State of Wyoming
Department of Transportation

Developing Tools to Mitigate the Impact on Design Errors and Omissions

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Department of Civil & Architectural Engineering and Construction Management
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16. Abstract
The main objectives of this research are to quantify the impact of design errors and omissions (E&Os) in Wyoming Department of Transportation (WYDOT) highway construction projects, identify their causes, propose mitigation strategies, develop tools to minimize the adverse effects of E&Os, and create plans and procedures for effective management. This will be achieved through analyzing change order data and insights from DOT professionals by utilizing questionnaire surveys and semi-structured interviews.

This report recommends an updated design review checklist for WYDOT to assist new engineers. It identifies communication issues as a major cause of design E&Os and highlights that plan and estimate errors increase project costs and change orders. To improve coordination, the report advocates for introducing real-time collaboration platforms. It also stresses the differing perspectives of design and construction staff on causes, impacts, and the use and effectiveness of design quality control tools. Finally, this research provides an updated policy and procedure document to handle design E&O.

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List of Acronyms

AASHTOW	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
ADOT	Arizona Department of Transportation
AGC	Associated General Contractors
AKDOT	Alaska Department of Transportation
ALDOT	Alabama Department of Transportation
AEC	Architecture, Engineering, and Construction
BAM	Bridge Analysis Manual
BIM	Building Information Modeling
BrM	Bridge Management
CADD	Computer-Aided Design and Drafting
CEI	Construction Engineering and Inspection
CMS	Construction Management System
D&C	Design and Computation (MicroStation module)
DB	Design-Build
DBB	Design-Bid-Build
DOT	Department of Transportation
DQC	Design Quality Control
E&O	Errors and Omissions
EDMS	Electronic Document Management System
EOR	Engineer of Record
ERC	Electronic Review Comments
FDOT	Florida Department of Transportation
FUSP	Frequently Used Special Provision
GDOT	Georgia Department of Transportation
IA	Independent Assurance
INDOT	Indiana Department of Transportation
ITD	Idaho Transportation Department
KYTC	Kentucky Transportation Cabinet
LADOTD	Louisiana Department of Transportation and Development
MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
NC Connect	North Carolina's Digital Platform
NCDOT	North Carolina Department of Transportation
NDDOT	North Dakota Department of Transportation
NOI	Notice of Intent
ODOT	Ohio Department of Transportation
PEPS	Professional Engineering Procurement Services
PIH	Plan-In-Hand
PM	Project Manager
PS&E	Plans, Specifications, and Estimates

QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QPL	Qualified Products List
RE	Resident Engineer
ROW	Right-of-Way
SCDOT	South Carolina Department of Transportation
SMS	Safety Management System
SPOD	State Pavement Optimization Database
SS	Special Specification
TMP	Traffic Management Plans
TRB	Transportation Research Board
TxDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation
VBA	Visual Basic for Applications
VDOT	Virginia Department of Transportation
VTrans	Vermont Agency of Transportation
WYDOT	Wyoming Department of Transportation
AIA	American Institute of Architects
ACL	Assistant Chief Legal (WSDOT process context)
CECW	Consulting Engineers Council of Washington
CPRC	Cost and Project Review Committee (GDOT process)
DOE	Department of Energy
FRA	Federal Railroad Administration
MBTA	Massachusetts Bay Transportation Authority
MCDOT	Maricopa County Department of Transportation
PMIS	Project Management Information System
SNAME	Society of Naval Architects and Marine Engineers
TAC	Technical Advisory Committee
TDOT	Tennessee Department of Transportation
WSDOT	Washington State Department of Transportation
AGC-DOT	Associated General Contractors - Department of Transportation
Bluebeam	A cloud-based platform for document collaboration
DTM	Digital Terrain Model
FHWA	Federal Highway Administration
Hicams	Highway Construction and Materials System
iCX	Integrated Construction Management System
LD-436	VDOT Design QC Checklist Form
PDDM	Project Development and Design Manual
PSEE	Project Suite Enterprise Edition
QAOs	Quality Assurance Objectives
SAP	Systems, Applications & Products
TEQ	Total Estimated Quantities

CHAPTER 1: INTRODUCTION

Throughout history, there have been many definitions of errors and omissions (E&Os), even though some psychologists contend that conceptions of error may not really exist because they are a result of a person's cognitive abilities (Reason & Hobbs, 2003). An error is a result that, in essence, entails a deviation of some type, whether it be from the intended course of action, route of planned actions toward a desired objective, or a deviation from the appropriate behavior at work (Reason & Hobbs, 2003). An implicit expectation occurs when something fails, but an error results from an unanticipated or chance action (Love & Lopez, 2012). The phrases modifications, omissions, faults, quality deviations, nonconformances, and failures have frequently been used interchangeably in studies that have looked at design errors in construction, such as (Hammarlund & Josephson, 1999); (Josephson, Larsson, & Li, 2002).

Investment in transportation infrastructure (such as roads, bridges, ports, and trains) is necessary to keep up with the demands of an expanding population and maintain an edge in an increasingly globalized economy (Love et al., 2016). The projects' size requires large economic investments that, if unsuccessful, could negatively impact regional economies (Herrera et al., 2020). Transportation agencies face significant challenges in delivering high-quality, constructible, and maintainable projects due to rising technological complexity, regulatory constraints, and resource limitations. Constructability reviews have effectively minimized cost overruns, delays, and design flaws by integrating construction knowledge early in project planning and design phases (Akhnoukh et al., 2020). Additionally, effective stakeholder engagement strengthens decision-making by incorporating diverse perspectives and addressing social and environmental impacts (Erkul et al., 2016).

Construction and design projects are suffering from a continuous increase of different challenges such as schedule delays, cost overruns, and poor quality (Herrera et al., 2020). One of the common causes of this problem is the rework or design changes that result from design errors (Han et al., 2013; Larsen et al., 2016). According to (Shane et al., 2009) about half of the transportation projects in the US are suffering from initial cost overruns. Cost overruns of 40 percent to 400 percent were recorded by the US General Accounting Office for 20 civil infrastructure projects in 17 states with a total projected cost of $205 million to $2.6 billion (Han et al., 2013). As a result, several research efforts have been conducted to analyze the reasons for cost overruns in the construction industry (Love & Lopez, 2012) and highway projects (Calahorra-Jimenez et al., 2020; Flyvbjerg et al., 2002 and Shane et al., 2009).

This study aimed to quantify the impact of design E&Os on Wyoming Department of Transportation (WYDOT) projects using change order data from an eight-year period, spanning from mid-2016 to mid-2023. It included surveys and interviews with engineers involved in construction projects, encompassing the design and construction phases. The study investigated the issues faced, the reasons behind these issues, and recommendations for improvement. Additionally, it cross-validated the data from change orders and examined trends across other state Departments of Transportation (DOTs), specifically regarding mitigation and collaboration strategies employed for quality control in design. Finally, the study presented a comprehensive design checklist that was developed to improve quality control in WYDOT projects, and feedback from the pilot study was collected from WYDOT engineers regarding its effectiveness and potential improvements.

1.1 Problem Statement

Design E&Os pose a significant challenge in the transportation industry, particularly in highway construction projects. These issues consistently lead to schedule delays, cost overruns, and rework, significantly impacting overall project performance and straining relationships between stakeholders. Many state DOTs, including the WYDOT, have been facing ongoing struggles to complete projects on time and within budget due to factors such as E&Os, scope changes, unforeseen site conditions, and resource-related delays.

Recent studies have underscored the widespread occurrence of design E&Os in transportation projects. A survey of WYDOT construction and district engineers pinpointed design E&O as one of the top five reasons for schedule delays. This trend reflects the broader industry landscape, where design changes resulting from E&Os are frequently cited as major contributors to rework and project setbacks.

While many state DOTs have established policies to address design E&Os, these often prioritize legal aspects over comprehensive strategies to prevent and mitigate their occurrence. A more proactive approach is needed to tackle the root causes of design E&Os and provide practical tools for their early detection and resolution.

1.2 Research Objectives

The primary objectives of this study are listed as follows:

1. To evaluate the impact of design E&Os and rework on project costs in WYDOT projects.
2. To determine the causes behind design E&Os on WYDOT projects and provide recommendations to minimize their occurrence.
3. To develop implementable Design Quality Control (DQC) tool(s) to minimize the negative impacts of design E&Os and rework.
4. To develop or improve policy and procedure documents to handle design E&Os effectively within WYDOT.

By addressing these objectives, this research aims to improve project performance, reduce rework, and enhance the overall efficiency of highway construction in Wyoming. The findings and recommendations in this report have potential applications not only for WYDOT but also for other state DOTs facing similar challenges in their transportation projects.

The following nine research tasks were carried out in this project to accomplish the objectives.

Task 1 : Conduct a comprehensive literature review on the causes and impacts of design E&O tools, best practices used by state DOTs to address design E&Os, and the latest innovations in the building and highway construction industry to address design E&Os. The team will also review WYDOT design review processes.
Task 2 : Select a sample representative of projects for change order analysis.
Task 3 : Determine the causes of design E&Os on the selected sample of WYDOT projects.
Task 4 : Evaluate the impact of design E&Os on the project performance (e.g., cost).
Task 5 : Interview construction and design personnel to gather their perspectives and validate findings from change orders, and identify trigger points that lead to design E&Os.
Task 6 : Develop fact sheets to summarize the impacts and causes of design E&Os on WYDOT projects.
Task 7 : Develop tools and guidelines to mitigate the impact of design E&Os on WYDOT projects.
Task 8 : Pilot the developed tool and gather feedback and recommendations on improving it.
Task 9 : Develop policy and procedure documents to facilitate the implementation of the proposed tools and guidelines.
Task 10 : Document the project findings and results and submit the final report.

1.3 Document Structure

This technical report is organized into the following sections:

Chapter 2 of this report reviews relevant literature and the practices for addressing design E&Os in the transportation industry, to provide the background on the existing work on causes identified, their impacts, and what other agencies have been doing to minimize the occurrence of design E&Os.

Chapter 3 outlines the research approach, including the criteria for project selection and the methods for data collection.

Chapter 4 presents the results and analysis of the change order data.

Chapter 5 contains the findings from surveys and interviews conducted with construction engineers.

Chapter 6 presents the findings from surveys and interviews with design engineers.

Chapter 7 provides an overview of the current design review procedures employed by various state DOTs.

Chapter 8 involves the development of an updated design checklist and its pilot testing.

Finally, Chapter 9 offers conclusions and recommendations based on the findings.

CHAPTER 2: LITERATURE REVIEW

2.1 Causes of Cost Overruns in Construction and Highway Projects

Overruns in both budget and time are common in transportation infrastructure projects (Love et al., 2014). E&Os in transportation infrastructure projects can result in significant budget and schedule overruns, impacting economies and reducing taxpayer trust in the government. These issues often arise when initial budgets change during the design phase, and errors remain undetected until construction starts, leading to costly rework (Love et al., 2014). Love et al. (2014) found common causes of rework to be tight timelines, insufficient audits and reviews, and a lack of detailed drawings and estimates as shown in Figure 1.

