such they were deemed inappropriate. This left two potential QAO options, Oversight and acceptance. The secondary selection factors for these

QAOs were analyzed to further understand the two possible QAOs so a final QAO decision could be made with confidence and the appropriate considerations.

The project delivery method for this project is DB. The appropriateness ratings for each QAO for the design build category were transcribed into the project QAO analysis form Figure 15 in the project delivery method row. Both Deterministic and Assurance are rated as least appropriate, but are not fatal flaws. However because of the amount of project responsibility that DB typically shifts to the design builder, the Deterministic and Assurance QAOs do not shift enough quality responsibility to the design builder to be in line with the intention of the delivery method. Deterministic and Assurance have been used on DB projects when the agency is minimally experienced in DB and is not comfortable with shifting too much of the quality responsibility.

The acceptance QAO shifts too much responsibility away from the agency because for a DB project and as a result incurs a least appropriate rating. The Oversight QAO is considered the best fit because the design builder is responsible for delivering both the design and construction of the project while the agency is responsible for clearly stating the requirements for the project but is not involved in the day-to-day management of project design or construction. The Oversight QAO allows the agency to ensure that the design builder is meeting the requirements of the project.

Primary selection factors	**Determin.**	**Assure.**	**Var.**	**Over.**	**Accept.**
Agency staff availability	X	–	+	++	++
Trust between agency and industry	+	++	++	++	++
Industry quality ability	+	+	+	+	+

Project delivery method	–	–	+	++	–
Project size	–	+	+	++	++
Quality responsibility to be shifted from agency	X	X	X	++	++
Tally of primary selection factor results	**X**	**X**	**X**	**++**	**++**
Secondary selection factors	**Determin.**	**Assure.**	**Var.**	**Over.**	**Accept.**
Project complexity	n/a	n/a	n/a	+	+
Project schedule sensitivity	n/a	n/a	n/a	++	++
Agency culture	n/a	n/a	n/a	+	+
Agency staff experience	n/a	n/a	n/a	++	++
Tally of secondary selection factor results	n/a	n/a	n/a	++	++
Rating key: X Fatal Flaw	–Least Appropriate		+ Appropriate	++ Most Appropriate	

Figure 21 - Completed project QAO analysis form for the demonstration project.

The project QAO selection tool indicated that the Oversight and acceptance QAOs are the most appropriate for the project. In cases like this, because projects and agencies are unique, it is up to the agency at this point to decide whether the Oversight or acceptance QAO would be the best fit for the project. At the time this tool was developed, the demonstration project was already well into construction, so the tool could not be used to select the QAO for the project. However, the Oversight QAO, which is one of the options indicated by the QAO selection tool, was implemented for the demonstration project, which seems to further validate the tool.

Appendix G.1 – Factor definitions

Project delivery method - "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." The project delivery methods considered in this guide are design-bid-build, design-build, construction manager general contractor and public private partnership (P3)/design-build-operate-maintain (DBOM).

Project size - The total dollar value of the project's design and construction budgets.

Agency staffing ability – The quantity of agency project staff, available to be committed to the project as compared to traditional levels.

Industry's ability to manage their own quality - The local Industry's level of competence in managing their own quality. The industry includes both the design and construction communities. Competence can be increased through experience, training, education, industry culture or a combination of any of the above.

Trust between the agency and the industry – The level of Agency confidence that project decisions will be based on achieving the best results for the project, rather than the individual or specific company. This requires the industry to overcome the well situated paradigm of lack of trust between the project participants (designer, engineer, contractor, consultant, and agency)

Quality responsibility to shift away from the agency – The amount of liability for the management of the project's quality that the agency wants to shift to another project partner (contractor, designer, engineer, design builder, CMGC, concessionaire).

Project complexity - The intricacy of project scope as compared to typical project in the same locale stemming from programming requirements, design constraints, construction methods, site conditions, budget and funding constraints, quality requirements, etc.

