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UNDERSTANDING COLLABORATION ENVIRONMENTS TO SUPPORT GREEN INFRASTRUCTURE CONSTRUCTION

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16. ABSTRACT
Close collaboration among stakeholders has long been recognized as an important factor of a successful project. In today's climate of a heightened focus on sustainability, collaboration needs to be taken to a new level in the design and construction process. This research investigates the issue of collaboration in light of project delivery system for transportation projects.

The research tested three different methods (i.e., multi-regression, generic algorithm, and step-wise method) to identify relationship between project delivery process and project outcomes. Taking into account r-square and p-value we concluded that the step-wise method with significant variables provided reliable results on environments and community results. The e**xpertise** and a**lignment of objectives among project delivery process factors** were the most significant input variables for a successful Environmental outcome in this model. The analysis also shows that **contractor's involvement** and i**nformation sharing** are important for successful community projects. Researchers developed best practices with associated factors and outcomes using above-mentioned qualitative as well as quantitative analysis. The best practices are (1) Alignment of cultures amongst organizations is a key to achieving environmental goals and (2) Engaging stakeholders, particularly the General Contractor, early in the project process results in effectively managed projects. The associated factors used in the quantitative analysis with relevant project outcomes were identified on each of two important practices identified in the qualitative analysis. Through the research findings, researchers learned that some factors and associated best practices have statistical relations with project outcomes (i.e., environments and community results). The research results may provide clients of public transportation projects an insight on practices and areas to be improved and enriched toward more environmental-friendly as well as community-friendly projects.

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Executive Summary

Close collaboration among stakeholders has long been recognized as an important factor of a successful project. In today's climate of a heightened focus on sustainability, collaboration needs to be taken to a new level in the design and construction processes. Most current project delivery systems can provoke adversarial relationships in times when the construction industry has become increasingly fragmented.

The objective of this research is to investigate the effects of project delivery system components on DOT projects performance. The research developed survey questionnaires and collected information on 84 projects, upon which multi-regression and step-wise regression analysis were performed. The research contributes to the knowledge of collaboration and project delivery systems in infrastructure construction by revealing the relationships between factors of project delivery systems and project performances.

The literature review summarizes the existing literature related to the project delivery process, including the important components and relationships involved in successful outcomes. While not an exhaustive review, it provided a direction for the survey questionnaire and interview questions developed later in the project. The research identified three areas of project delivery process: organizational integration, alignment of interests, and information sharing. For each area, factors are also indentified through the literature survey.

The quantitative section of the report documents the quantitative analyses that were performed as part of this study. We tested three different methods (i.e., multi-regression, step-wise method, and genetic algorithm) to identify relationships between project delivery processes and project outcomes. Taking into account R-square and P-value we concluded that the step-wise method provided reliable results on environment and community related performances. The **expertise** and **alignment of objectives among project delivery process factors** were the most significant input variables for a successful environmental outcome in this model. The analysis also shows that **contractor's involvement** and **information sharing** are important for successful community related performance.

The qualitative section of the report documents the qualitative analyses that were performed as part of this study. Five practices were identified to improve the project delivery process for better outcomes. They are (1) Alignment of Cultures, (2) Coordination, (3) Engagement of Stakeholders, (4) Using the Expertise of Contractors, and (5) Learning Organization. The keyword analysis shows that aligning cultures and engaging stakeholders are the most important practices.

The research team developed best practices with associated factors and outcomes using above-mentioned qualitative as well as quantitative analysis. The best practices are: (1) Alignment of cultures amongst organizations is a key to achieving environmental goals and (2) Engaging stakeholders, particularly the General Contractor, early in the project process results in effectively managed projects. The associated factors used in the quantitative analysis with relevant project outcomes were identified on each of two important practices identified in the qualitative analysis.

Through the research findings, the research team identified that some factors and associated best practices have statistical relations with project outcomes (i.e., environment and community objectives). The research results provide DOT personnel and project managers of public transportation projects an insight on practices and areas to be improved and enriched toward more environmental-friendly as well as community-friendly projects.

1. Introduction

1.1 Background and Problem Statements

Close collaboration among stakeholders has long been recognized as an important factor of a successful project. In today's climate of a heightened focus on sustainability, collaboration needs to be taken to a new level in the design and construction process. Most current delivery systems can provoke adversarial relationships in times when the construction industry has become increasingly fragmented. In this regard the owners of the public transportation projects need to improve the organization and structure of the project delivery system to improve the level of collaboration. This research investigates the issue of collaboration in light of project delivery system for transportation projects.

1.2. Objectives

The objective of this project is to investigate the effects of project delivery system components (commercial terms and project organization) on the performance of transportation infrastructure projects based on several measures. The outcome of this objective serves as a best practices guide for integrated project delivery processes for state Departments of Transportation (DOTs) to improve the project cost, duration, environmental, safety, and community impacts.

Although the integrated delivery process requires more efforts in the design phase, it reduces total costs of changes to projects. Close collaboration among stakeholders has long been an important factor of a successful project. In today's climate of a heightened focus on sustainability, collaboration needs to be taken to a new level in the design and construction process.

Specifically, green infrastructure projects require more collaborative efforts and integrated processes in the course of project delivery process. Most current delivery systems can provoke adversarial relationships in times when the construction industry has become increasingly fragmented. Current best practices for integrated processes, including teambuilding and value engineering, are not fully leveraged because the traditional delivery system does not support them.

In order to achieve the objectives of this project, this report documents two main components as follows:

- **Identify critical components and relationships**: The first component of this approach is to identify relationships between project delivery process components and WSDOT project performance. This phase involves a survey to construction project engineers who were involved in WSDOT projects. Critical components of the delivery process were then identified using statistical analysis of survey data.
- **Develop best practices**: The research effort then moves to identifying circumstances in which each of the critical components is fully leveraged. The research team (1) interviewed with key professionals (selected based on responses to the aforementioned survey) and (2) performed qualitative analysis of interview results to identify conditions where each component of the delivery process works to its full potential.

1.3. Research Structure

The following sections provide a brief implementation report, current progress on the work plan, and documentation of the project progress. The report is organized into a Literature Survey, Quantitative Analysis, Qualitative Analysis, and Conclusions.

The quantitative section of the report documents the quantitative analyses that were performed as part of this study. The section details (1) the development of an online survey that was distributed to DOT engineers; (2) the data collection plan; and (3) the data analysis methods employed to investigate the relationships between collaboration variables and performance indicators.

The qualitative section of the report documents the qualitative analyses that were performed as part of this study. This section details (1) the development of interview questions for select DOT engineers; (2) a summary of the interviews findings; and (3) the data analysis methods employed to investigate the relationships between responses to the interview questions and performance indicators. The research team then developed best practices with associated factors and outcomes using the above-mentioned qualitative as well as quantitative analysis.

2. Research Methodology

This section of the report documents the research methodology used by the research team. The research process began with a series of research questions that are answered by one or more project tasks. Figure 1 shows the research questions and related project tasks in this project.