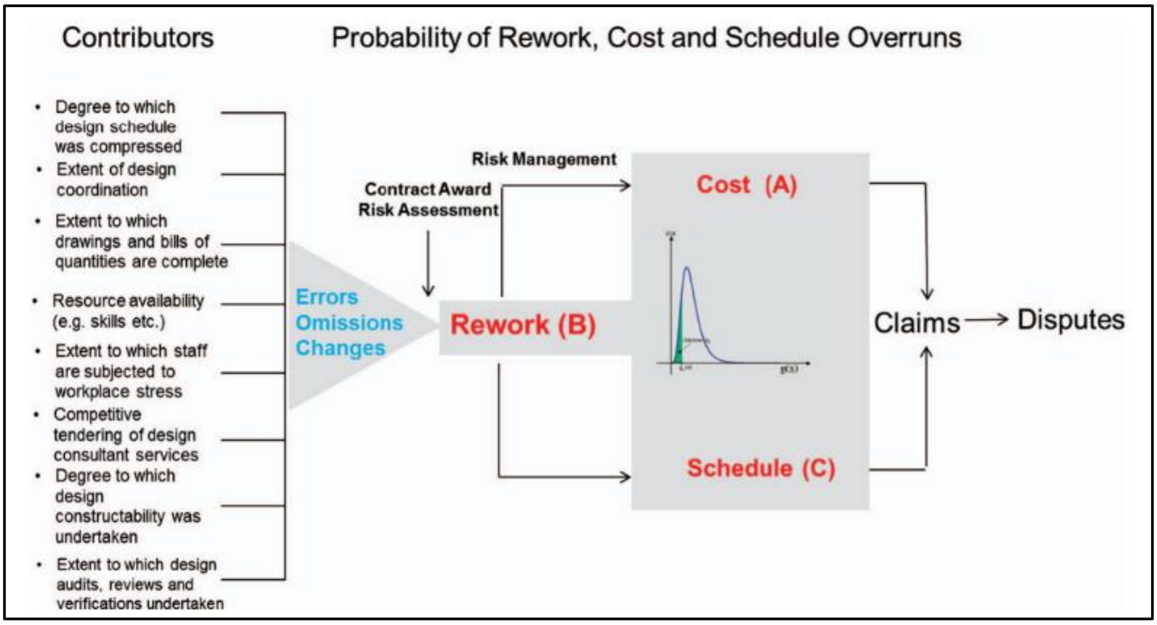

Figure 1: Causes of projects overruns due to rework and consequences (Love et al., 2014)

Furthermore, to assess the reasons for cost overruns in road projects, Calahorra-Jimenez et al. (2020) have conducted a study where they linked design, project modifications, and procurement as the root causes of budget overruns. Through expert interviews, it was revealed that the top three contributors to these overruns are: "E&Os in the design," "inadequate designer capabilities," and "lack of a solid understanding of fundamental engineering principles." Among these, design E&Os emerged as the primary issue, often stemming from the division of responsibilities that leads to conflicting goals between design and construction teams (Calahorra-Jimenez et al., 2020). This misalignment can ultimately hinder effective project outcomes.

Moreover, Shane et al. (2009) have conducted a study to identify the reasons for cost overruns in highway projects. The authors have identified 18 main categories that lead to cost overruns. Internal factors like poor project management and design flaws, inconsistent contingency provisions, execution errors, and unclear contract terms, early design challenges, especially related to location or purpose, can create coordination problems and component failures. As the project advances, constructability issues may emerge, and inadequate resolution of these problems is likely to drive up costs. Underestimating project costs can occur during the planning and design phase due to external factors like local government requirements, inflation fluctuations, and scope changes. In the construction phase, costs may rise because of factors beyond the control of the owner or agency, including changes in regulations, economic shifts, and unforeseen incidents. (Shane et al., 2009)

In addition, Creedy et al. (2010) In their investigation of 231 highway projects from Queensland, they found "Design/project scope change" was the highest factor that occurred among the projects. Table 1 lists the factors influencing project cost, ranked from highest to lowest impact.

Table 1: Ranking reasons of cost overruns in Queensland highway projects (Creedy et al., 2010)

Rank	Principal Cost Overrun Factors
1	Design and scope change (HL/1)
2	Insufficient investigations and latent conditions (HL/2)
3	Deficient documentation (specification and design) (HL/3)
4	Owner project management costs (HL/4)
5	Services relocation (HL/5)
6	Constructability (HL/6)
7	Price escalation (HL/7)
8	Right-of-way costs (HL/8)
9	Contractor risks (HL/9)
10	Environment (HL/10)

Flyvbjerg et al. (2002), in a study of 258 transportation projects found that cost overruns are primarily caused by underestimating project costs. It is revealed that 90 percent of highway projects face this issue, with an 86 percent chance of going over budget, the cost overruns in the types of projects are as shown in Table 2. The study argued that inaccurate cost estimation is a global problem, with North America slightly outperforming Europe, and noted little improvement in estimation methods over the last seventy years (Flyvbjerg et al., 2002).

Table 2: Inaccuracy of transportation project cost estimates by project type (Flyvbjerg et al., 2002)

Type of Project	Number of Cases (N)	Average Cost Escalation (percent)	Standard Deviation	Level of Significance (p)
Rail	58	44.7	38.4	<0.001
Fixed links	33	33.8	62.4	0.004

Roads	167	20.4	29.9	<0.001
All projects	258	27.6	38.7	<0.001

Herrera et al. (2020) found 38 factors of cost overruns that were sorted into 14 categories. Table 3 displays the factors along with their frequency and ranking. The Influence Index (II) identified five critical and prevalent causes of cost overruns: (1) "failures in design," (2) "price variation of materials," (3) “inadequate project planning," (4) "project scope changes," and (5) "design changes", where, "failures in design" was regarded as having the greatest impact on cost overruns. Errors, inconsistencies, and missing details in the design can cause delays in construction.

Table 3: Top Cost overrun factors with respect to the influence index (Herrera et al., 2020)

ID	Factors	Relative Frequency	RII	II	Influence Rank
F12	Failures in design	12.78%	0.5947	7.60%	1
F21	Price variation of materials	6.67%	0.5053	3.37%	2
F32	Inadequate project planning	5.56%	0.3421	1.90%	3
F35	Project scope changes	5.56%	0.2632	1.46%	4
F11	Design changes	4.44%	0.2579	1.15%	5
F3	Unrealistic contract duration	4.44%	0.1711	0.76%	6
F33	Inadequate bidding method	3.33%	0.1947	0.65%	7
F2	Legal issues	3.33%	0.1842	0.61%	8
F28	Late decision making by owner	2.78%	0.1688	0.52%	9
F15	Political situation	3.33%	0.15	0.50%	10
F19	Financial difficulties of owner	2.78%	0.1526	0.42%	11
F6	Inadequate contractor's experience	2.78%	0.1474	0.41%	12
F7	Poor site management and supervision	3.33%	0.1158	0.39%	13
F14	Economy issues	2.78%	0.1316	0.37%	14
F37	Poor site investigation	2.22%	0.1632	0.36%	15
F9	Poor communication among stakeholders	2.78%	0.1237	0.34%	16
F20	Payment delays to contractor	2.22%	0.1526	0.34%	17
F31	Staffing problems	2.78%	0.1211	0.34%	18
F36	Ground conditions	2.22%	0.1474	0.34%	19
F29	Scope changes due to the owner	2.22%	0.1079	0.24%	20
F5	Inadequate construction methods	1.67%	0.0895	0.15%	21
F25	Poor contract management	1.67%	0.0895	0.15%	22
F27	Land acquisition	1.67%	0.0868	0.14%	23
F18	Financial difficulties of contractor	2.22%	0.0605	0.13%	24
F16	Unethical activities	1.67%	0.0789	0.13%	25
F24	Shortage of materials	1.67%	0.0789	0.13%	25
F34	Project characteristics	1.67%	0.0658	0.11%	27
F26	Lack of owner's management skills	1.67%	0.0447	0.07%	28
F8	Claims and disputes with stakeholders	1.11%	0.05	0.06%	29
F4	Delays of activities	1.11%	0.0421	0.05%	30
F30	Low productivity of labor	1.11%	0.0368	0.04%	31
F23	Change orders due to the owner	0.56%	0.0526	0.03%	32
F13	Slow permits by local authorities	0.56%	0.0526	0.03%	32
F10	Poor coordination among stakeholders	0.56%	0.0474	0.03%	34
F22	Shortage of equipment	0.56%	0.0421	0.02%	35
F1	Late decision making by consultants	0.56%	0.0316	0.02%	36
F38	Relocation of underground utilities	0.56%	0.0316	0.02%	36
F17	Weather	1.11%	0.0158	0.02%	36

Design-related issues, including errors, omissions, and changes, are key contributors to cost and schedule overruns in highway projects. The later these errors are identified, the greater the rework, delays, and costs. The following section provides more details on the causes of these design E&Os.

2.2 Causes of Design E&Os in Construction and Highway Projects

Transportation agencies are experiencing growing construction challenges. Tight project schedules can lead to E&Os in contract documents, resulting in poor bids, construction issues, and maintenance problems later on (Gambatese & McManus, 1997)Several interconnected factors contribute to these errors in highway projects. Understanding these causes can help prevent similar issues in the future. This section discusses some common reasons for design E&Os.

According to the Arizona DOT (ADOT) (2019), Error is defined as "An incorrect, conflicting, insufficient, or ambiguous plan and/or specification; use of an inappropriate design criteria or standard" and an Omission is defined as "A failure to include an element, feature, system, or equipment necessary to the complete function of a project; a failure to perform." (ADOT, 2019). E&Os are typically identified during the construction phase, but they can also emerge during the design and advertising phases, indicating that deficiencies may not be apparent until later stages (ADOT, 2019). As per the guideline document by ADOT some of the major causes behind design E&Os identified are:

1. ***Design Negligence or Gross Negligence:*** Errors and omissions often arise from failure to adhere to the expected standard of care in design practices.
2. ***Inadequate Documentation or Communication:*** Poorly communicated or documented information can lead to misunderstandings about project requirements, resulting in omissions of critical components which were implied throughout the procedures section.
3. ***Inaccurate Calculations:*** Some specific examples mentioned in the document illustrate mistakes in quantities, such as incorrect pipe or embankment calculations, which can lead to increased costs and additional work.
4. ***External Factors:*** Challenges such as changes in site conditions, including material source exhaustion, complicating the project and contribute to discrepancies that lead to errors.
5. ***Betterments Requested During Construction:*** Changes requested by project owners during construction can complicate design integrity and lead to conflicts regarding project scope, which was mentioned as the context of premium costs related to betterments in the E&Os document.
6. ***Lack of Resources:*** The document references issues related to understaffing or a lack of adequately skilled personnel, suggesting that these factors can lead to carelessness or a lack of attention to detail. This concept is indirectly explored in discussions about the standard of care and the responsibilities of consultants.

According to AASHTO (2000) many states conduct reviews of plans and specifications near the end of the design phase. Late plan reviews with construction personnel are ineffective because significant costs have already been incurred (Selcuk et al., 2024). Changes at this stage can be costly, disrupt the project schedule, conflict with permits, and damage credibility among those involved (AASHTO 2000) .

Moreover, as stated by (Hamilton et al., 2020) Stakeholders in the Department of Transportation and Development (DOTD) projects have identified several reasons for plan errors, including a lack of knowledge regarding DOTD standards, inadequate selection of qualified consultants, and inconsistent communication in the review process. Additionally, there is a need for stricter quality control and assurance procedures, along with a general lack of experience among plan reviewers. High turnover among design staff also contributes to these issues. While most participants feel there is ample time for quality control throughout most of the project, the final stages often lead to tight schedules that hinder effective QC/QA activities.

Generally, the common types of errors that may occur in the plans as stated by (Hamilton et al., 2020) are: “Quantities not matching throughout the plans”, “Cross sections not being checked for constructability”, “Maintenance of traffic issues”, and “Lack of clarity in the plans”.

A study on road projects in Tanzania identified several reasons for inadequate design, including the inexperience of client and consultant staff, lack of sequence in the design process, insufficient time and guidelines for reviews, reliance on outdated practices, and political pressures (Rwakarehe et al., 2014). Since design and construction companies often do not track errors, mistakes typically go unnoticed initially, leading to costly rework that contributes to budget and schedule overruns (Han et al., 2013).

Chang et al. (2011) proposed a framework to analyze the reasons for and impacts of design changes in construction projects in Taiwan, examining seven projects across various types, such as highway widening. They observed 339 change items, categorizing them into three groups: 1) Under owner’s control (e.g., new requests, incomplete information), 2) Under designer’s control (e.g., errors, poor coordination), and 3) Beyond control (e.g., evolving needs, policy changes). Notably, highway projects had the most changes (264 items) and costs. Designers found that issues like collaboration difficulties, inexperience, and errors hindered their work, highlighting that redesigns take longer and inaccuracies can be costly (Chang et al., 2011).