Schedule sensitivity - The vulnerability of the project schedule to changes due to delays, conflicts, and/or events outside of the designer's and/or contractor's control, such as coordination of observations, inspections and/or testing performed by the agency.

Agency staff experience– The average number of years of experience of the agency staff committed to the project.

Agency culture – In this context agency culture refers to the agency's attitude toward the implementation of change in project management techniques.

Appendix G.2 – Factor Appropriateness Ratings Sheet

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Availability of agency project staff					
fully staffed	++	+	+	+	X
moderately staffed	-	+	+	+	-
minimally staffed	X	-	+	++	++

*needs to be considered in conjunction with the other factors.

- If a full staff is available for the project, as compared to typical past projects, the Deterministic is the best fit because it requires a large staff to manage the day to day quality needs of the project: inspection, observation, materials testing, etc. Acceptance is a fatal flaw in this case because these resources will be underutilized due to the fact that acceptance shifts the bulk of the quality responsibilities away from the agency.
- A moderately staffed project, as compared to typical projects, 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.
- Deterministic and acceptance are best suited for opposite extreme ends of the agency project staff availability spectrum.
- Acceptance and Oversight are both most 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 of a project which is exactly the use for both the Oversight and acceptance QAOs.

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Trust between agency and industry					
Low	++	+	+	-	X
Moderate	+	+	+	+	+

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
High	+	++	++	++	++

*needs to be considered in conjunction with the other factors.

- As the amount of quality shifts away from the agency the amount of collaboration amongst all the project team members increases which is directly reflected in the amount of trust that is needed between the agency and industry
- The acceptance QAO shifts the most amount of quality responsibility away from the agency. Without having trust between the agency and the industry it is incredibly difficult to implement the acceptance QAO, which is why it is a fatal flaw.
- All levels of trust are appropriate for the Deterministic QAO, however it is the only one that is highly appropriate for a low level of trust because the agency is responsible for all elements of quality requiring the rest of the project team to react to the agency.

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Industry ability to manage their own quality					
Low	++	+	+	-	X
Medium	+	+	+	+	+
High	-*	+	+	++	++

*needs to be considered in conjunction with the other factors.

- When shifting responsibility for quality away from the agency it is critical that the party receiving the responsibility has the ability to successfully meet the responsibilities. This could require additional training, education, and/or resources by the party receiving the new responsibility.
- The "industry" in this selection factor is meant to be the local design, consulting and/or contracting community.
- Additional requirements or qualifications may need to be included in the RFP to ensure that the party's proposing on the project can manage the level of quality responsibility successfully.

- As the quality responsibility shifts away from the agency the importance of succinctly stating the quality requirements in the RFP, specification and contract documents increases.
-

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Project delivery method					
Design bid build	++	+	+	+*	-
Design build	-	-	+	++	-
CMGC/CMAR	-	+	+	++	+
P3/DBOM	X	-	-	+	++

*needs to be considered in conjunction with the other factors.

- As the amount of project responsibility shifts away from the agency, design bid build (DBB) to public private partnership (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.
- The fatal flaw rating corresponds to the implementation of the Deterministic QAO on a PPP project, because the Deterministic QAO requires the agency to retain all control of the quality assurance, but in PPP projects almost all quality control over the project shifts away from the agency to the concessionaire
- DB shifts much of the project responsibility to the design builder at an early stage of the project. As a result, in order for the design builder to most effectively manage the quality of the work the majority of the quality responsibilities needs to be shifted as well which is why the Oversight QAO is most appropriate.
- DB is least appropriate for Deterministic and Assurance because the amount of project responsibility shift does not match the amount of quality responsibility shift. However the Assurance QAO has been used on DB projects because of the discomfort some agencies have with transferring so much project and quality responsibility to one design builder. This usually stems from an agency's inexperience in DB and/or alternative project QAO.