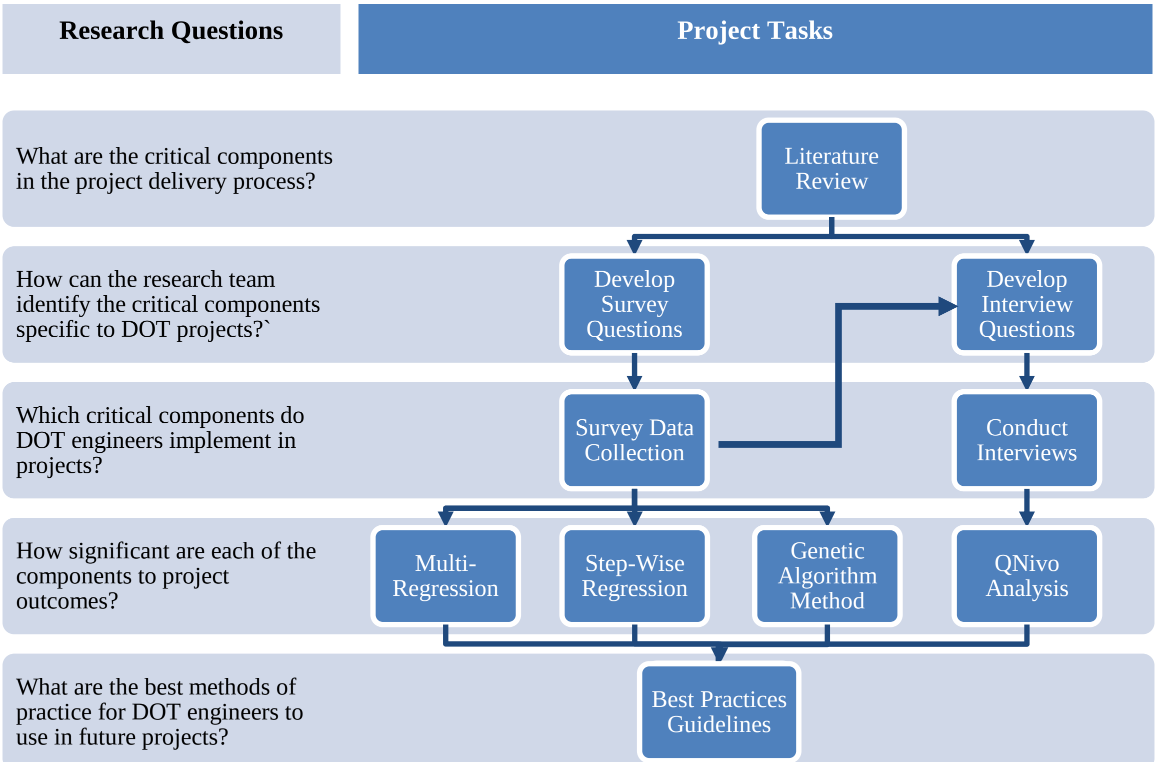

Figure 1 – Research Methodology Process

As shown in Figure 1, this research project began with a thorough literature review to determine existing project delivery components that are critical to positive outcomes. The literature review informed the development of survey questions, and both of those components were used to develop interview questions.

After the data collection period, to distribute surveys and conduct interviews, the information was analyzed with multiple tools. Regression models were developed based on the survey results, and QNivo Analysis software was used to determine the number of references to critical factors in each of the interviews. The regression models and qualitative analysis were used to develop guidelines for practitioners.

3. Literature Review

This section of the report summarizes the existing literature related to the project delivery process, including the important components and relationships involved in successful outcomes. While not an exhaustive review, it provided a direction for the survey questionnaire and interview questions developed later in the project.

3.1. Project Delivery System: Process View

There are a variety of project delivery systems in construction industry which all aim at delivering construction projects to project owners with desired quality and within expected cost and schedule.

Miller et al (2000) defines project delivery system as "a system for organizing and financing design, construction, operations and maintenance activities that facilitates the delivery of a good or service". Construction Industry Institute (2001) asserts that a suitable project delivery and contracting strategy would assign roles and responsibilities in an optimal way for the performance of project activities and facilitate the optimal performance of these activities with respect to owner's objectives. Oyetunji and Anderson (2006) further state that the "project delivery system defines the sequence of project phases, parties involved in the project, and implicitly assigned roles and responsibilities to project parties".

Furthermore, the Associated General Contractors of America (AGC 2004) defines project delivery method as "the comprehensive process of assigning the contractual responsibilities for designing and constructing a project." It further states that "a delivery method identifies the primary parties taking contractual responsibility for the performance of the work".

However, Ballard et al (2011) asserted that delivering projects that meet owner's values and expectations cannot be achieved by merely selecting from a list of project delivery systems and contracting strategies. Instead, project delivery systems should be adapted to the contexts that reflect the unique characteristics of owners and projects. In other words, project delivery systems should be viewed as products of design based on a paradigm that achieves the best outcomes through integration of organizations and people, alignment of interests and management process.

In this research, the research team adopted Ballard et al (2011)'s view assuming that the project delivery system is not merely a contractual form but an organic process which includes integration, alignment of commercial interests, and management process.

3.2. Integration: Project Delivery Structure that Allows or Encourages Collaboration

There are various definitions of integration in different disciplines. Lawrence & Lorsch's (1967) definition of integration is probably the oldest systematic definition of the term offered in the field of organization theory. They define the term as "the quality of the state of collaboration which exists among departments that are required to achieve unity of effort because of environmental demands". Kahn (1996) adds the element of "interaction" and defines the term as a multidimensional process that includes "interaction" and "collaboration".

In construction context, project team integration has been defined as "where different disciplines or organizations with different goals, needs and cultures merge into a single cohesive and mutually supporting unit with collaborative alignment of processes and cultures" (Baiden et al 2011). The degree of achieved integration for delivering a construction project is subject to applied contractual, organizational, and technological mechanisms (Mitropoulos and Tatum 2000). Partnering, cross-functional teams and informal relationships are some examples of organizational mechanisms. Moreover, Building Information Modeling (BIM) could act as a technological mechanism for achieving integration by sharing information among different parties. These mechanisms are designed to bring all project parties at the table and facilitate their full collaboration and integration in a project.

The literature survey on integration or collaborative environments shows that structural integration, alignment of interests, and information sharing are critical areas, on which our quantitative and qualitative investigation would be built. The factors identified in literature review are reflected on survey questionnaire (Appendix A). The details on each factor were described in Table 1.

4. Quantitative Analysis

This section of the report documents the quantitative analyses that were performed as part of this study. The following subsections detail (1) the development of an online survey that was distributed to DOT engineers; (2) the data collection plan; and (3) the data analysis methods employed to investigate the relationships between collaboration variables and performance indicators.

4.1. Survey Questionnaire Design

Survey questions were developed by the project team to determine the most important factors in the integrated project process. The research group developed survey questionnaires based on (1) information acquired from a meeting with a group of Washington State Department of Transportation (WSDOT) officers and (2) the literature on sustainable construction and project delivery process.

The Principle Investigators (PIs) held a meeting with a group of WSDOT officers in Olympia, WA to discuss the research objectives and methodologies and to determine the relevant questions to be included in the survey. The PIs also acquired information on currently applied measures in the field of sustainability as well as other performance data. This meeting included key personnel in the Design Office; Design Policy, Standards and Research; Environmental Services Office; Construction Office; Work Zone Training; and Policy, Research and Publications. While, a complete literature summary was provided in Section II of the report.

The on-line survey was created with the Catalyst web tool available through the University of Washington (UW). Questions and content were also revised based on feedback from WSDOT engineers through recommendations provided by email communications. Applicable changes to survey questions were made based on the feedback received from the engineers. The complete survey questionnaire is included in Appendix A.

4.2. Data Collection Plan

Surveys were distributed to DOT engineers in a number of states in order to gain perspective on the project delivery processes that influence projects success. DOT websites, existing contacts, and other sources were used during the data collection process. Surveys were then distributed by email to DOT engineers who were asked to complete the survey for one or more projects that they had been directly involved with. The following sections present the data collection plan in more detail.

4.2.1. Project List from DOTs

DOT websites were used to collect project information, including project descriptions, costs, and contacts, in order to distribute surveys to DOTs for completion. Contacts were project engineers and project managers that have familiarity with the project and are able to answer questions regarding relationships with engineers, planners, contractors, and suppliers involved in the project. The criteria used for selecting projects included the following: (1) the project must be recent (i.e. completed within the past 5 years) and (2) total project budget is more than $3 million.

4.2.2. Distribute Survey

About 500 surveys or survey requests were sent to collect information for over 800 projects in several states, including Washington, Florida, Illinois, Indiana, Wisconsin, Texas, California, Oregon, and New York (where the same project engineer could provide information on more than one project). Individual emails were sent to contacts for each project. During the survey distribution process, several new projects were referenced and included in subsequent email distributions

While many surveys have been distributed, the response rate was expected to be low. As shown below, approximately 500 surveys were distributed to DOT contacts. As shown in Figure 2, although less than 100 were received, the project team planned for a low response rate.