Fuadie et al. (2017) identified 30 causal factors for design errors based on studies by (Love et al., 2012; Love & Edwards, 2004; Peansupap & Walker, 2009) as shown in Table 4.

Table 4: Design Error Causal Variables ((Fuadie et al., 2017; P. E. D. Love et al., 2004, 2**)**

Classification	Variables
People	Skill level Experience Accountability Well-being Cognitive dissonance Personality type Lack of training/education Poor resourcing Poor management
Organization	Poor use technology Poor strategy & leadership Lack of professionalism Poor project governance
Project	Poor scope definition Traditional procurement Competitive tendering Adversarial attitudes Poor design integration Learning and cultural organizational support
Learning in design	Group learning Individual learning and sharing Absorptive capability Personal relationship Characteristics of knowledge source Learning equilibrium Work characteristics Skill Base & Experience
Other aspects	Client and End-User Requirements Schedule Pressure Design Fees Planning During Design Design Checks, Audits, and Reviews

2.3 Impact of Design E&Os on Project Performance

Design E&Os in engineering plans can significantly impact public safety, lead to construction delays, and increase costs, highlighting the need for high-quality engineering plans (Hamilton et al., 2020). According to Han et al. (2013), even with best practices adopted by construction managers, design errors can still result in schedule overruns. Additionally, these errors may create schedule pressures that lead to further mistakes in construction activities that are not directly related to the original errors.

Design errors are a major cause of project cost and schedule overruns, rework, and accidents during and after construction (Love et al., 2013). They have been linked to severe incidents, including injuries and fatalities among workers and the public (Lopez et al., 2010). Furthermore, design errors continue to be a primary cause of construction and engineering infrastructure failures, as well as project schedule and cost overruns (Sun & Meng, 2009). A study conducted in Saudi Arabia on the causes of claims and disputes in construction projects found that significant contributors included: "change or variation orders due to new requirements from clients" (78 percent), "variations in quantities due to new requirements from clients" (74 percent), "delay caused by contractors" (74 percent), "design errors or omissions" (72 percent), and "inconsistencies in the drawings and specifications" (70 percent) (Assaf et al., 2019).

Inadequate design (due to design E&Os or inaccurate estimates) is also considered one of the major causes of road project overruns in Tanzania, leading to an average cost overrun of 26 percent, accounting for 61 percent of the causes. It also resulted in a time overrun of 32 percent, with an 85 percent impact compared to other causes. Previous research indicates that change orders, stemming from design E&Os , are the most significant outcomes. (Rwakarehe et al., 2014). Previous research and initiatives have shown that change orders, which result in rework, are the most significant outcomes of design E&Os .

Han et al. (2013) developed a system dynamics model to evaluate how design errors affect project schedules. Their model accounted for the causes and effects of errors and the relationship between them. The study, applied to a university building project, found that late identification of design errors resulted in higher schedule pressure, contributing to a 3.5-month project delay (Han et al., 2013). The findings highlight that even with managerial efforts to stay on schedule, design errors remain a major factor in overruns.

Li and Taylor (2014) examined the impact of undiscovered design errors on project costs in a Kentucky Transportation Cabinet Road resurfacing project, which incurred $466,595.29 in additional costs and delayed completion by 7 weeks. They found that perfect design quality assurance (QA) would increase design costs by 11.8 percent but lower construction costs by 17.4 percent, resulting in a total project cost reduction of 13.5 percent. Alternatively, improving construction staff's ability to spot design errors early could decrease total project costs by 13.6 percent, despite a 2 percent rise in costs for constructability reviews. The study underscored the importance of early detection of design errors to manage unexpected construction expenses.

Change orders are another critical factor affecting project performance. Khalafallah & Shalaby (2019) developed a model to assess the cost and duration impacts of change orders. Using data from 38 public projects, they identified 67 change orders and categorized them into seven groups. The study found that the leading technical cause of change orders was poor scope definition (40 percent), followed by inadequate coordination with authorities (16 percent) and unplanned interruptions (15 percent). This highlights the importance of clear project planning and coordination to minimize disruptions and additional costs.

Beyond design errors and change orders, effective communication plays a crucial role in managing construction project performance. Trach et al. (2021) explored the connection between communication and rework costs using an artificial neural network (ANN) model and found that project complexity, team size, coordination, prior experience, and IT infrastructure significantly impact communication efficiency; poor communication increases rework, highlighting the need for effective information flow and collaboration among stakeholders to minimize costs and delays.

Overall, these studies emphasize the necessity of early design error detection, proactive change order management, and effective communication strategies to minimize delays, cost overruns, and inefficiencies in construction projects.

2.3.1 Change Orders

Design E&Os significantly impact construction projects, leading to increased change orders that can cause cost overruns, schedule delays, and quality issues. Change orders are legal documents that account for additional work required due to the owner's directive changes, unforeseen site conditions, unanticipated circumstances, or inaccuracies in initial estimates (Ch. et al., 2010).

Recognizing potential change order variables during the pre-award phase can help mitigate risks of contractual deviations for owners, who are often concerned that change orders will negatively affect project goals(Shrestha & Ruiko, 2018). Throughout the construction phase, typical triggers for change orders include owner scope changes, unexpected site conditions, and design errors (Alnuaimi et al., 2010; Shrestha & Maharjan, 2018). Research indicates that many disputes, delays, and additional expenses can be traced back to issued change orders (Mishmish & El-Sayegh, 2018).

A study on road projects in the UAE identified agency-directed variations, which are significant contributors to claims, with errors in estimation and changes in project scope noted as major causes for change orders related to road maintenance activities (Mishmish & El-Sayegh, 2018). Specifically, tasks such as chip seal, striping, and asphalt overlay were impacted by these issues (Shrestha et al. 2019).

Furthermore, Alleman et al. (2020) categorized change orders in highway projects into five main types: 1) agency-directed change orders, which stem from instructions from contracting officers; 2) unforeseen conditions, relating to latent site issues; 3) plan quantity discrepancies; 4) plan E&Os, which arise from incorrect contractual designs; and 5) others, including contractor-modified changes (Alleman et al., 2020).

Texas DOT (2016) reported that design E&Os accounted for 31 percent of change orders over an eleven-year study, highlighting estimation and measurement discrepancies as contributing factors (Hamilton, Leary, & Dye, 2020). In Florida, a study found that the timing of change orders and unforeseen conditions significantly affected their costs (Serag et al., 2010). In

Oman, client-initiated additional works and design changes were similarly significant causes of change orders (Alnuaimi et al., 2010).

Ultimately, design errors not only lead to inefficiencies but also necessitate costly rework, further exacerbating time and budget constraints. The dismantling of incorrect components due to construction issues often requires more time and resources than initially estimated, emphasizing the critical need for accurate designs from the outset.

2.3.2 Reworks

Building and engineering projects are often plagued by issues such as going over budget and falling behind schedule, primarily due to rework (Love & Edwards, 2004). Rework, defined as the unnecessary effort of redoing tasks that were incorrectly completed, arises from various factors like design errors, construction issues, and changes in scope (Love, 2002). It can increase project costs significantly, sometimes by more than 10 percent or even up to 52 percent, according to various studies (Love, 2002; Love & Edwards, 2004).

The repercussions of rework extend beyond financial implications; they can adversely affect team morale, communication, and overall employee mental health (Love & Edwards, 2004). Common causes include incompatibility with requirements, scope changes, discrepancies between expected and actual quality, and errors by project professionals (Forcada et al., 2017; Forcada et al., 2014; Hwang et al., 2009; Hwang et al., 2019; Love et al., 2016). Specific issues leading to rework include poorly documented contracts, insufficient consultant fees, inadequate workmanship, and poor coordination among project teams (Love & Edwards, 2004).

In their study Hwang et al. (2019) identified the main sources of rework are design-related, as design errors and resulting changes that might result from insufficient details, incorrect interpretation, or inadequate drawing preparation, would lead to rework. Khalesi et al. (2020) found that the “Design errors”, “Design changes”, “Difference among plans and operational specifications”, “poor quality of implementations”, and “non-compliance with specifications” were the five most significant causes of rework.

Ye et al. (2015) found that design management factor is from the five top significant factors that affects rework in China construction projects, the design management factor involves “Lack of constructability because of separation between design and construction conditions”, “Poor coordination of design team members”, and “Design error/omission because of too many design tasks and time boxing”.

According to (Hwang et al., 2019) Design E&Os are stated as one of the substantial sources of rework in construction projects according to several studies such as (Forcada et al., 2017; Forcada et al., 2014; Hwang et al., 2009; Love et al., 2016; Love et al., 2010; Ye et al., 2015).

Consequently, there are direct and indirect effects of rework on project success, making it a major cause of construction projects' budget and schedule overruns (Hwang et al., 2019). An analysis of four California highway construction projects revealed an average cost increase of 24.8 percent and a schedule delay of 69 percent. The key factors contributing to these overruns include additional work requested by the owner post-design commencement, overly optimistic scheduling due to inaccurate estimates, and omissions related to prior errors (Chang, 2002), with most cost and schedule overruns stemming from design stage errors and changes.

Different reasons for different kinds of rework costs were found during various research. Chang et al. (2011) lists the rework costs and reasons for related research as shown in Table 5.

Table 5: Rework costs and reasons of related research (2011)

Related Research	**Costs**	**Reasons**
Cnuddle (1991)	10–20% of project cost	46% created during design, 22% from construction
Burati *et al.* (1992)	12.4% of project cost	79% created during design, and 17% construction
Hammarlund *et al.* (1990)	11% of project cost	79% cost arose from 20% of quality failure
Hammarlund and Josephson (1991)	4% of project cost	51% design related, 26% poor installation of materials, 10% material failure
Josephson and Hammarlund (1996)	2.3–9.4% of project contract amount	50% from site, and 32% from owner or design organizations

A system dynamics model analyzed rework costs in highway projects in Spain, identifying three main cause categories: organizational issues (like poor design and inadequate supervision), managerial flaws (such as poor communication and lack of resources), and people-related factors (including stress and inexperience) (Forcada et al., 2014) . Key findings revealed that unexpected events, design errors, and scope ambiguities led to significant budget and schedule overruns, with late-discovered mistakes proving particularly costly. Client inexperience was noted as a contributing factor to these ambiguities (Forcada et al., 2014).

A study analyzed the direct and indirect costs of design errors in construction projects, using data from 139 projects collected through a questionnaire survey which revealed that design errors, on average, accounted for 14.2 percent of the total contract value. Specifically, direct costs were 6.85 percent, while indirect costs were 7.36 percent (Lopez & Love, 2012). The design error costs as a percentage of the actual contract value are shown in Figure 2.

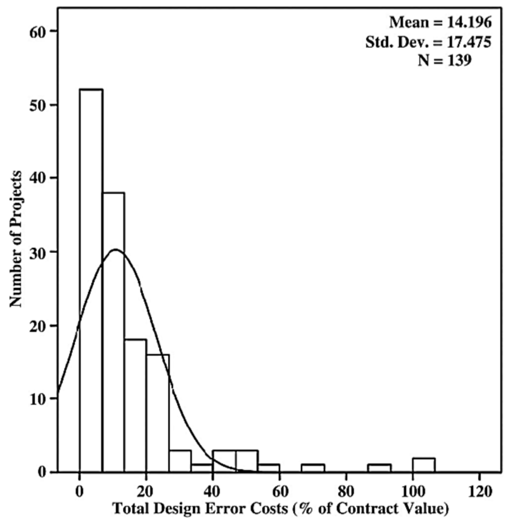

Figure 2: Total design error costs as percentage of contract value (Lopez & Love, 2012)

In summary, the literature highlights the significant impact of design E&Os on the execution of construction and highway projects. These errors can result in delays, increased costs, and compromised public safety, underscoring the importance of addressing their root causes. Factors such as insufficient training, poor communication, and inadequate quality control contribute to the prevalence of E&Os. As transportation agencies continue to face mounting pressures, a proactive approach to identifying and mitigating these issues is essential to enhance project outcomes and ensure accountability in the design process.