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Project size					
<$10M	++	++	+	+*	-
$10M - $50M	++	++	+	+	+
$50M-$500M	-	+	+	++	++ *
$500M - $2B	X	-	+	++*	++
>$2B	X	-	+	++*	++

*needs to be considered in conjunction with the other factors.

- As the project size increases the QAOs shifts from Deterministic towards acceptance. As a project becomes larger in size the complexity increases, the agency resources needed increases and the risk increases requiring the agency to shift some of the agency quality responsibility to shift to other project participants in order to meet the needs of the project.
- Deterministic is a fatal flaw for projects over $500M primarily as a result of the inherent complexity of the project requiring expertise outside of the agency and the amount of risk on the project. Additionally, the Deterministic QAO is agency staff intensive and as the project grows in size the amount of demand for agency resources grows which the agency may not be able to meet.
- Acceptance is not appropriate for projects under $10M primarily due to the fact that these projects are typical "run of the mill" projects where it would not be worth creating the infrastructure to support an acceptance QAO. However if the agency already has ability to implement the acceptance model, past experience with the acceptance QAO and infrastructure in place to manage the acceptance QAO, there is nothing prohibiting the acceptance QAO from being implemented on projects under $10M.
- Assurance is not appropriate for projects over $500M because it does not adequately react to the needs associated with the inherent complexity of the project and the need to spread the risk of large projects.
- Variable has so much flexibility it is appropriate for all sizes of project.

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Shift the quality risk away from the agency					
All	X	X	X	++	++
Some QA and some QC	-	-	++	++	+
Some QA	- *	-	+	++	+*
Some QC	+ *	+	+	++	X
None	++	-	-	X	X

*needs to be considered in conjunction with the other factors.

- The categories of *the amount of shift of quality risk away from the agency* selection factor are essentially the definitions for the fundamental QAOs. Such as, Deterministic keeps all control with the agency which is equivalent to shifting none of the quality risk away from the agency. The 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 responsibility.
- The Oversight and acceptance QAOs shift at a minimum the day to day management of quality away from the agency, therefore if the agency desires to shift none of the quality responsibility to other project team members then each of these QAOs is a fatal flaw.
- Assurance and Variable shift at a minimum some of the project quality responsibility away from the agency, therefore if the agency has a goal to retain all quality responsibility then Assurance and Variable are less appropriate.

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Project complexity					
Low	++	+	+	+	+

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Medium	+	+	+	+*	+
High	-	+	++	++	++

*needs to be considered in conjunction with the other factors.

- As the project complexity increases the amount of expertise needed from outside the agency tends to increase. As a result the agency no longer has the expertise required to assure the quality. As a result as the complexity of a project increases, the QAO shifts from Deterministic towards acceptance.
- Low complexity project is most appropriate for a Deterministic QAO because the expertise needed typically resides in the agency.
- A highly complex project will require more and more expertise from outside of the agency, resulting in the agency being able to communicate the quality requirements effectively.
- If a project has only a few complex items on a project, it may be that the QAO for those elements is different from the remainder of the project that is more along the lines of a typical project (such as special materials or a construction sequencing item).

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Schedule sensitivity					
Low	+	+	+	+	+
Medium	-	+	+	+	+
High	-	+	+	++	++

*needs to be considered in conjunction with the other factors.

- Overall schedule sensitivity is not a decisive factor in the selection of a project QAO unless the schedule is highly sensitive to delays resulting from quality coordination issues from varying members of the project team.
- Specifically schedule sensitivity comes into play when work is being conducted around the clock and has no float in the schedule.

- Schedule sensitivity can be assuaged if there is a good quality plan and communication plan between all parties involved in the day to day quality of the project (design and construction)

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Agency culture					
Traditional	++	+	-	-	-
Moderate	+	+	+	+	+
Progressive	-	+	+	++	++

*needs to be considered in conjunction with the other factors.