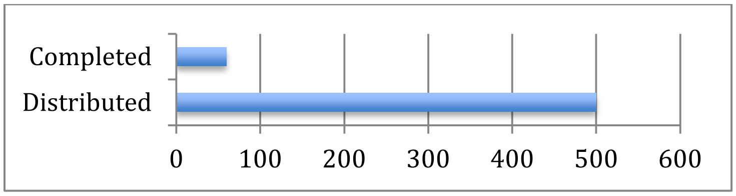

Figure 2 – Survey Distribution and Response Summary

Since this was expected, due to the fact that many surveys were distributed to engineers with on-going responsibilities, a significantly large number of surveys were distributed in order to collect information for a statistically significant number of responses. Multiple follow-up e-mails and phone calls were performed to increase the response rate as much as possible. Figure 3 shows the number of survey responses received from different DOTs across the country.

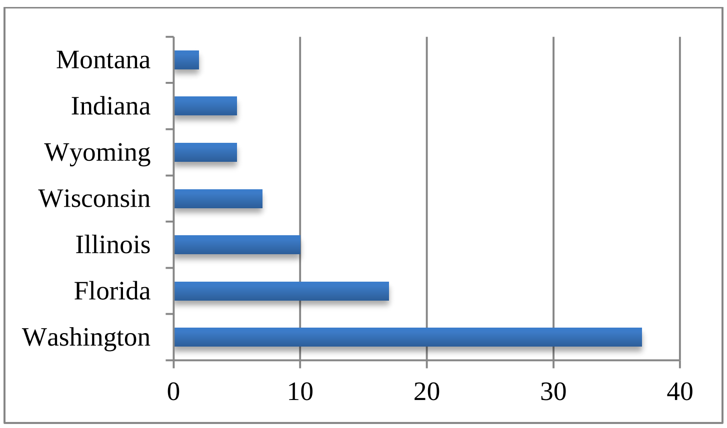

Figure 3 - Number of Responses from state DOTs

As shown in the figure, responses have been received from seven DOT agencies. The highest number of responses has been received from WSDOT. Additional surveys have been sent to Oregon DOT, New York DOT, Texas DOT, and California DOT, however, project engineers did not complete surveys.

4.3. Data Analysis

This section of the report documents the steps taken to develop mathematical equations to represent the results of the survey. The approach is first defined, followed by an explanation of variables and data analysis methods.

4.3.1. Approach

Survey responses were downloaded and organized using UW Catalyst and Microsoft Excel. Survey respondents were contacted to complete any missing or skipped questions; any remaining missing values were omitted.

Survey questions were used to develop groups of input and output variables that were used in three separate analysis methods. The analysis methods used include Multi-Regression Analysis, Step-Wise Regression Analysis, and Genetic Algorithms (GA), as documented in the following sections.

Variables are based on responses to the questions in the survey, and each analysis method assigns coefficients to input variables based on the values for each output variable. Each analysis method results in one equation for each output variable containing any number of input variables with coefficients.

4.3.2. Values Definition

Input variables are the responses to the survey that involve the relationships between DOT engineers and the project team. Responses to 10 questions were used as input variables in the quantitative analyses. Some of these questions ask for specific project details, such as phase in which the general contractor and specialty suppliers were first involved. Others ask respondents to compare this project to other projects, such as whether this project "resulted in a culture of trust between all parties" as compared to other projects. Table 1 summarizes the input variables.

Table 1. Summary of Input Variables

Input Variable	Description	Value
	Organizational Integration	
General Contractor (GC) Involvement	When the GC was first involved in the project	1 – 5 scale provided by the respondent that ranged from Feasibility to Construction Phase
Major Contractors and Specialty Suppliers	When the major contractors and specialty suppliers were first involved in the project	1 – 5 scale provided by the respondent that ranged from Feasibility to Construction Phase
	Alignment of Interests	
Expertise Leveraged	How much trades' or supplier's expertise leveraged in design and planning	1 – 5 scale provided by the respondent
Relationships Developed	How well relationships between participating organizations developed during the project	1 – 5 scale provided by the respondent
Disputes Settled	Percentage of disputes settled amicably, without recourse to litigation or the threat of litigation	1 – 5 scale based on percentages (e.g. 0%, 25%, 50%, 75%, 100%) provided by the respondent
Partnering Relationship	Presence of and/or duration of partnering relationship with contractor	1 – 5 scale based on previous relationship and length
Culture of Trust	How well cultures among participating organizations were aligned How well project leaders created a culture with emphasis on openness, trust, mutual respect and collaboration	Average of the two 1 – 5 scale responses provided by the respondent
Incentives	Presence of incentives in the project	1 if no incentives were included and 5 if there were incentives
Alignment of Objectives	How well commercial interests of the project team member organizations aligned to pursuit of project objectives compared to other similar projects	1 – 5 scale provided by the respondent
	Information Sharing	
Information Sharing	Whether project information was shared freely among the project team member organizations during construction	1 – 5 scale provided by the respondent

Output variables are responses to the survey that involve the results or outcomes of the project. Questions were grouped into 5 categories that were used as output variables in the quantitative analyses. Some questions involved project specifics, such as outcomes for the budget and schedule. Other outcomes are based on rating scales that asked respondents to rate this project as compared to other projects, such as impacts to the environmental goals and community impacts. The following sections summarize the output variables.

Environment: Success of the environmental goals of the project was compared to scope of environmental goals as determined by responses to two separate questions. Respondents were asked to rate the "Relative scope for specific environmental goals" (goals that were identified by the survey respondent in a prior question) and "How successfully did the project achieve the environmental goals" on a 1 – 5 scale. A new scale was then applied to answers based on average of ratings for the environmental goals to achievement. This was based on the results shown in Table 2.

Table 2. Environment Factor Summary

Description	Score
5 - High	5
4	4
3 – Medium	3
2	2
1 - Low	1

Safety: Respondents were asked about "Number of safety incidents" and "The total number of man-hours used in the construction of this project." A 1 – 5 scale was applied to the responses based on proportion of incidents to man-hours (i.e. the number of safety incidents divided by the number of man-hours for the project). The scale was based on the results shown in Table 3.

Table 3. Safety Factor Summary

Description	Score
No Safety Accidents	5
Less than a 0.001 Ratio	4
0.001 to 0.0019 Ratio	3
0.002 to 0.0029 Ratio	2
Equal to or more than 0.003 Ratio	1

Budget: The survey asked questions about the Total Construction Budget *not including* approved change orders, Total Construction Budget *including* approved change orders, and the Actual Construction Cost of the project. The Budget category was based on the Actual Construction Cost of the project minus the Total Construction Budget including approved change orders. A 1 – 5 scale was applied based on the percentages over/under budget, as shown in Table 4.

Table 4. Budget Factor Summary

Description	Score
Equal to or Under Budget	5
Less than 1% Over Budget	4
1% to 1.9% Over Budget	3
2% to 2.9% Over Budget	2
More than 3% Over Budget	1

Duration: The survey asked questions about the scheduled construction duration *not including* approved change orders, scheduled construction duration *including* approved change orders, and the actual construction duration of the project. The Duration category was based on the actual construction duration of the project minus the scheduled construction duration *including* approved change orders. A 1 – 5 scale was applied based on the percentages over/under the project schedule, as shown in Table 5.

Table 5. Duration Factor Summary

Description	Score
Equal to or Ahead of Schedule	5
Less than 1% Behind Schedule	4
1% to 4.9% Behind Schedule	3
5% to 24.9% Behind Schedule	2
More than 25% Behind Schedule	1

Community: This category is rating the level of performance in mitigating the impacts of construction activities on the community. Respondents were asked to use a 1 – 5 scale reflecting the "Level of performance in mitigating the impacts of construction activities to community, such as traffic." Responses were used directly for this category.

Once the input and output variables were established, three analysis methods were used to determine the coefficients for each input variable that would provide the highest correlation to the output variables. These methods are documented in the following sections.