2.4 Frequency of change orders and Design E&O occurrence in DOT projects

Various studies and DOT reports have examined the frequency of change orders in highway projects, as well as their causes and impacts. Since 2018, the Pennsylvania DOT has averaged spending over 1 million annually on change orders due to design errors and 15 million on omissions (PennDOT, 2024). In Indiana, the DOT (INDOT) has identified that more than 12 percent of its projects experience delays linked to design E&Os, highlighting the pervasive issue of cost overruns (Bordat et al., 2004). In Texas, an analysis revealed that 31 percent of change orders over eleven years, accounting for an average of $45 million annually, were attributed to design-related issues(Jalili et al., 2016). Similarly, a review of 610 Kentucky roadway projects demonstrated that 39.84 percent of change orders stemmed from contract omissions, resulting in an average contract value increase of 4.53 percent (Taylor et al., 2012). These findings collectively underscore the critical financial and operational consequences of design E&Os across various state DOTs, emphasizing the need for improved design processes and error minimization strategies in infrastructure projects.

Taylor et al. (2012) conducted a statistical analysis on 610 Kentucky roadway projects in the interval between 2005 and 2008 to assess the change orders caused according to the project type (construction or maintenance), different road types, and construction type and found that the frequency of change orders due to contract omissions (“extra work is required for construction but was not included in the original contract”) was 39.84 percent (Highest frequency occurred 243 times) leading to an average increase in contract value of 4.53 percent, the details as shown in Table 6 below.

Table 6: Change Order Reason, Frequency, and Impact (Taylor et al., 2012)

Reason Code	Frequency (%) out of 610 total change orders	Average Change Order Amount ($)	Average % Change in Original Contract Amount
Asphalt lot pay adjustment	188 (30.82%)	7,699.93	0.79
Fuel and asphalt adjustment	218 (35.74%)	82,336.07	7.05
Contract omission	243 (39.84%)	57,410.90	4.53
Utility issue	60 (9.84%)	35,428.11	3.16
Contract item overrun	227 (37.21%)	104,857.53	6.73
Geotechnical issue	71 (11.64%)	90,777.41	3.02
Owner-induced enhancement	186 (30.49%)	88,297.13	7.8
Environmental issue	20 (3.28%)	19,737.72	0.47
F-Value		**4.025**	**13.024**
P-Value		**0**	**0**

Shrestha & Maharjan (2018) conducted a study analyzing data from 185 highway projects in Texas, each with costs exceeding 10 million dollars. Their findings revealed that the growth rate of change orders for these projects was 7 percent. Furthermore, they established that any increase in change orders above 5 percent would significantly affect both project costs and scheduling.

More than half of INDOT's projects experienced cost overruns, and approximately 12 percent faced schedule delays due to change orders. These change orders were primarily related to design E&Os. (Bordat et al., 2004). A study analyzing data from INDOT projects conducted between 1996 and 2000 investigated the frequency of change orders in highway projects to predict future occurrences. By employing Poisson and negative binomial models, the research provided insights into this phenomenon findings are illustrated in the Figure 3 below (Anastasopoulos et al., 2010).

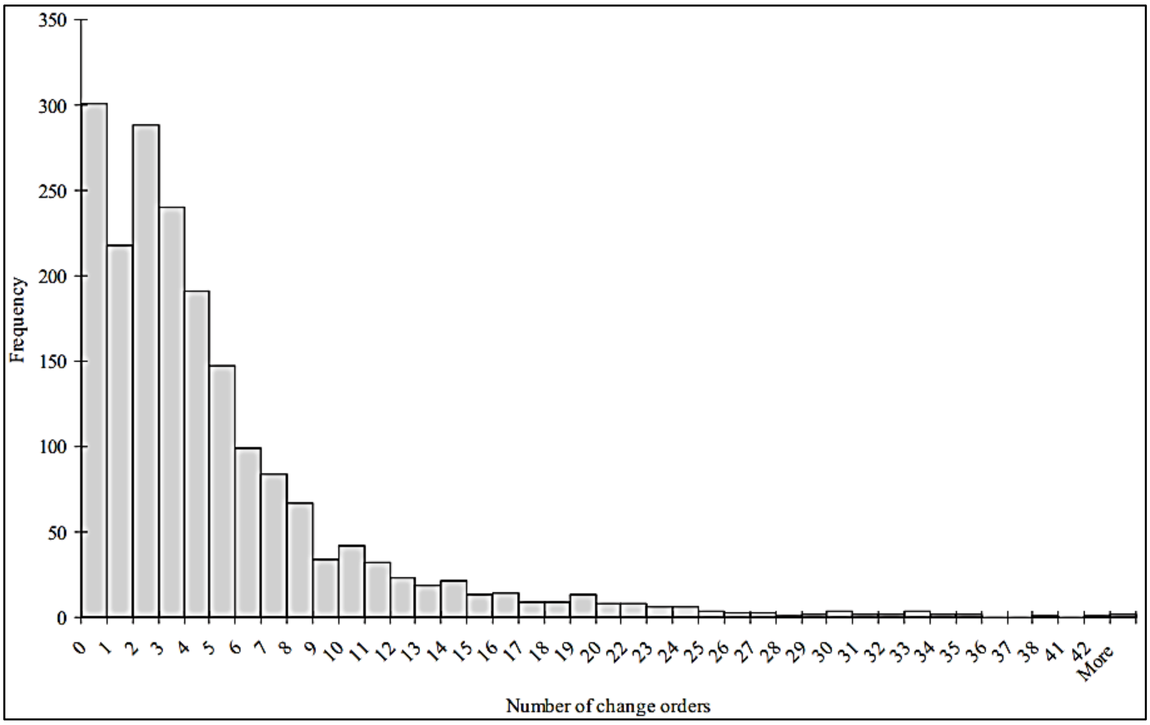

Figure 3: Frequency of Change orders in the studied projects (Anastasopoulos et al., 2010)

Additionally, Figure 4 illustrates the average number of change orders across the studied projects based on project type. Figure 5 highlights the number of projects categorized as having "Zero Change Orders" according to project type.

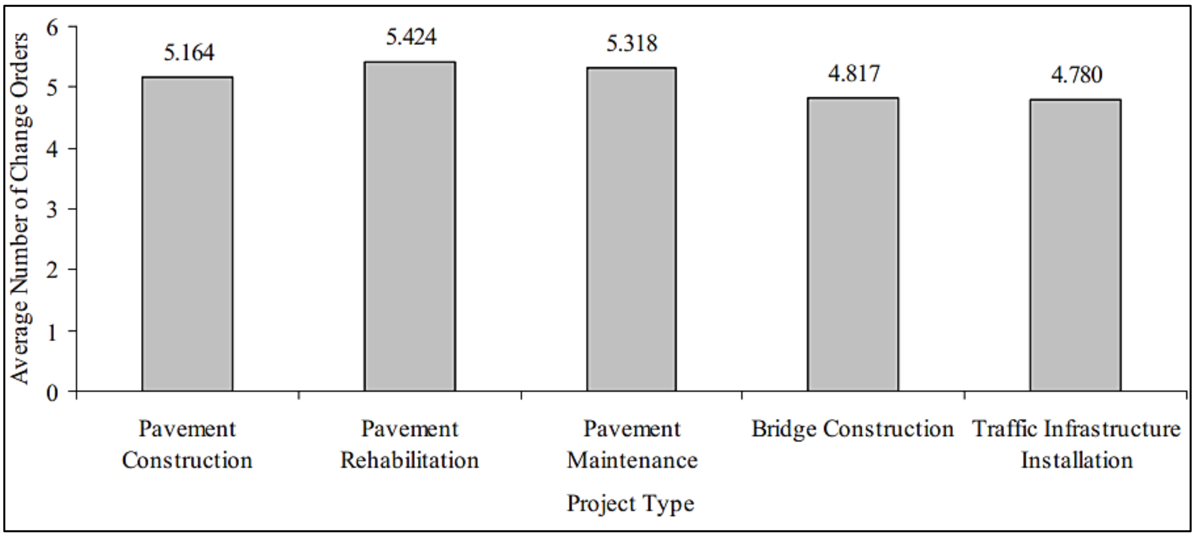

Figure 4: Average number of change orders with respect to the project type (Anastasopoulos et al., 2010)

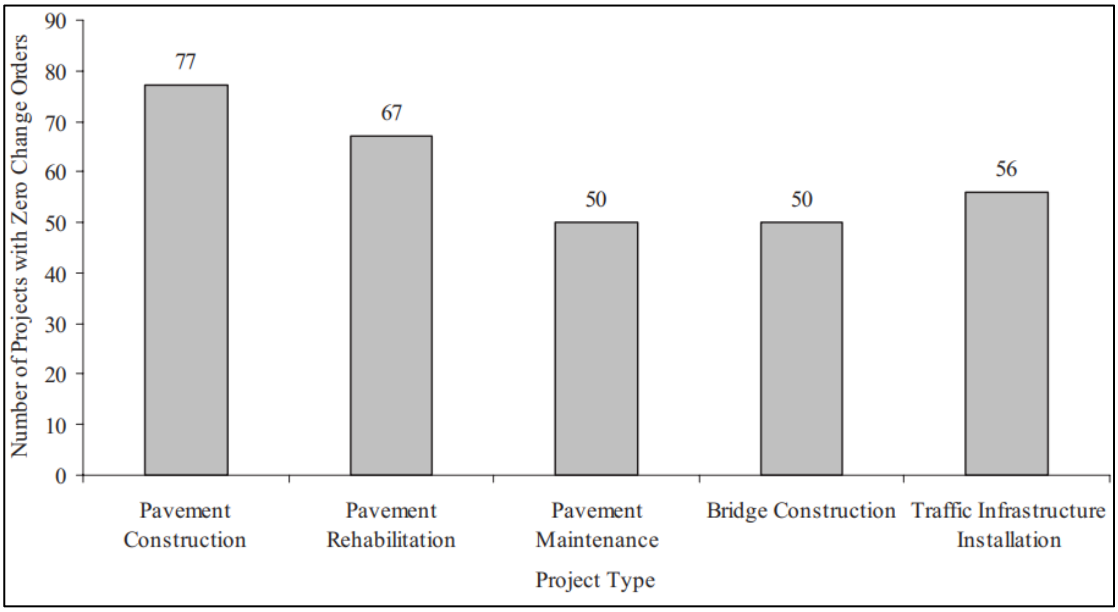

Figure 5: Number of projects with Zero Change orders with respect to the project type (Anastasopoulos et al., 2010)

Anastasopoulos et al. (2010) study analyzed factors influencing the frequency of change orders in projects using the Zero-Inflated Negative Binomial (ZINB) model. The study found that a 100 percent increase in planned project duration leads to a 14.3 percent rise in change orders. Notably, smaller contract amounts (under $100,000) experienced 29.6 percent fewer change orders than large contracts (over $1 million), while contracts in the $100,000-$300,000 range also had fewer. Additionally, resurfacing and traffic projects had 14.2 percent fewer change orders than other types, and projects with fixed completion deadlines incurred 12 percent more change orders than those based on available days. This highlights how project size, type, and duration significantly impact the likelihood of change orders. (Anastasopoulos et al., 2010).

For zero-change-order projects, the likelihood of remaining in a zero-change-order condition decreases as contract duration and award amount increase. This indicates that longer contracts and larger dollar amounts are less likely to have no change orders. Additionally, traffic projects have a higher probability of remaining change-order-free than other project categories.(Anastasopoulos et al., 2010).

2.5 Project Delivery Methods in Highway Projects

When it comes to delivering highway projects, the primary methods used are design-bid-build (DBB), design-build (DB), and construction manager-general contractor (CM/GC). Additionally, the progressive design-build (PDB) approach is increasingly being adopted by agencies, especially in the water/wastewater and airport sectors (Gad et al., 2019; Alleman et al., 2020).

In the DBB method, commonly used for highway projects, the owner signs two separate contracts—one with the designer and another with the contractor—allowing each party to focus on their own interests while the contract structure aims to align them; however, this can lead to designers prioritizing deadlines and profit over producing error-free designs (Li & Taylor, 2014).