- Regardless of the project QAO, the agency is the leadership for the project and the agency culture ultimately dictates the culture of the project. The agency culture has to be aligned with the project QAO. The more alternative a project QAO is as compared to the traditional Deterministic QAO the greater the need for a progressive agency culture.
- The agency culture cannot only be with a few of the project staff, but has to be instituted throughout the agency. If the project team is progressive but the executive level of the agency is traditional, it will be difficult for a project team to be able to implement any non-traditional ideas such as alternative QAO.
- A moderate culture indicates that the agency is not the leading edge of the industry but willing to try new ideas tested out by other agencies. Because there is some acceptance of new ideas a moderate culture is appropriate for all QAOs.

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.
Agency project staff experience					
<5 years	+	+	+	-	- *
5 years - 10years	+	+	+	+	+
10 years - 20 years	++*	++	++	++	++
>20 years	+	+	++	++	++

Selection factor category	Determin.	Assure.	Var.	Over.	Accept.

*needs to be considered in conjunction with the other factors.

- 10 – 20 years experience is most appropriate for all QAOs. However the experience is used in different ways across the different QAOs. The Deterministic uses the experience to do more effective inspections whereas the acceptance QAO uses the experience to create the quality requirement details, identify flaws in the quality plans and resolve any quality issues that may arise.
- Less than five years of experience is not 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 and this experience can only be achieved through time in the field.
- The experience level categories are the average for all the agency staff. In general there needs to be a combination of more experienced staff with less experienced staff which is again why the 10 -20 year experience level is the most appropriate for all QAOs because there is this combination.
- The experience considered in this selection factor is primarily project or field experience. When shifting to a more alternative QAO such as Oversight or acceptance this experience may need to be complemented with training on how to manage the quality process at a higher level, away from the day to day level of management
- As the amount of quality responsibility shifts to other project participants the role of the agency shifts towards a role of managing requirements. This shift can be difficult for some agency staff and can require additional training, education and/or resources to successfully take on the new role.

Appendix G.3 – Project QAO selection tool forms

Project QAO Selection Factor Profile Form

Select the specific category for each selection factor that applies to your project. Factor definitions are included in Appendix A.

Primary factor categories					
Trust between agency and industry	☐Low		☐Medium		☐High
Industry quality ability	☐Low		☐Medium		☐High
Agency staff availability	☐Minimal		☐Moderate		☐Full
Project delivery method	☐DBB	☐DB	☐CMGC/CMAR		☐P3/DBOM
Project size	☐ <$10M	☐ $10M-50M	☐ $50M-$500M	☐ $500M-$2B	☐ >$2B
Quality responsibility to be shifted from agency	☐ None	☐ Some QC	☐ Some QA	☐ Some QC and QA	☐ All
Secondary factor categories					
Project complexity	☐Low		☐Medium		☐High
Project schedule sensitivity	☐Low		☐Medium		☒High
Agency culture	☐Traditional		☐Moderate		☐Progressive
Agency staff experience	☐<5 years	☐5 – 10 Years	☐10 – 20 years		☐>20 years

Figure 22 - Project quality assurance organization profile form

Project Quality Management Organization Analysis Form

Using the category of each factor that applies to your project, look up the value for each factor from the factor applicability ratings in Appendix B and fill in the corresponding ratings in the below matrix. If you are not able to select a project QAO using only the primary selection factors, then continue with the same process for the secondary selection factors.

Primary selection factors	**Determin.**	**Assure.**	**Var.**	**Over.**	**Accept.**
Agency staff availability					
Trust between agency and industry					
Industry quality ability					
Project delivery method					
Project size					
Quality responsibility to be shifted from agency					
Tally of primary selection factor results					
Secondary selection factors	**Determin.**	**Assure.**	**Var.**	**Over.**	**Accept.**
Project complexity					
Project schedule sensitivity					
Agency culture					
Agency staff experience					
Tally of secondary selection factor results					
Rating key: X Fatal Flaw	–Least Appropriate		+ Appropriate	++ Most Appropriate	

Figure 23 - Project quality assurance organization analysis form