4.3.3. Multi-Regression Analysis Method

Multi-regression analysis method was used to explore the relationships between the input and output variables. R Analysis Software and built-in functions were used to develop linear models that would fit the input variable coefficients to the output variables.

The following tables show the results for each output variable and the format is replicated for the other quantitative analyses in the rest of this report. The following points describe each column of the tables:

- **Estimate**: optimum coefficient for each of the variables included in the multi-regression analyses
- **Std. Error**: the standard error calculated with R Analysis Software
- **T-Value**: calculated t-values with R Analysis Software
- **Pr(>|t|)**: based on the t-value, this is the probability of observing data within the range of those observed

Input variables that are more significant have lower Pr(>|t|) values. R Analysis Software and other references consider significant variables as those with a Pr(>|t|) value lower than 0.05. Tables 6 through 10 show the results of the multi-regression analysis for each project outcome.

Table 6. Multi-Regression Method: Environment

Environment	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.37	0.28	1.31	0.19
GC Involvement	0.04	0.15	0.26	0.80
Major Involvement	0.00	0.19	0.02	0.99
Expertise	0.31	0.14	2.19	0.03
Relationships	0.24	0.17	1.40	0.17
Disputes Settled	0.13	0.11	1.17	0.25
Partnering	-0.01	0.06	-0.20	0.84
Culture of Trust	0.26	0.15	1.67	0.10
Incentives	-0.08	0.06	-1.37	0.18
Alignment of Objectives	0.17	0.10	1.63	0.11
Information Sharing	-0.10	0.10	-1.01	0.32
Multiple R-squared: 0.697, Adjusted R-squared: 0.6549				

Table 7. Multi-Regression Method: Safety

Safety	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.34	0.43	7.81	0.00
GC Involvement	0.27	0.22	1.22	0.23
Major Involvement	-0.41	0.28	-1.46	0.15
Expertise	-0.19	0.21	-0.87	0.39
Relationships	0.56	0.26	2.14	0.04
Disputes Settled	0.13	0.17	0.79	0.43
Partnering	0.11	0.09	1.20	0.23
Culture of Trust	-0.47	0.24	-1.98	0.05
Incentives	0.04	0.09	0.41	0.68
Alignment of Objectives	0.05	0.15	0.35	0.73
Information Sharing	0.01	0.15	0.05	0.96
Multiple R-squared: 0.2153, Adjusted R-squared: 0.1063				

Table 8. Multi-Regression Method: Budget

Budget	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.62	0.56	4.67	0.00
GC Involvement	0.56	0.29	1.93	0.06
Major Involvement	0.45	0.37	1.22	0.23
Expertise	-0.13	0.28	-0.46	0.65
Relationships	0.19	0.34	0.56	0.58
Disputes Settled	-0.03	0.22	-0.11	0.91
Partnering	0.18	0.12	1.48	0.14
Culture of Trust	0.27	0.31	0.86	0.39
Incentives	-0.07	0.11	-0.59	0.56
Alignment of Objectives	0.00	0.20	0.02	0.99
Information Sharing	-0.40	0.20	-1.98	0.05
Multiple R-squared: 0.1828, Adjusted R-squared: 0.06934				

Table 9. Multi-Regression Method: Duration

Duration	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.20	0.40	8.10	1.01e-11
GC Involvement	0.04	0.21	0.17	0.86
Major Involvement	0.17	0.26	0.65	0.52
Expertise	-0.09	0.20	-0.43	0.67
Relationships	0.14	0.24	0.57	0.57
Disputes Settled	-0.10	0.16	-0.63	0.53
Partnering	0.07	0.08	0.89	0.38
Culture of Trust	-0.06	0.22	-0.26	0.80
Incentives	0.08	0.08	0.96	0.34
Alignment of Objectives	0.09	0.14	0.63	0.53
Information Sharing	0.20	0.14	1.37	0.17
Multiple R-squared: 0.1771, Adjusted R-squared: 0.06278				

Table 10. Multi-Regression Method: Community

Community	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.79	0.42	1.88	0.06
GC Involvement	0.26	0.22	1.20	0.23
Major Involvement	0.01	0.28	0.05	0.96
Expertise	-0.11	0.21	-0.53	0.60
Relationships	0.02	0.26	0.06	0.95
Disputes Settled	0.17	0.17	1.01	0.31
Partnering	0.04	0.09	0.41	0.68
Culture of Trust	0.05	0.23	0.22	0.83
Incentives	0.03	0.08	0.32	0.75
Alignment of Objectives	0.08	0.15	0.53	0.60
Information Sharing	0.28	0.15	1.83	0.07
Multiple R-squared: 0.3916, Adjusted R-squared: 0.3071				

Discussion

As shown in the tables above, all of the input variables are used to develop an equation for each output variable, using positive and negative coefficients. While most of the input variables had positive coefficients (reflecting positive impact on the desired outcomes), there were some input variables that had coefficients with negative values.

The multi-regression analysis also does not account for variables that are included in the model but might not be significant for a specific outcome. In order to eliminate some of the variables to determine which are actually influencing the outcomes consistently, a step-wise approach was explored.

4.3.4. Step-wise Regression Method

The step-wise regression method is a similar approach as the multi-regression analysis method, but only input variables that improve the correlation of the results are included in the final model. This method was used to improve upon the multi-regression models since the R Software is able to test several combinations of variables that would be difficult to enumerate manually.

There are three basic approaches to the step-wise regression method. These are defined as follows:

- Forward method – Test each input variable and keep the one that results in the highest R^2 value. Add the next variable based on which increases R^2 the most. Stop when none of the other input variables are significant. As described in the previous section, significant variables are those with a Pr(>|t|) value less than 0.05.
- Backward method – Begin with all input variables in the model. Remove a variable at each step that has the least significance. Continue until only significant variables remain.
- Forward with Backward Look method – Perform both forward and backward approaches and choose the model with the highest R^2. The R^2 value is an indication of the best fit for the model.

According to Makridakis et. al. (1998), neither forward nor backward stepwise analyses are guaranteed to produce the best combination of input variables, and the Forward with Backward Look also has its limitations since it is not able to test every combination of variables. The last approach was used for the analysis in this study since it is able to account for several combinations of variables, without running *every* combination—a procedure that is impractical. The authors continue to explain that “since this is impractical we often have to rely on less than perfect answers, and the third method [Both] is of considerable value” (Makridakis et. al. 1998, 285). The results of the analyses are shown in Tables 11 through 15. One table is included for each output variable, along with the input variables and coefficients that were included in the final model.

Table 11. Step-Wise Method: Environment

Environment	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.37781	0.23588	1.602	0.1133
Expertise	0.29171	0.12074	2.416	0.0181
Relationships	0.27127	0.15484	1.752	0.0838
Culture of Trust	0.2342	0.14761	1.587	0.1167
Incentives	-0.0767	0.051	-1.504	0.1366
Alignment of Objectives	0.21364	0.08868	2.409	0.0184
Multiple R-squared: 0.6887,	Adjusted R-squared: 0.6685			

Table 12. Step-Wise Method: Safety

Safety	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.42697	0.40721	8.416	1.61E-12
GC Involvement	0.29577	0.20635	1.433	0.1558
Major Involvement	-0.5145	0.24157	-2.13	0.03639
Relationships	0.62739	0.22603	2.776	0.00691
Partnering	0.12701	0.08559	1.484	0.14189
Culture of Trust	-0.3838	0.21655	-1.772	0.08033
Multiple R-squared: 0.1924,	Adjusted R-squared: 0.1399			

Table 13. Step-Wise Method: Budget

Budget	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.7659	0.529	5.228	1.40E-06
GC Involvement	0.5302	0.2704	1.961	0.0535
Partnering	0.1698	0.1119	1.518	0.1331
Culture of Trust	0.4176	0.1871	2.232	0.0285
Information Sharing	-0.3519	0.1831	-1.922	0.0582
Multiple R-squared: 0.1524,	Adjusted R-squared: 0.109			

Table 14. Step-Wise Method: Duration

Duration	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.54708	0.30903	11.478	< 2e-16
Information Sharing	0.27943	0.08021	3.484	0.0008
Multiple R-squared: 0.1303, Adjusted R-squared: 0.1196				

Table 15. Step-Wise Method: Community

Community	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.8461	0.3739	2.263	2.64E-02
GC Involvement	0.2928	0.196	1.494	0.1391
Disputes Settled	0.2472	0.1138	2.173	0.0328
Information Sharing	0.3008	0.128	2.35	0.0213
Multiple R-squared: 0.3822, Adjusted R-squared: 0.3587				

Discussion

As shown in the tables above, each model has a smaller number of input variables included. This is a result of dropping the variables that do not improve the R^2 value, or the "goodness of fit." There are also far fewer variables that have negative coefficients in these models, as compared to the multi-regression analysis. Since there were a number of negative coefficients for input variables (particularly ones that have high p-values) these results were revised and are included in a following section.