In traditional DBB projects, costs are split between design and construction, with the designer managing design costs and the contractor overseeing construction expenses. Early detection of design errors can reduce overall project costs, but may increase design costs, affecting the designer's profit (Li & Taylor, 2014). If errors go unnoticed, construction costs typically rise, impacting the contractor's profit. This creates a conflict of interest, as each party prioritizes its own profit while the owner focuses on total project costs (Li & Taylor, 2014).

While highway construction traditionally uses DBB, there is a shift towards DB and CM/GC methods. According to the Federal Highway Administration (FHWA), 17 agencies allow CM/GC and all permit DB. Research shows that DB experiences smaller price increases from order modifications compared to DBB (Alleman et al., 2020).

According to the categorization of change orders, "unforeseen conditions" have the greatest impact on a project's overall cost growth. When considering different delivery methods, "agency-directed change orders" have the most significant impact within DB delivery methods. In contrast, "plan E&Os" are found to have the highest impact when using the DBB delivery method, as detailed in Table 7.

Table 7: Average cost growth by change-order type and delivery method (Alleman et al., 2020)

Change Orders	**DBB (N = 65) (%)**	**CM/GC (N = 19) (%)**	**DB/LB (N = 21) (%)**	**DB/BV (N =57) (%)**	**All (N = 162) (%)**
Agency-directed change orders	1.2	0.7	1.6	1.9	1.5
Unforeseen conditions	2.4	1.5	1.8	1.8	2
Plan quantity changes	1.1	0.3	0.6	0.2	0.6
Plan errors and omissions	0.9	0.6	0.1	0.5	0.6
Other	0.1	0.2	0.8	0.3	0.3
Total cost growth per method	**5.8**	**3.4**	**5**	**4.7**	**5**

The DBB delivery system is often criticized for its restrictive communication between designers and constructors, which can lead to E&Os in the design phase, negatively impacting the constructability of design solutions, often resulting in poor design quality and increased rework (Ye et al., 2015). Research indicates that these issues contribute to a higher frequency of design-related problems and significant cost overruns in DBB projects (Gad et al., 2015). To address these challenges, experts recommend adopting alternative delivery methods like DB, which enhances communication and requires the design-builder to maintain high design quality within established project costs and schedules (Fernández-Solís & Chugh, 2018; FHWA, 2006; Plusquellec et al., 2017). Furthermore, implementing quality control and quality assurance practices can help monitor progress and ensure that design solutions function as intended (Gad et al., 2015). Ultimately, while DBB remains a common approach, the trend is shifting towards the design-build method as a viable solution to mitigate the pitfalls associated with traditional design-bid-build projects.

The primary focus of this project is to examine the impacts of design E&Os on DBB project delivery, particularly as WYDOT emphasizes this area of concern. Through this analysis, we aim to identify how such errors can affect project timelines, costs, and overall quality, providing valuable insights that can lead to improved practices and outcomes in future projects. The DBB method tends to have a higher occurrence of design E&Os due to poor communication between designers and contractors, which often results in a higher percentage of cost overruns. This issue can be alleviated by implementing design quality procedures and conducting Constructability Review Processes (CRP) as discussed in Section 2.8.

2.6 Enhancing Project Performance Through Design Quality Control

Han et al. (2013) developed a system dynamics model to evaluate the impact of design errors on project performance, considering factors such as design errors, frequent change orders, and long approval times. The model assesses the relationship between these factors and their effect on schedule delays. It was implemented on a university building project to analyze schedule performance, revealing that design errors were a major contributor to project delays. Late identification of design errors led to increased schedule pressure, ultimately delaying the project by 3.5 months beyond the planned completion. The model effectively demonstrated how design errors negatively impact construction activities, even when those activities are not directly related to errors.

Similarly, Li & Taylor (2014) applied a system dynamics model to evaluate the cost impact of undiscovered design errors and rework in a Kentucky Transportation Cabinet road resurfacing project, with the model of the workflow as shown in Figure 6.

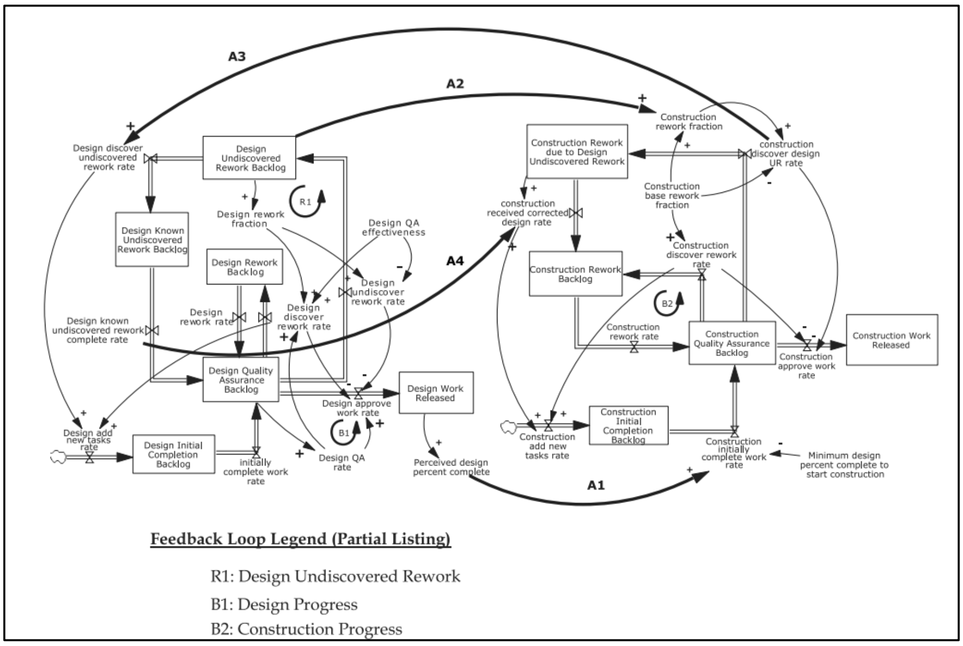

Figure 6: Simplified model of the workflow section (Li & Taylor, 2014)

Their analysis showed that design errors accounted for 13.02 percent of the contract value, leading to significant cost overruns and a project extension from 31 to 38 weeks. The model was structured into three key sections: workflow, resource allocation, and cost accounting. Sensitivity analysis indicated that Design QA effectiveness had the highest impact on project costs and duration, highlighting the importance of improving quality assurance early in the design phase, as quantified in Table 8. Further evaluation of different policies demonstrated that early identification of design errors and conducting constructability reviews could reduce total project costs by 13.5 percent and construction costs by 17.4 percent, despite a slight increase in design costs (Li & Taylor, 2014).

Table 8: Results of Implementing two different policies (Li & Taylor, 2014)

Description	**Base Case (Undiscovered Rework)**	**Policy 1 (Design QA Perfect)**	**Policy 2 (Review Before Completion)**
Total project cost ($)	$5,000,741	$4,324,856	$4,318,381
Percentage improved (%)	—	13.5	13.6
Design cost ($)	$664,741	$742,856	$664,741
Percentage improved (%)	—	-11.8	0
Construction cost ($)	$4,336,000	$3,582,000	$3,582,000
Percentage improved (%)	—	17.4	17.4
Constructability review cost ($)	$0	$0	$71,640[a]
Construction duration (week)	38	31	31
Percentage improved (%)	—	18.4	18.4

[a]**Note:** This paper assumes that constructability review costs 2 percent of the construction contract value. This rough estimation is based on two case studies conducted for NCHRP Project 20-07/Task 124. For the two projects studied, the constructability review process cost 2.26 percent and 1.50 percent of the construction contract value, respectively (Punston et al., 2002).

These studies emphasize that design errors significantly impact project performance in terms of cost and schedule overruns. Implementing effective design quality control tools can help mitigate these risks, ensuring a more streamlined and efficient construction process. By enhancing quality assurance mechanisms in the design phase, project teams can reduce rework, minimize delays, and improve overall project outcomes.

2.7 Impact of Incorporating New Technologies on Project Performance

Many commonly used procedures and technologies from the construction industry have been adapted to meet the growing need for new technology in the transportation sector, such as Building Information Modeling (BIM), which has been proven to be greatly effective in the construction industry. While BIM has been used extensively in the construction industry for several decades, it has been accepted and applied more slowly in the transportation infrastructure sector (Costin et al., 2018; Fanning et al., 2015). BIM implementation can potentially contribute significant value throughout the life cycle of infrastructure asset management (Fanning et al., 2015). Rapid advances in BIM offer new potential to increase construction efficiency and effectiveness and improve the use of new technologies throughout project lifecycles in buildings and infrastructure (Shou et al., 2015).

Transportation infrastructure damage and aging are critical issues. Traditional inspection and management methods have become inefficient due to significant network development, necessitating modern automated technologies (Costin et al., 2018). BIM and emerging infrastructure management technologies enhance network reliability, sustainability, and safety, while reducing maintenance costs and risks and increasing stakeholder revenues (Fanning et al., 2015).

BIM covers the entire construction lifecycle, defining project scope, producing high-quality 3D designs, and supporting 4D scheduling and 5D cost estimation, thereby improving facility management (Shou et al., 2015). Complex transportation projects involve many stakeholders, and modeling and degradation analysis assist in identifying cost-effective design, construction, and operational solutions (Fanning et al., 2015). Enhanced cross-disciplinary cooperation through BIM reduces design errors, risks, and liability, providing stakeholders with better project insights (Fanning et al., 2015).

BIM also enhances construction process control, internal coordination, cross-disciplinary collaboration, issue resolution, decision-making, risk management, and productivity, leading to fewer design mistakes and less rework (Hwang et al., 2019). Projects that utilize BIM show significantly lower rework percentages than those that do not. Table 9 shows the comparison between projects with BIM and projects without BIM with respect to the rework effect for different project types. Additionally, it serves as a single database to minimize information loss and enhance communication among project stakeholders and facility managers (Hwang et al., 2019). Research has shown that projects using BIM experience significantly lower percentages of rework compared to those without BIM (Fanning et al., 2015). A comparative analysis evaluating the impact of BIM on accelerated bridge construction in the Denver metropolitan area revealed that the application of BIM reduced costs related to change orders and rework by approximately 5-9 percent compared to projects that didn’t use BIM.

Table 9: Rework Status: project with BIM and projects without BIM (Hwang et al., 2019)

Project Profile	Project with BIM:			Project without BIM:			p-value
	Number Experienced Rework	Total Projects	Percentage (%)	Number Experienced Rework	Total Projects	Percentage (%)	
All	85	164	51.80	119	165	72.10	**0.001**
Type							
Building	32	69	46.40	48	75	64.00	**0.033**
Industrial	35	64	54.70	43	59	72.90	**0.036**
Infrastructure	18	31	58.10	28	31	90.30	**0.003**
Size (million)							
<15	16	27	59.30	14	21	66.70	0.084
15–50	22	43	51.20	30	41	73.20	**0.037**
50–100	27	52	51.90	40	55	72.70	**0.026**
>100	20	42	47.60	35	48	72.90	**0.014**
Note: Bold p-values indicate statistical significance at the 0.05 level (two-tailed Chi-square test).							

Moreover, a study utilizing the Stepwise Weight Assessment Ratio Analysis (SWARA) method alongside BIM technologies identified and ranked 49 causes of rework, demonstrating that BIM could reduce working time by 4.6 percent by addressing these causes (Khalesi et al., 2020). The Michigan DOT (MDOT) initiated digital delivery in 2012, enhancing predictability, repeatability, and dependability with 3D models, resulting in a calculated net benefit of over $18 million between 2012 and 2016—a 32 percent return on investment (Mitchell et al., 2019).

According to a survey by MDOT, design firms use 3D models to review designs, communicate with development teams, conduct constructability reviews, compute project quantities, establish construction layouts, and check designs for errors (Mitchell et al., 2019)The report emphasized the financial benefits of 3D models over 2D plans, as shown in Table 10. It suggested that MDOT advance data integration techniques and improve risk management in digital project delivery.