4.3.5. Genetic Algorithms Method

To further investigate if better correlations can be identified between the input and output variables, Genetic Algorithms were used as an innovative method to explore these correlations. To this end, Non-Dominated Sorting Genetic Algorithms II (NSGA2) was used. NSGA2 is robust multi-objective genetic algorithms tool, which was selected because of its important characteristics such as fast non-dominated sorting, crowding, elitism, strings real-coding, and constrained-domination principle (Deb et al. 2001; Deb 2005), in addition to its superior performance compared to other multi-objective genetic algorithms (D'Souza and Simpson 2002; Deb et al. 2001; Weile et al. 1996). This model aimed at identify the best fit between the input and output variables that would achieve three objectives, including (1) maximizing R^2; (2) maximizing the adjusted R^2; and (3) minimizing the mean square errors. The reason for selecting these three objectives, instead of just one objective, is that it resulted in a more diversified solution set. This diversified solution set enabled the model to avoid early convergence that results in low quality solutions. In terms of the model parameters, the population size was 1000, number of generations was 10,000, crossover probability was 0.9, crossover parameter in the SBX operator was 20, and mutation probability for real coded vectors was 0.047619. Tables 16 through 19 show the obtained results for output variables.

Table 16. GA Method: Environment

Environment	Estimate
(Intercept)	0.03
Relationships	0.89
Disputes Settled	-0.44
Incentives	-0.18
Alignment of Objectives	1.37
Information Sharing	-0.64
Multiple R-squared: 0.26, Adjusted R-squared: 0.20	

Table 17. GA Method: Safety

Safety	Estimate
(Intercept)	3.35
Major Involvement	-3.03
Relationships	2.09
Disputes Settled	0.39
Culture of Trust	-1.76
Alignment of Objectives	0.47
Multiple R-squared: 0.25, Adjusted R-squared: 0.19	

Table 18. GA Method: Duration

Duration	Estimate
(Intercept)	-5.00
GC Involvement	-2.67
Relationships	1.86
Information Sharing	1.43
Multiple R-squared: 0.13, Adjusted R-squared: 0.09	

Table 19. GA Method: Community

Community	Estimate
(Intercept)	-4.99
Relationships	-1.26
Partnering	1.88
Alignment of Objectives	2.48
Multiple R-squared: 0.08, Adjusted R-squared: 0.04	

Discussion

As shown in the tables above, there were several positive and negative input variables for four of the five outcomes. The GA Method failed to produce a feasible solution for the Budget outcome. Both Relationships developed and Alignment of Objectives resulted in positive Environmental results. Relationships, Disputes Settled, and Alignment of Objectives resulted in better Safety records. Relationships and Information Sharing resulted in projects completed on time. Partnering and Alignment of Objectives resulted in positive Community outcomes. It is noteworthy that the genetic algorithm method identified some equations with higher correlations when the sample set of projects were limited. However, when data about the complete set of projects was collected, the previous two regression models provided equations with higher correlations.

4.3.6. Step-wise Method (Only Significant Variables)

The step-wise method was revised to include only the input variables that were significant ($p < 0.05$) in the models. This method was used to improve upon the step-wise regression model.

The results of the analyses are shown in Tables 20 through 24 that follow. One table is included for each output variable, along with the input variables and coefficients that were included in the model.

Table 20. Step-Wise Method: Environment

Environment	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.8895	0.2180	4.079	0.000106
Expertise	0.4029	0.1308	3.081	0.002828
Alignment of Objectives	0.5360	0.0709	7.560	5.86e-11
Multiple R-squared: 0.5788,	Adjusted R-squared: 0.5683			

Table 21. Step-Wise Method: Safety

Safety	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.7899	0.3648	10.388	<2e-16
Major Involvement	-0.4837	0.2472	-1.957	0.05387
Relationships	0.3345	0.1055	3.172	0.00215
Multiple R-squared: 0.1147,	Adjusted R-squared: 0.09252			

Table 22. Step-Wise Method: Budget

Budget	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.1834	0.4515	7.051	5.37e-10
Culture of Trust	0.2452	0.1215	2.018	0.0469
Multiple R-squared: 0.04788,	Adjusted R-squared: 0.03612			

Table 23. Step-Wise Method: Duration

Duration	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.54708	0.30903	11.478	< 2e-16
Information Sharing	0.27943	0.08021	3.484	0.0008
Multiple R-squared: 0.1303,	Adjusted R-squared: 0.1196			

Table 24. Step-Wise Method: Community

Community	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.0802	0.3421	3.158	0.00224
Disputes Settled	0.2561	0.1145	2.237	0.02808
Information Sharing	0.3258	0.1279	2.547	0.01277
Multiple R-squared: 0.3647,	Adjusted R-squared: 0.3489			

As shown in the tables above, these results include the significant variables from the Step-Wise Regression Analysis. The following points summarize the findings for each model based on Step-Wise Method (Only Significant Variables) analysis:

- Environment – The Expertise and Alignment of Objectives were both positive input variables for a successful Environmental outcome in this model.
- Safety – The safety model includes two factors that result in a lower number of safety incidents. However, the coefficient for only one of the variables was positive – Relationships.
- Budget – Project that remained on or under budget included a positive Culture of Trust.
- Duration – A single variable remained in the Duration model – Information Sharing. This model shows the importance of communication to completing a project on time.

- Community – All of the input variables for the Community model were positive. This model shows that Disputes Settled and Information Sharing are important for successful community projects.

4.1. Quantitative Analysis Findings

We tested three different methods (i.e., multi-regression, generic algorithm, and step-wise method) to identify relationship between project delivery process and project outcomes. Taking into account r-square and p-value, we concluded that the Step-Wise Method with Significant Variables provided the most reliable results and include inputs that are valuable for each model. The following points summarize the quantitative analysis findings for each outcome supported by meaningful statistical data analysis:

- Step-Wise - Environment (Adjusted R-squared: 0.5683, from Table 20)
  The **Expertise** and **Alignment of Objectives** were the most significant (lowest Pr(>|t|) values) input variables for a successful Environmental outcomes.
- Step-Wise - Duration (Adjusted R-squared: 0.1196, Table 23)
  A single variable remained in the Duration model – **Information Sharing**. This model shows the importance of communication to completing a project on time.
- Step-Wise - Community (Adjusted R-squared: 0.3489, from Table 24)
  All of the input variables for the Community model were positive. This model shows that **General Contractors Involvement**, **Disputes Settled**, and **Information Sharing** are important for successful community projects.

5. Qualitative Analysis

This section of the report documents the qualitative analyses that were performed as part of this study. The following subsections detail (1) the development of interview questions for select DOT engineers; (2) a summary of the interviews; and (3) the data analysis methods employed to investigate the relationships between responses to the interview questions and performance indicators.