Table 10: Overall cost savings and overruns of 3D models vs 2d Plans (millions of dollars, statewide) (Mitchell et al., 2019)

Categories	2D Plans	3D Models
Total Engineer's Estimates	$1,148.90	$288.30
Total Bid Costs	$1,159.20	$277.40
Total Final Contract Costs	$1,168.10	$275.40
Net Cost Savings at Award	($10.20)	$11.00
Net Cost Savings at Project Closeout	($8.90)	$2.00
Net Program Cost Savings	**($19.20)**	**$12.90**
Percent Program Cost Savings	**-1.70%**	**4.50%**

2.8 Design Quality Control (DQC) Tools in Highway Construction

Transportation agencies require "biddable" and "buildable" project designs to secure competitive pricing. Recent concerns among transportation authorities, contractors, and design specialists indicate that inadequate plans can lead to project delays, cost increases, and expensive construction claims (AASHTO, 2000). Effective design checks, reviews, and robust project management practices are essential to prevent engineering and construction failures (Love et al., 2013). Implementing quality control (QC) early can help limit design errors. Design QC ensures deliverables meet quality standards by identifying problems before construction starts (Gransberg & Molenaar, 2008).

Rwakarehe et al. (2014) made recommendations to reduce inadequate design in Tanzanian road projects including better project management, improving design document reviews, providing road safety and design manuals, and increasing the number of design personnel to handle higher workloads.

Love & Sohal (2003) recommended to enhance design quality and minimize construction errors, firms should focus on the needs of owners and end-users, create accurate drawings, manage design documentation, and conduct design analysis. Controlling changes and ensuring quality service are essential, and implementing constructability analysis can further reduce errors. (Love & Sohal, 2003).

In DBB contracts, the owner's oversight and design approval are crucial for maintaining project timelines (Kocot et al., 2023). Delays in design approval can further complicate schedules and funding. Enhanced collaboration helps mitigate disputes, emphasizing the need for clearly defined quality management responsibilities (K. R. Molenaar et al., 2015).

State Transportation Agencies (STAs) are increasingly incorporating innovations in Quality Assurance Organizations (QAOs) alongside the roles of owners and contractors in Quality Management Systems (QMSs), which are evolving, often sharing responsibility for quality management (FHWA, 2012). There are five fundamental Quality Assurance Organizations for the highway construction and design industry identified (K. R. Molenaar et al., 2015) ranging from deterministic, with the highway industry having the highest control over quality roles, responsibilities, and activity, to acceptance, where the agency is responsible only for verification testing and final acceptance. Figure 7 shows the summary of the five QAOs concerning the level of agency control and approach to quality.

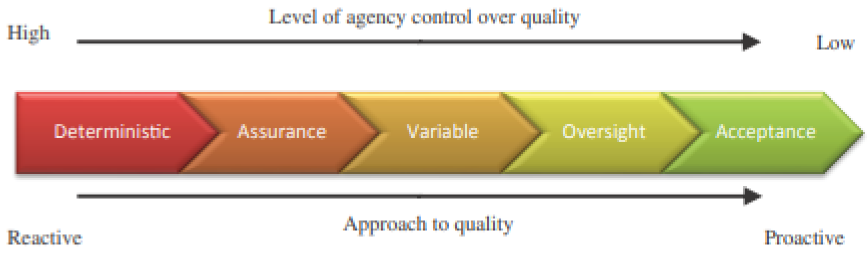

Figure 7: Fundamental highway industry QAOs based on agency and approach to quality (Molenaar et al., 2015).

In the assurance model, the agency supervises all quality aspects except design and construction quality control. The variable approach allows for the delegation of quality control and acceptance roles to third parties during different project phases. Oversight involves the agency taking a supervisory role while delegating design and construction quality control to external parties. Finally, the acceptance model, seen mainly in Public-Private Partnership (PPP) agreements, limits the agency's involvement to final acceptance and verification testing, assigning all other quality responsibilities to the concessionaire. The Figure 8 below shows the matrix of agencies that can be used to identify a set of tools compatible with the project QAO and specific project requirements.

	Tools	QAOs Compatible				
		D	A	V	O	S
Pre-Award Tools						
Owner Led	*B.1. Pre-bid meeting with specific focus on quality	+	+	+		
Owner Led	B.2. Industry review of requests for proposals with a focus on quality			+	+	+
Owner Led	B.3. Alternative quality management approaches in procurement	+	+	+	+	+
Owner Led	B.4. Quality-based selection system	+	+	+	+	+
Owner Led	B.5. Use of warranties	+	+	+	+	+
Owner Led	B.6. Requirements management—verification	+	+	+	+	+
Contractor Led	B.7. One-on-one procurement meetings with a focus on quality			+	+	+
Contractor Led	B.8. Contractor involvement in establishing and streamlining quality control standards	+				+
Contractor Led	B.9. Alternative Technical Concepts		+	+	+	
Contractor Led	B.10. External contractor panel input	+	+	+		
Post-Award Tools						
Design Review	B.11. Independent party design review	+	+	+	+	
Design Review	B.12. Over-the-shoulder agency review			+	+	+
Design Review	B.13. In-progress design workshops			+	+	
Design Review	B.14. Discipline task force	+	+	+	+	+
Construction – Teaming	B.15. Formal partnering with regulatory agencies	+	+	+	+	
Construction – Teaming	B.16. Formal team-partnering/goal-setting process	+	+	+	+	+
Construction – Teaming	B.17. Co-location of quality management personnel	+	+	+	+	+
Construction – Teaming	B.18. No low-bid requirement for subcontractors	+	+	+	+	+
Construction – Teaming	B.19. Use of dual CEI/OCEI roles					+
Construction – Process Control	B.20. Innovation in witness and hold points			+	+	+
Construction – Process Control	B.21. Continuous internal process audit					+
Construction – Process Control	B.22. Real-time electronic quality management information	+	+	+	+	+
Construction – Process Control	B.23. Financial incentives/disincentives for quality	+	+	+	+	
Construction – Process Control	B.24. Contractor-controlled QC testing	+	+	+	+	+
Construction – Training	B.25. ISO 9000 training sessions					+
Construction – Training	B.26. Project-specific quality management team training	+	+	+	+	+

D = Deterministic QAO, A = Assurance QAO, V = Variable QAO, O = Oversight QAO, S = Acceptance QAO
+ = Compatible, blank cell = Incompatible
*B.1, B.2, etc., refer to numbering of tools in Appendix B.

Figure 8: DQC Tool selection chart (Molenaar et al., 2015)

2.8.1 Checklists, Manuals, and Standards

State DOTs use checklists, manuals, and drawings in their QA/QC procedures, with some providing training for engineers to improve plan reviews. Dedicated quality assurance divisions exist in some states to manage these processes and ensure accountability through title blocks on plans. Successful states focus on refining existing processes instead of creating new ones, identifying inefficiencies and formalizing improvements. They establish performance metrics to enhance the quality and efficiency of their programs (NCHRP, 2011).

A quality review checklist is a tool used to ensure that all necessary quality control measures have been taken during the design process (Brown, 2002). The checklist typically includes a list of quality control items or requirements that must be met, along with a space for the reviewer to indicate whether each item has been completed or not. The specific items included on a quality review checklist will depend on the nature of the design project and the particular quality control needs. Some common items that may be included on a quality review checklist for a design project include:

- Compliance with design standards and regulations
- Accuracy of calculations and measurements
- Completeness of design documentation
- Clarity and readability of design documentation
- Consistency with project requirements and specifications
- Adequacy of testing and validation procedures

A quality review checklist ensures that all necessary quality control measures have been considered and that the design meets the required standards and specifications. Reviewers can use a checklist to ensure that no important quality control items are overlooked and that the design is of the highest possible quality.

2.8.2 Constructability reviews

A constructability review evaluates a design from a construction standpoint to identify potential issues that could impact its buildability. The construction expert reviews the design and suggests design changes to optimize the building process, save money, time, and reduce conflicts. The designer and contractor communicate better and produce a higher-quality product after such a review (Hancher et al., 2003). Conducted by a multidisciplinary team, these reviews aim to spot conflicts and inefficiencies early on, thus improving design quality and reducing changes or delays during construction. Integrating constructability reviews into the design process enhances feasibility and leads to more successful outcomes (Brown, 2002).

A survey by Hancher et al. (2003) on constructability programs in state agencies revealed that 58 percent of state DOTs have a formal CRP (based on 19 responses). It identified four common barriers to these programs: "lack of adequate time for review," "lack of practical construction experience by design personnel," "manpower restrictions," and "contractors' limited input to remain competitive." Additionally, the research highlighted common constructability challenges faced by Kentucky Transportation Cabinet projects, including traffic control, existing utilities, geotechnical issues, ROW, bridge structures, and new utilities (Hancher et al., 2003).

The goal of constructability reviews is to examine the potential advantages and drawbacks of various design approaches (Stamatiadis et al., 2014). Constructability can enhance project goals and building performance by integrating construction knowledge throughout the procurement process and managing project and environmental constraints (Love et al., 2004).

According to (Stamatiadis et al., 2014) based on NCHRP Report 390 (Anderson & Fisher, 1997) only 23 percent of the state DOTs utilize a formal CRP. In addition, the authors have found, based on a survey conducted, that most of the states utilize a form of CRP. The reason for using the form instead of the formal process is because of the designers' inexperience in construction, ineffective communication among construction and design personnel, lack of historical documentation of construction changes, and the timing of these reviews throughout the project development. Besides, the authors added that these problems may be mitigated by conducting reviews in early project stages to reduce the possibility of redesign and additional costs incurred due to rework, development of a lessons learned database that includes the common areas of potential problems and to be used as a training tool for personnel throughout the project phases.

CRP consists of several reviews that are conducted throughout the project phases, where there is a defined review process for each phase. The reviewing process is considered a tradeoff between minimizing errors and the costs associated with the design errors. As shown in Figure 9, the relationship between the effort made to review the designs for minimizing errors and the costs associated with the design errors, where to achieve the minimum cost, the design errors should be minimized.

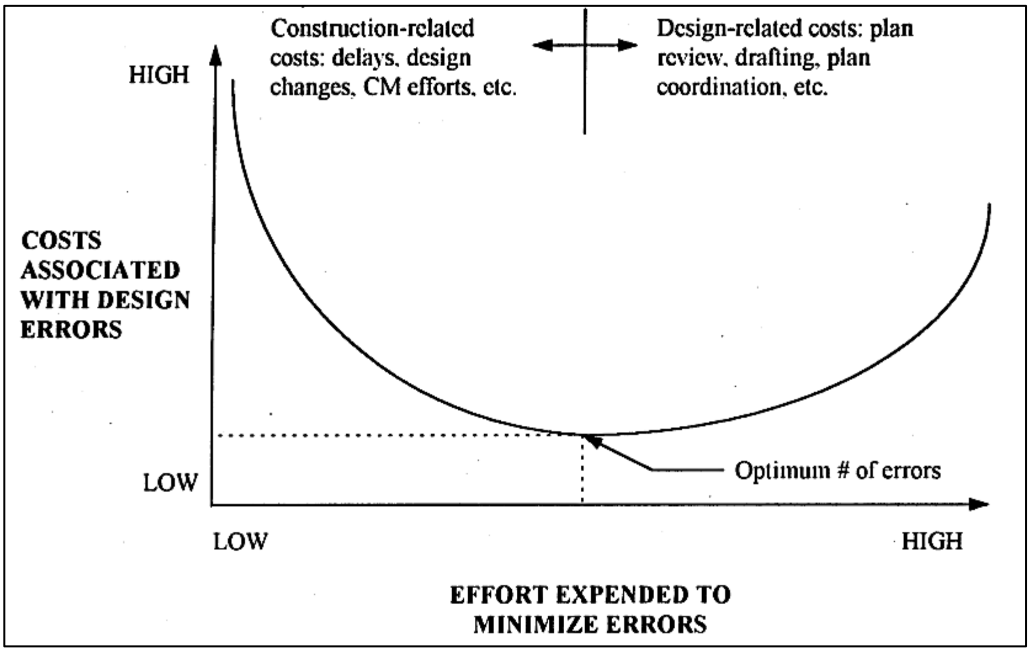

Figure 9: Relationship between minimizing errors and the cost associated with design errors (Gambatese & McManus, 1997)

"Constructability Review Procedures Manual" was developed by Tennessee DOT (TDOT) (TDOT, 2016), which provides the guidelines for conducting constructability reviews to improve the plan development process and quality as well. Figure 10 shows the CRP Diagram.

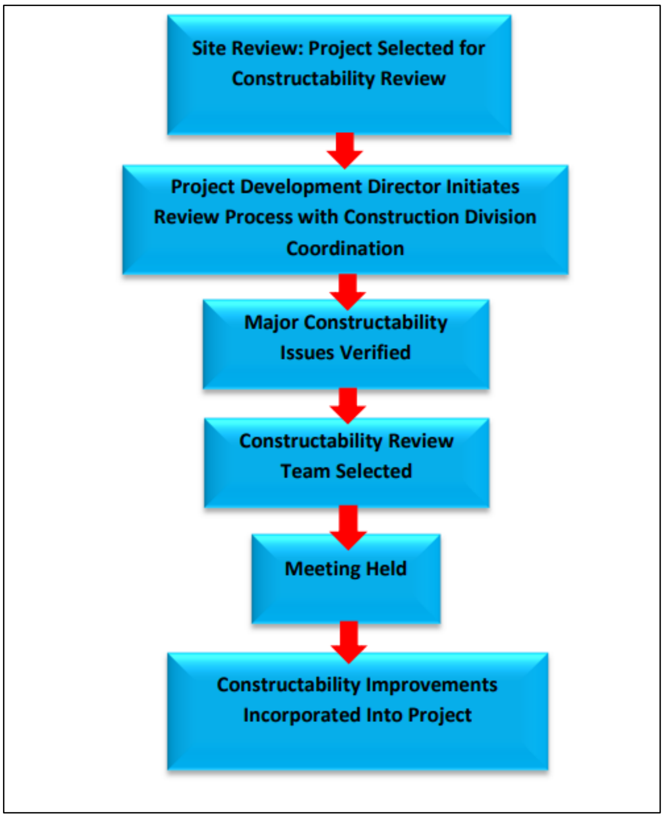

Figure 10: Constructability Review Diagram (TDOT, 2016)

2.8.3 Early Involvement of Contractors in Design

To reduce cost overruns in highway projects using the DBB method, administrators can benefit from early involvement of contractors in the design phase to help eliminate errors and distribute risks associated with engineering information (Calahorra-Jimenez et al., 2020). During the procurement phase, establishing clear communication between road administrators and bidders is essential for defining the project's scope and preventing ambiguities in the Request for Proposal (RFP). Additionally, establishing a single point of accountability can help monitor phase durations and secure funding for smooth transitions between project stages (Calahorra-Jimenez et al., 2020).

Gransberg (2013) emphasizes the importance of involving contractors early in the design process for emergency projects. Six case studies from various states highlight how contractor inclusion can accelerate project delivery. The advantages of the early contractor involvement approach include the ability for designers to tailor projects based on real-time information from constructors, leading to faster and more reliable construction processes. This method allows for significant time savings as work can be organized into biddable "work packages," and using time-based incentives encourages contractors to meet tight deadlines. Additionally, while design liability remains with the designer, the collaboration enhances design documentation quality and minimizes delays caused by errors or omissions, demonstrated by six case study projects with Florida DOT, Maine DOT, Minnesota DOT, Missouri DOT, NewYork State DOT and Utah DOT completed without modifications, with five finishing ahead of schedule (Gransberg, 2013).

2.8.4 BIM for DQC

BIM is a collaborative process that involves creating and managing digital models of a building's design, construction, and operation (Donato et al., 2018). BIM technology allows for the early evaluation of design alternatives using analysis/simulation tools that increase the overall quality of the building (Jasiński, 2021). It also enables rigorous analysis, simulations, and performance benchmarking, leading to improved and innovative solutions, better production quality, and better customer service (Azhar & Asce, 2011) . Additionally, BIM supports design quality control by enabling better coordination, error detection, and cost estimation throughout the design process (Jasiński, 2021).

Some of the benefits, challenges, and risks of BIM in the ACE industry are described below based on Azhar & Asce (2011) & Tang et al. (2020):

BIM enhances the design process by improving quality control through tools for clash detection, organized documentation, and better visualization of construction processes. It allows for early identification and resolution of design issues while enabling rigorous analysis and simulations that lead to innovative solutions and improved production quality. However, challenges in BIM implementation include human factors like the adaptation to new tools, infrastructure costs, and client resistance to additional expenses. In the context of infrastructure design, BIM supports the management of asset networks, such as highways and utilities, through the integration of graphical and non-graphical data, facilitating comprehensive asset management.

2.8.4.1 Case studies with the implementation of BIM in highway construction:

I-80 Eastbound Ramps at I-380, 3D model deliverable *(FHWA, 2020a)*

BIM was utilized in the redesign of the I-80/I-380 interchange by creating a federated model that integrated multiple infrastructure disciplines, including geotechnical, roadway, drainage, lighting, and utilities. This approach facilitated better collaboration among stakeholders, allowing for early discussions and alignment on project deliverables. The benefits included enhanced accuracy and data accessibility for quality control and design review, which aided contractors during project orientation and public participation. Additionally, the project highlighted the importance of using compatible software and equipment, ultimately leading to more efficient workflows and promoting the adoption of BIM technologies within the local construction industry.

NYSDOT KEW Gardens Project; BIM as an as-built record *(FHWA, 2020b)*.

The Kew Gardens Interchange (KGI) project leveraged BIM to create a detailed as-built record, particularly for underground utilities. BIM was utilized across various project phases with 3D, 4D, and 5D modeling to enhance construction planning, management, and financial processing.

The use of BIM resulted in improved adherence to schedules and budgets, quicker contractor payments, and enhanced accuracy in quantity measurements. It also facilitated better coordination in product delivery. Key benefits included establishing BIM requirements in RFPs, but a challenge was the need for continuous updates to the as-built model when encountering underground utilities. These lessons led to a BIM implementation plan aimed at identifying future projects for BIM use and collaboration with the FHWA.

2.8.5 Pre-Bid Meeting with Specific Focus on Quality

Pre-bid meetings focused on quality to allow bidders to ask project managers and the design team clarifying questions, reducing confusion, and resulting in more precise bids. These meetings ensure bidders understand the agency's priorities and emphasize high-quality documentation. The Washington State DOT's George Sellar Bridge Project illustrates their success, as contractors found the meetings beneficial for preparing bids and clarifying designers' intent. (Molenaar et al., 2015).

2.8.6 Independent Party Design Reviews

According to Molenaar et al. (2015) STAs are responsible for design reviews but may rely on independent parties when needed. A skilled, unbiased consultant joins the independent review team, allowing the agency to maintain control while reducing resource and time expenditure. This approach is especially useful for specialized projects or when the agency faces time constraints. For example, in the Willamette River Bridge Project, ODOT partnered with Oregon Bridge Delivery Partners (OBDP) for design reviews within a CMGC framework. OBDP operated separately during the design phase to ensure impartiality, conducting internal reviews alongside contractor and agency assessments, with the contractor performing regular constructability reviews to enhance the design.

2.8.7 Over-the-Shoulder Agency Review

Over-the-shoulder agency reviews are informal meetings between an agency and designers to assess design progress without pausing the design process (Molenaar et al., 2020)These evaluations offer prompt insights, focus on essential tasks, and guarantee compliance with designated design standards, improving project quality and feasibility. The design-build method uses over-the-shoulder agency reviews, allowing informal assessments during the design phase without formal submissions. This ensures compliance with contract requirements and promotes agency input. They are often included in Requests for Proposals (RFPs) and are a practical tool for alternative project delivery methods such as DB or CM/GC approaches For instance, MnDOT applied this approach in the T.H. 61 Hastings Bridge Project to address unstable soils, while UDOT utilized it for the I-15 Widening and Beck Street Bridge Projects to enhance collaboration among the agency, design team, and contractor’s quality manager (Molenaar et al., 2015).

2.8.8 In-Progress Design Workshops

The meetings between the designer, contractor, and agency throughout the design process focus on discussing and verifying design progress. This ensures a shared understanding of project assumptions and expectations, resolves issues early, and enhances project quality. Such meetings can occur at any stage of design and are particularly effective for alternative project delivery methods. For instance, MnDOT scheduled in-progress design workshops for the Hastings Bridge Project to address specific concerns like pier and arch designs (Molenaar et al., 2015).

2.8.9 Discipline Task Force

A disciplined task force is a team that ensures coordination across project disciplines, including designers, construction personnel, and agency experts. MnDOT created a task force for quality management during the Hastings Bridge Project, focusing on core areas such as roadways, drainage, structures, traffic, and utilities, along with Intelligent Transportation Systems and geotechnical design (Molenaar et al., 2015).

2.8.10 Financial Incentives/Disincentives for Quality

Financial incentives have been well in use for speedy project delivery, but not so much for quality. It comprises appropriate contract clauses defining incentive terms and the necessary mechanisms for comparing a contractor's performance to incentives earned. It could be proposed that this be introduced in the design process for DBB, as well as incentives and disincentives based on the quality of designs produced (Molenaar et al., 2015).

2.8.11 Drone application in the AEC industry

Drone application is mainly discussed concerning inspection in the built environment. The inspection capability of drones includes infrastructure and building inspections, construction site inspections, and post-disaster assessments. Drones can expedite site inspection, progress monitoring, problem detection, proper documentation, and detect violations from data collected by remote sensing. For instance, erosion and sediment control practices can be inspected, and the project progress can be monitored remotely by using a drone to collect high-quality aerial images and data. Emerging technologies, such as artificial intelligence (particularly machine learning), are being proposed to improve data collection and processing. suggest that deep learning-based object detection can provide an innovative approach to drone inspection tasks in the AEC industry.

One of the gaps in the body of research is the lack of tools for the timely identification of points of disagreement between the owner and the design-builder's design team. Identifying instances of failing to meet contract requirements is crucial as the first step in a dispute avoidance strategy. However, differing interpretations of specific clauses can often be the source of disputes, especially when related to design performance (Kocot et al., 2023). Design quality management becomes more challenging when conducted on a DB project, as the contract is awarded before the completion of the design, and the owner typically transfers traditional QA responsibilities to the design-builder. While in DBB projects, the owner retains more control over the design quality process, and the design quality audit can be adapted here.

2.9 Policies and Procedures for Design E&Os in DOT Documents

A Document by Michigan DOT (2003) "Michigan DOT Common Design Errors/Omissions 2003-1, Jan. 22, 2003" identifies the common errors that occur in the design plans and provides guidelines on how to deal with these errors. The document gives instructions regarding what to be written in the design documents based on the commonly identified design errors. These instructions include (More details on the errors list could be found in Appendix B of (Hamilton et al., 2020) report.

1. <u>Title Sheet:</u> "Physical Reference Numbers must be included in the P.O.B. and P.O.E. stationing blocks along with Control Section Mile Points".
2. <u>Typical Cross Sections - Misc Details:</u> "Driveway widths and types - Detail M openings on commercial drives, Min 30' opening face to face of curb. Dimensions should be shown edge to edge of curb & gutter at the throat."

3. <u>Notesheet:</u> “Make sure that any pay items triggered by a FUSP or SS are included.”
4. <u>Plan/Profile Sheets:</u> “Pavement widths dimensioned, centerline to edge, at all locations where the width changes. Include stationing at these points.”
5. <u>General:</u> “Adding items of work to Standard Pay Items by note is to be avoided. All non-standard pay items need a Special Provision.”