5.1. Interview Questions

The interview questions were developed based on previous literature review and results of the quantitative analysis. Questions focused on the following three categories that were identified as primary components in project relationships:

- **Organizational Integration**: The needs and cultures of different organizations with unique goals merge into a single cohesive and mutually supporting unit with collaborative alignment of processes and cultures.
- **Alignment of Interests**: The contractual alignment of key parties' interests with the project owners' interests. Under ideal conditions, transactions of services and products, including delivery and price terms, are contractually defined. In addition, communication, safety, and quality are contractually encouraged. Contractual incentives are an example of fostering alignment of interests.
- **Information Sharing**: The type and frequency of communication between all parties involved in the contract. In addition, information passed within the DOT for lessons learned or experience from prior projects.

For each of the categories identified above, interviewees were asked (1) "How does the importance of this category (e.g. alignment of interests) vary by project type or by context?" and (2) "What factors are important to this category (e.g. alignment of interests)?" Interviews and discussions generally followed these questions, with plenty of room for interviewees to expand on topics specific to their DOT work. Interviewees were also encouraged to use specific examples from their experience.

5.2. Summary of Interviews

Interviewees were selected based on their responses to the survey portion of this project and time availability. Seven contractors from three DOTs (Washington DOT, Florida DOT, and Indiana DOT) were interviewed for the qualitative section of this study. Table 25 summarizes the organizations and job description of each interviewee. Responses and qualitative data analysis from the interviews are grouped and summarized in the following sections.

Table 25. Interviewee Summary

Organization	Job Description
WSDOT	Project Engineer
	Construction Project Engineer
	Construction Project Engineer
	Construction Project Engineer
	Office Engineer
FDOT	Construction Project Manager
IDOT	Construction Project Manager

Note: Project Engineers at WSDOT are responsible for managing the projects used in the survey responses

As shown in Table 25, most of the interviewees for this portion of the project are project engineers or managers at the DOT.

5.3. Data Analysis

This section of the report documents the analysis for the conducted interviews, where several important factors were identified. These factors are as follows.

- Alignment of Cultures
- Coordination
- Engagement of Stakeholders
- Using the Expertise of Contractors
- Learning Organization

The complete interview transcripts were transcribed into QSR NVivo 9.2 Analysis Software to determine the number of references of each of the factors listed above in the interviews. Each factor was entered into the software using the Word Frequency function. The frequency results are shown in Table 26, as well as the relative percentage of references for that specific factor.

Table 26. Frequency Results from Interview Responses

Factor	Frequency	Percentage
Alignment of Cultures	24	41%
Coordination	1	2%
Engagement of Stakeholders	2	3%
Using the Expertise of Contractors	29	49%
Learning Organization	3	5%
Total	59 references	100%

As shown in the table above, two factors had much higher frequencies that the others. The Alignment of Cultures and Expertise of Contractors were both mentioned several more times during the interviews than the other factors.

The following sections describe each factor, beginning with the definition of the term as identified by previous literature and informed by the quantitative analysis described in Section III of this report. Next, supporting evidence from interviews, including direct quotes, is included to expand on why it is considered a success factor. Limitations, challenges, and potential improvements are described at the end of each section.

5.3.1. Alignment of Cultures

The culture between each organization is unique and every participant arrives at the project with a different perspective. For individual projects, team members must align their separate perspectives to complete the project.

The importance of aligning cultures was articulated by several of the interviewees. For example, one engineer highlighted the importance of bringing together perspectives at the start of a project to work towards a common goal as follows:

> “Even though we may have different perspectives, we all want to safely and profitably deliver a project and move on to the next. As long as we all understand and have the same goal, I guess you can't really get off the ground until you achieve that. Otherwise you're working towards different goals.” (WSDOT engineer)

As mentioned above, the “safety and profitability” of a project depends on how well different perspectives work together. And as the engineer above went onto saying, “just intending to do it, typically isn't enough.” In order for cultures to truly be aligned, there need to be face-to-face meetings at the start of a new project.

One of the limitations to the alignment of cultures at the beginning of a project is maintaining the work towards a common goal for the extent of the project. One engineer mentioned that small details can quickly derail cultures that are in alignment:

> “If you start out with a common goal and you start bickering over some relatively small matter, it can turn your whole contract sour and suddenly you're not integrated and everything becomes a battle. Helping each other understands how each other's organization works and how you need to receive submittals or RFIs or if we do bump into a conflict, how do we agree upfront how to deal with it without disintegrating our organizations.” (WSDOT engineer)

As described above, it is important to continually work on aligning cultures throughout a project, not just at the beginning.

5.3.2. Coordination

As project complexity increases, the number of moving parts and involved parties typically increases as well. In order to ensure everyone is continuously tied into the project, coordination is key. Coordination occurs, for example, with face-to-face meetings, email communication, and phone calls.

Coordination can be particularly important for new types of projects and work that the DOT or contractor may not have completed before. One engineer expressed the increased need of coordination with this example:

> “It's all about the complexity. If you're doing the same type of work that we've done ten times with maintenance staff, we'll have a good understanding of what you want to do…But if we're doing something that's brand new; we've never done before, like building the sign bridges over the freeway that has signs over each lane that we can use for speed limit signs on each lane, that's a big deal. It's a big change. It's a very sophisticated system. It has sensors in the roadway. It has sign structures. It has communication between the roadway, the region headquarters, and back to

> the sign. Tremendously complicated facility. And we haven't ever done it before. So it becomes a lot more complex to coordinate all of those efforts and make sure that in the end we're going to build something that functions and does what we expect it to." (WSDOT engineer)

As described above, a new project undertaken by the DOT required extra care to ensure it was completed properly.

One of the primary limitations of coordination is the amount of time it can take to accomplish it effectively. On large projects, time may be budgeted to allow for ample coordination, but on smaller projects, or repetitive ones, it may be more difficult to coordinate between the DOT and contractors due to time constraints. Time spent coordinating may take away from working on completion towards the actual end of the project.

5.3.3. Engagement of Stakeholders

At the start of each project, it is important to ensure that all participants are involved and engaged early. This includes meetings with the DOT and contractors involved with the project.

The importance of engaging stakeholders was underlined by one engineer's statement:

> "We really went way out to extend these people at the earliest possible stages of the design process in order to get all these things. Everybody's concerns met. And get buy-in on the project from this point forward." (FDOT manager)

As noted above, it is important for engagement to occur at the beginning of a project. In order to meet everyone's concerns, it is important to get stakeholders involved during the design process and well before construction begins.

Training programs are a way to work towards engaging project participants in a more meaningful manner. While these can be implemented, there are still limitations to how much influence they can have on certain projects or people as one engineer mentioned:

> "Everybody was trained in more of a partnering format, and it made a big difference. But within that, you still have issues or jobs or contractors or project offices that just don't quite mesh. And still doesn't work very well. But overall we raised the level of interaction with that program" (WSDOT manager)

Despite some of the best efforts to increase interaction between all parties, there are still limitations to these programs.

5.3.4. Using the Expertise of Contractors

DOTs use contractors to utilize skills that might not be readily accessible within the agency. In order to fully use the skills and expertise of the contractors, frequent communication and periodic reviews were noted as important factors to the project delivery process. Individual skills of contractors should also be expedited through contractual incentives and other devices.

For example, one engineer emphasized the importance of leveraging contractors' skills:

> "We do utilize some expertise from contractors in the terms of construction. Constructability reviews. Is this project constructable as designed? Those begin probably around the 90 % phase." (FDOT manager)

The constructability of a project is important, but projects also need to be completed on time by using the skills and capacity contractors have available. Another engineer mentioned tools that are included in contracts to provide the best product for the public:

> "We sometimes use different devices in our contract. If one of our goals is to minimize the impact to the public, then maybe we'll put an incentive in that says you get 'X' number of dollars for a day early that you're done. That can be very effective." (WSDOT engineer)

As described above, contractor's skills are important to constructability of a project. The capacity of contractors to complete a job on time, or early, is also an important factor that can be emphasized through the use of incentives.

Not every contract is written perfectly, and this is a limitation to fully utilizing the expertise of contractors to complete a project. An engineer mentioned that a contract needs to be complete and clearly articulated and agreed upon with the contractor:

> "You need to be very careful in reviewing documents when it's the first time you've done it, to say what you want and mean what say. Then talking to the contractor about what your goals are when you have a pre-construction meeting. Make sure that he understands. Have him talk back to you. What's his goal? How does he expect to meet our goals? It's all about communication." (WSDOT engineer)

As described above, the way contracts are written is important to a successful outcome.

5.3.5. Learning Organization

Learning organization is an important success factor for transportation projects. One example of implementing learning organizations mentioned by multiple engineers was to have manuals and guides for engineers. In order to ensure project information and lessons learned are passed down to others, DOTs need to have accessible educational tools. One engineer stated:

> "There's a formal lessons learned procedure, where we'll identify times where we've done or redone something. Those are obvious times to track that. Or if a contract went to a dispute review board--we just couldn't work it out. There are provisions in the contract where it goes before the dispute review board where you can hash out your differences." (WSDOT engineer)

As described above, these tools are particularly useful during projects where something may not have gone correctly. Another engineer reiterated this point through his comments:

> "Much of that process is controlled by design manual or construction manual that they give guidance on how we're supposed to follow a project. Beyond that we have input on other things…Things to follow the process in a consistent manner. We're striving to improve those

> processes as we do things. For each project we look at past projects to see how that worked, and how we can make it work better." (WSDOT engineer)

DOTs are constantly trying to improve the work that they do, and a manual or other tool can be useful to pass lessons down to new engineers. Lesson manuals and guidelines are helpful, but they do have limitations. Experience is vital for DOTs to manage projects. One engineer said that very few things can make up for direct experience:

> "Number one is just having people that have experience makes a huge difference. Because the more you see the more interconnections you see with issues. Even if early on in your career you get explanations of rationale behind an issue, sometimes it doesn't click because there isn't enough background to rally grab a hold of it." (WSDOT engineer)

This is not a reason to discount learning tools that should be available for DOT engineers. However, it should be kept in mind when passing down lessons to young engineers.

5.4. Qualitative Analysis Findings

Five practices were identified to improve the project delivery process for better outcomes. They are (1) Alignment of Cultures, (2) Coordination, (3) Engagement of Stakeholders, (4) Using the Expertise of Contractors, and (5) Learning Organization. The frequency test (Table 26) shows that aligning cultures and engaging stakeholders are the most important practices. The following points summarize the major findings from the qualitative analysis portion of this study:

- Alignment of cultures amongst organizations: The culture between each organization is unique and every participant arrives at the project with a different perspective. Multiple interviewees mentioned that team members must align their separate perspectives to complete the project. This may be constrained by the process through which DOTs select contractors, but there needs to be resources and efforts dedicated to improve working together at the start of new projects.
- Engaging and involving stakeholders in the project: It is important for engagement to not only occur at the beginning of a project, but throughout the project duration. In order to meet everyone's concerns, stakeholder engagement needs to be part of the organizational structure of the DOT. In particular, there needs to be guidelines for involving stakeholders early in the design process and well before construction begins.

Despite the low frequency in Table 21, fostering learning and collaboration through programs and in projects needs to be improved and enhanced for better projects outcomes. Lesson manuals and guidelines are helpful, but they do have limitations. Experience is vital for DOTs to manage projects, but these tools are particularly useful during projects where something may not have gone correctly. In order to ensure project information and lessons learned are passed down to others, DOTs need to have accessible educational tools. The research team believes that fostering learning and collaboration improves the environments and changes the organizational culture in which collaboration and integration would be nourished and enriched.

6. Conclusions and Recommendations

6.1. Findings from quantitative and qualitative analysis

The quantitative section of this report documents the quantitative analyses that were performed as part of this study. We tested three different methods (i.e., multi-regression, generic algorithm, and step-wise method) to identify relationships between project delivery processes and project outcomes. Taking into account the Adjusted R-squared and P-values we concluded that the Step-Wise Method with Significant Variables provided reliable results on environments and community results. The **expertise** and **alignment of objectives among project delivery process factors** were the most significant input variables for a successful environmental outcome in this model. The analysis also shows that **contractor's involvement** and **information sharing** are important for successful community outcomes.

The qualitative section of the report documents the qualitative analyses that were performed as part of this study. Five practices were identified to improve the project delivery process for better outcomes. They are (1) Alignment of Cultures, (2) Coordination, (3) Engagement of Stakeholders, (4) Using the Expertise of Contractors, and (5) Learning Organization. The keyword analysis shows that aligning cultures and engaging stakeholders are the most important practices.

6.2. Best Practices derived from Analysis (Recommendations to the Industry)

Researchers developed best practices with associated factors and outcomes using the above-mentioned qualitative as well as quantitative analysis. They are the list of recommendations to the owners of public transportation projects. The associated factors used in the quantitative analysis with relevant project outcomes were identified on each of two important practices identified in the qualitative analysis.

Alignment of Cultures

The alignment of cultures between participating organizations was positively identified in the quantitative analysis as significant in achieving environmental goals. Multiple interviewees also mentioned that team members must align their separate perspectives to complete the project.

Quantitative Factors:

- <u>Alignment of Objectives</u>
  How well commercial interests of the project team member organizations aligned to pursuit of project objectives compared to other similar projects
- <u>Culture of Trust</u>
  How well project leaders created a culture with emphasis on openness, trust, mutual respect and collaboration

Successful Quantitative Outcome:

- <u>Environment</u>
  The Expertise and **Alignment of Objectives** were the most significant (lowest Pr(>|t|) values) input variables for a successful Environmental outcome in this model.

Engaging Stakeholders

Engaging stakeholders, particularly the General Contractor, early in the project process results in effectively managed projects. It is important for engagement to not only occur at the beginning of a project, but throughout the project duration. Early general contractor engagement resulted in projects that were at or under budget and ones that had fewer safety incidents. Several interviewees also mentioned the importance of holding meetings with contractors early on in the project process.

Quantitative Factors:

- General Contractor Involvement
  When the GC was first involved in the project
- Major Contractors/Specialty Suppliers Involvement
  When the major contractors and specialty suppliers were first involved in the project
- Information Sharing
  Whether project information was shared freely among the project team member organizations during construction

Successful Quantitative Outcomes:

- Duration
  A single variable remained in the Duration model – **Information Sharing**. This model shows the importance of communication to completing a project on time.
- Community
  All of the input variables for the Community model were positive. This model shows that **General Contractor Involvement**, Disputes Settled, and **Information Sharing** are important for successful community projects.

Through the research findings, the research team learned that some factors and associated best practices have statistical relations with project outcomes (i.e., environments and community results). The research results provide an insight on practices and areas to be improved and enriched toward more environmental-friendly as well as community-friendly projects.

6.3. Recommendations for Future Research

The following points summarize the recommendations for future research:

- Future research questions could incorporate the types of technology employed in communication within DOTs, amongst contractors, and to the public.
- Further refinement and definitions of more abstract terms (i.e. Alignment of Objectives, Information Sharing) could be expanded in future research.
- Investigation of the mechanics on how each project delivery factor leads to a project outcome through descriptive case studies is needed.

References

Associated General Contractors of America (AGC) (2004). *Project Delivery Systems for Construction*. AGC, Arlington, VA

Baiden, B.K., Price, A.D.F. (2011). The effect of integration on project delivery team effectiveness. International Journal of Project Management, 29(2), 129-136

Ballard, G., Kim, Y., Azari, R., Cho, S. (2011), Starting from Scratch: A New Project Delivery Paradigm, Research Summary 271, Construction Industry Institute (CII), Austin, TX.

Construction Industry Institute (CII). (2001). Project Delivery and Contract Strategy. Publication RR165-12, Austin, Texas

Deb, K. (2005). "Real-coded Genetic Algorithms," Kanpur Genetic Algorithm Laboratory, Indian Institute of Technology, Kanpur, India. <http://www.iitk.ac.in/kangal/resources.shtml>, (November 12, 2005).

Deb, K., Agrawal, S., Pratap, A., and Meyarivan, T. (2001). "A Fast Elitist Non-Dominated Sorting Genetic Algorithm for Multi-objective Optimization." KANGAL Report 200001, Genetic Algorithm Laboratory, Indian Institute of Technology, Kanpur, India.

D'Souza, B., and Simpson, T. (2002) "A Genetic Algorithm Based Method for Product Family Design Optimization" Proceedings of DETC 2002: 2002 ASME Design Engineering Technical Conferences, Montreal, Canada.

Kahn, B.K. (1996). Interdepartmental Integration: A Definition with Implications for Product Development Performance. Journal of Product Innovation Management, 13(2), 137-151

Lawrence, P.R., Lorsch J.W. (1967). Differentiation and integration in complex organizations, *Administrative science quarterly*, 12 (1)

Makridakis, Spyros, Wheelwright, Steven C., and Hyndman, Rob J. (2008), *Forecasting: Methods and Applications*, (New Jersey: Wiley, 1998).

Mitropoulos, P., and Taum, C. B. (2000). "Management-driven integration." *Journal of Management in Engineering*, 16(1), 48–58

Oyetunji, A. A., & Anderson, S. D. (2006). Relative Effectiveness of Project Delivery and Contract Strategies. *Journal of Construction Engineering and Management, 132*(1), 3-13

Weile, D. S., Michielssen, E. and Goldberg, D. E. (1996), “Genetic Algorithm Design of Pareto-Optimal Broadband Microwave Absorbers,” IEEE Transactions on Electromagnetic Compatibility, 38(3), 525–528.

Appendices

A. Appendix A – Survey Questionnaire

University of Washington, TransNow Research Project Survey

Faculty and students from the Construction Management and Civil Engineering Departments at the University of Washington are conducting a research effort to improve the project delivery process for transportation infrastructure projects. The following brief survey includes qualitative questions on the safety, environmental, and social performance of this project as compared to other similar projects. We expect the survey for each project will take approximately 15 minutes to complete. Thank you for your participation in this research effort.

Please begin the survey below.

Project Description

Please provide the project name. __________

Please provide a brief description of the project scope (what is actually being designed/constructed). __________

What was your personal role on this project? __________

Lead construction firm: __________

Project location: __________

Which of the following best describes industry group for this project? (You may check more than one response.)

- ○ Pavement
- ○ Bridge
- ○ Widening
- ○ Rail
- ○ Ferry
- ○ Other: __________

Budget and Schedule

What was the Total Construction Budget for this project, not including approved change orders? __________

What was the Total Construction Budget for this project, including approved change orders? __________

What was the Actual Construction Cost for this project? __________

What was the scheduled construction duration for this project, not including approved change orders? __________

What was the scheduled construction duration for this project, including approved change orders? __________

What was the actual construction duration for this project? __________

Was this project typical or representative of most of the projects that your company performs?

- Typical
- Not Typical. Please explain: __________

Construction Management

Please choose the project delivery system from those listed below that most closely characterizes the delivery system used for this project. If more than one delivery system was used, select the primary system.

- Traditional Design-Bid-Build – Serial sequence of design and construction phases; Owner contracts separately with designer and constructor.
- Design-Build – Owner contracts with Design-Build Contractor.
- CM at Risk – Owner contracts separately with designer and CM at Risk. CM holds the contracts.
- Multiple Design Build – Owner contracts with two or more Design-Build contractors, one or more each for process and facilities.

Was this a fast track project?

- Yes
- No

Project Complexity

For each criteria listed below, please choose a rating below that best describes this project as it compares to other similar projects. Use the definitions below as general guidelines.

- Low - Characterized by the use of well established, proven technology, a relatively small number of process steps, a relatively small project size, , well established, proven construction methods.
- Average – Characterized by the use of established technology, a moderate number of process steps, a moderate project size, established, proven construction methods.
- High- Characterized by the use of new, "unproven" technology, an unusually large number of process steps, large project size, new construction methods.

Criteria	1 – Low	2	3 – Med.	4	5 – High
Complexity (e.g. heavy industrial, light industrial, building, infrastructure)	O	O	O	O	O
Uncertainty (e.g. schedule changes, uncertainty, environmental unknowns)	O	O	O	O	O
Speed driven when the project delivery process was being designed.	O	O	O	O	O

Project Performance

Safety Performance

Number of safety accidents: __________

Number of man-hours in construction: __________

Environmental Performance

The number of Environmental Non-Compliance Events: __________

If your agency has a specific environmental rating system for transportation projects, please indicate the score this project received. If your agency does not have an environmental rating system, please write N/A. __________

Please describe the environmental goals related to this project: __________

For each criteria listed in the table below, please choose a rating below that best describes this project as it compares to other similar projects.

Criteria	1 – Low	2	3 – Med.	4	5 – High
Level of environmental regulation compliance	O	O	O	O	O
Relative scope for specific environmental or sustainable goals.	O	O	O	O	O
How successfully did the project achieve the environmental goals?	O	O	O	O	O

Impact on Community during Construction

For the criterion listed in the table below, please choose a rating below that best describes this project as it compares to other similar projects.

Criterion	1 – Low	2	3 – Med.	4	5 – High
Level of performance in mitigating the impacts of construction activities to community, such as traffic.	O	O	O	O	O

Integrated Organization

Please select the project phase when the following members were first involved with this project.

Members	Feasibility	Conceptual Design	Detail Design	Construction Document	Construction Phase
General Contractor (GC)	O	O	O	O	O
Major/Specialty contractors/suppliers	O	O	O	O	O

For each criteria listed below, please choose a rating below that best describes this project as it compares to other similar projects.

Criteria	1 – Low	2	3 – Med.	4	5 – High
Level of general contractors' participation in decision making in design phase.	O	O	O	O	O
Level of the subcontractors/suppliers'	O	O	O	O	O

participation in decision making in design phase.					
How much trades' or suppliers' expertise leveraged in design and planning.	O	O	O	O	O

For each criteria listed below, please choose a rating below that best describes this project as it compares to other similar projects regarding the relationship between participating organizations.

Criteria	1 – Low (0%)	2	3 – Med. (50%)	4	5 – High (100%)
How well relationships between participating organizations developed during the project.	O	O	O	O	O
Percentage of disputes settled amicably, without recourse to litigation or the threat of litigation.	O	O	O	O	O

Did you have a partnering agreement on this project with the primary contractor?

- ○ No
- ○ Yes
- ○ Don't Know

How long have you worked in a partnering relationship with this contractor?

- ○ Less than one year
- ○ 1 to 2 years
- ○ 2 to 5 years
- ○ More than 5 years
- ○ Did not have partnering relationship with contractor

For each criteria listed below, please choose a rating below that best describes this project as it compares to other similar projects.

Criteria	1 – Low	2	3 – Med.	4	5 – High
How well were cultures among participating organizations (e.g. design engineers, general contractor, suppliers, sub-contractors) were aligned, or compatible, during construction?	O	O	O	O	O
How well did project leaders create a culture with emphasis on openness, trust, mutual respect and collaboration?	O	O	O	O	O

Alignment of Interests

In the contractual agreement between the DOT and the general contractor, were there incentives related to cost or time?

- No
- Yes

Were there incentives not related to cost or time?

- No
- Yes. Please describe the incentives: ___________

Were the incentive clauses fully agreed upon by contractor?

- Contractor did not participate in formulating the incentives
- Contractor participated actively

Were opportunities for improving project performance not taken because of the problem 'who pays/who gains'?

- Yes
- No
- Don't know

For each criteria listed below, please choose a rating below that best describes this project as it compares to other similar projects.

Criteria	1 – Low	2	3 – Med.	4	5 – High
How transparent were estimated and actual costs among members of the project team compared to other similar projects?	O	O	O	O	O
How well were the commercial interests of the project team member organizations aligned to pursuit of project objectives compared to other similar projects	O	O	O	O	O
Was the project information shared freely among the project team member organizations during construction?	O	O	O	O	O
Was information between design-procurement-construction linked electronically on the project?	O	O	O	O	O