Arizona DOT (ADOT) (ADOT, 2019) has published a document for dealing with the E&Os in projects. The document states the guidelines and procedures to assess and deal with the design errors for the consultant and in-house design projects, to provide suggestions for resolving issues with the consultant design firm, or suggestions for settling issues with the relevant ADOT Division Director. Summary of ADOT Procedures:

1. The erroneous designs, plans, or specifications shall be addressed by ADOT, along with the identification of corrective activities and the resolution of any resulting implications.
2. After receiving notification from the Resident Engineer of a possible error or omission, the Project Manager shall take the necessary actions to determine whether or not the error or omission was the consequence of carelessness or gross negligence.
3. Together, the consultant or in-house team and the project manager will work to find a solution that works for everyone involved and can be implemented quickly and cheaply.
4. Following the methods laid out in this guidance, ADOT will pursue compensation for mistakes related to a consultant's carelessness or severe negligence.
5. Similar records will be kept by ADOT for the cost of design mistakes and oversights made in-house.

Figure 11 outlines the ADOT process for addressing design E&Os during the advertising and construction phases. It begins when a problem is reported to the Resident Engineer (RE) along with supporting documentation. ADOT assesses the issue's severity and works with consultants and in-house designers to determine financial responsibility for resolution. If the problem remains unresolved, the district engineer can refer the matter to the E&Os Claims Review Board, which will make a recommendation within 30 calendar days. The Department must communicate its decision to the Consultant/Designer within 15 working days of the Board’s conclusion. Internal stakeholders should assess the situation to decide on potential legal action if the consultant disagrees with the Board's decision (ADOT, 2019).

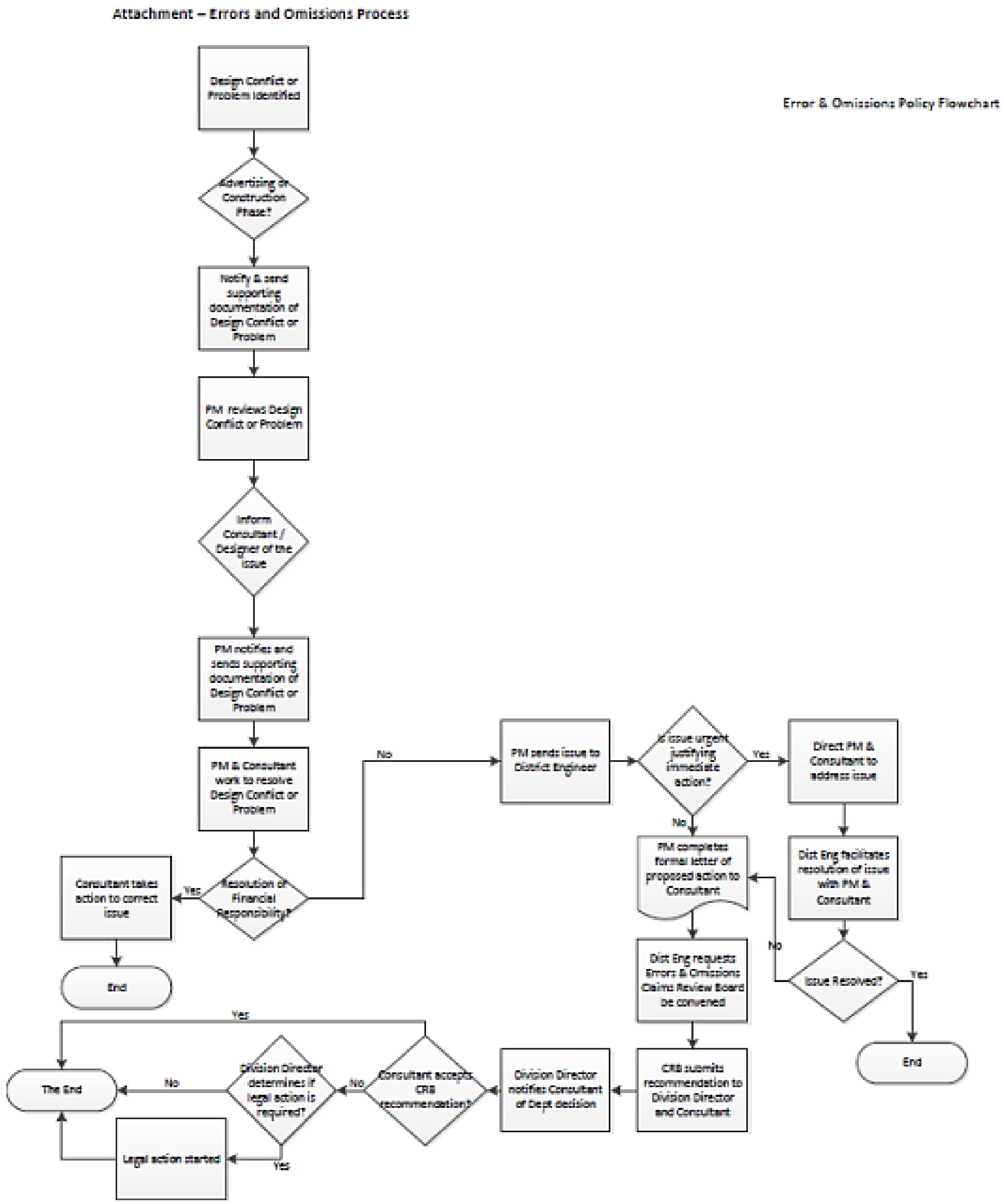

Figure 11: ADOT Process for dealing with Design E&Os (ADOT, 2019)

As for the Louisiana Department of Transportation and Development (LaDOTD) (LaDOTD, 2016), to increase design responsibility and retrieve additional project expenses caused by design consultants' carelessness or negligence, an E&Os policy has been established. First, the policy has stated some definitions that are related to the design E&Os, standard of care, and recoverable costs. According to this policy, the design issues that need to be addressed may arise from Plan and specification flaws that need fixing before the project is either constructed or used as intended, Contract administration violations due to delayed submission review and poor information response, and Issues with both cost estimation and inspection procedures throughout construction. It is worth mentioning that there is a separate document that is issued by the LaDOTD to deal with the quality of design, which states the procedures of the internal quality plan.

According to LaDOTD (2016), the DOTD would incur extra costs as a result of E&Os, which would have been avoided if the provided construction plans were correct. If the E&Os are defined before construction, the consultant is responsible for modifying the designs at his own cost. As a result, the process of addressing the E&Os problems and recovering the associated costs in accordance with the LaDOTD can be summarized as follows (LaDOTD, 2016):

1. *Identification and Notification:* If an E&Os issue arises during construction, the contractor informs the engineer, who then notifies the project and task managers to determine the nature of the problem. If it's a design issue, the design consultant suggests solutions at no extra cost to the Department. The engineer may direct a field change without initially notifying the Project Manager, but the consultant remains liable for the error.

2. *Investigation:* The Project Manager, with the Engineer and Task Manager, evaluates E&Os concerns and any breaches of standard care. If no error occurred, the consultant is not liable for costs incurred by DOTD. If recoverable losses are found, the Project Manager advises on the next steps.

3. *Decision Notification*: If the Chief Engineer's designee agrees with the Project Manager that costs are due to the consultant's negligence, the consultant is informed in writing about the costs, payment options, and potential appeals.

4. *Review Panel Meeting:* The consultant can request a Review Panel for an E&Os inquiry. The consultant presents findings, and the Panel, including DOTD Technical Staff, will determine responsibility and recoverable costs. The Chief Engineer informs the consultant of the outcome, which could lead to payment or legal disputes.

5. *Recovery and Collection:* DOTD can pursue compensation for damages after steps 3 or 4. The consultant can pay E&Os costs at any time, and upon agreement, a settlement is drafted and executed.

6. *Litigation:* If the consultant disagrees with the Review Panel's decision after step 5, DOTD may file a lawsuit. The Project Manager provides all relevant documentation to the DOTD Legal Section for further action.

It is worth noting that the consultant, through repayment for damages, and/or DOTD may agree to fix the problem at any step in the defined process, which ends the procedure.

The DOTD has had problems with the quality of finished plans supplied by consultants in the past. These plans were either incomplete, had quantity mistakes, or did not adhere to the DOT-specified design criteria. This project was initiated by DOTD with the primary goal of raising the quality of plans (Hamilton et al., 2020).

In the report by (Hamilton et al., 2020) For assessing the consultant's plan in DOTD, some practices were recommended for dealing with the consultant plans in DOTD. These recommendations are categorized into two groups: Plan Quality and Consultant Past Performance Rating (CPPR) system.

<u>Considering the Plan Quality:</u>

Summary of the Proposed Plan for Quality Assurance Manager Position in the Plan Checking Unit (PCU)

1. *PCU Leadership:* The Quality Assurance Manager may lead the PCU, focusing on improving QC/QA procedures, training personnel and consultants, ensuring compliance with audits, and managing monthly change order reviews.
2. *Document Review:* All DOTD manuals and documents related to QC/QA should be reviewed for consistency and necessary updates.
3. *Standard Practices for Plan Review:* Implement practices for reviewing comments and consultant responses, including proper formatting, prompt feedback, joint review meetings, and documentation of decisions and QA audits.
4. *QC/QA Training:* Provide comprehensive training for in-house personnel, consultants, and LPAs to ensure uniformity in QC/QA practices.
5. *Consultant QC/QA Plans:* Require consultants to develop formal QC/QA plans for projects of specific sizes.
6. *Constructability-Biddability Review Team:* Consider forming a review team to engage early in project development to improve plan quality.
7. *Post-Construction Review Process:* Strengthen the post-construction review by conducting thorough evaluations and collaborative feedback sessions.
8. *Consultant Fee Proposals:* Introduce separate line items for QC/QA in consultant fee proposals to facilitate better focus on QC/QA tasks and tracking hours worked.
9. *Annual Design Conference:* Organize an annual conference focused on design quality, involving DOTD personnel and consultants.

Similarly, the Consultant Past Performance Rating System for the DOTD outlines several key recommendations to enhance evaluation procedures. A guide will be created to clarify performance rating processes, defining levels such as "outstanding" and "satisfactory," referencing existing rating definitions. Training will be provided to ensure uniformity among raters in consultant evaluations. To improve consistency, it is suggested that the number of performance ratings be reduced to two per year, conducted at major milestones, with a process to ensure timely completion. Additionally, simplifying the rating criteria and developing objective quality measures are advised. Clear performance expectations should be established at project kickoff meetings, followed by mandatory consultant meetings post-evaluation, and a notification system should be implemented to streamline the process.

Various state DOTs have established procedures to handle design E&Os in consultant projects, focusing on quality control, accountability, and resolution processes. California DOT (Caltrans) emphasizes a detailed checklist for quality control in design and implements a structured review process involving a Management Review Panel and the Chief Engineer to address design breaches.

Montana DOT follows a stepwise approach to identify and resolve errors, track consultant liability, and pursue payment recovery through a structured dispute resolution process.

Ohio DOT requires consultants to promptly correct errors without additional compensation and follows a thorough investigation and review process involving multiple department officials before referring disputes to the Consultant Resolution Board.

North Dakota DOT (NDDOT) classifies errors based on project phases and escalates unresolved cases to an E&Os Review Board (EORB), which has the authority to take legal action if necessary.

New Mexico DOT (NMDOT) holds consultants accountable for design accuracy, requiring liability insurance and resolving disputes at the lowest possible level, escalating to the Claims Review Board if needed.

Utah DOT (UDOT) utilizes a Quality Assurance/Quality Control (QA/QC) program and a consultant checklist for resolving disputes through collaboration. They recover costs for negligence when necessary, with final decisions being made by the Claims Review Board.

WSDOT follows a multi-step process involving area liaisons, executive reviews, and potential legal action if disputes remain unresolved.

Across all DOTs, common principles include ensuring design accuracy, establishing formal procedures for addressing errors, holding consultants accountable for additional costs, and implementing structured dispute resolution processes to mitigate financial and legal risks. **Appendix A** provides more details on the Policies and Procedures from these State DOTs**.**

2.10 Chapter Summary

The transportation sector is one of the most important sectors that influences a country's economy and requires significant investment. Many transportation projects are experiencing continuous schedules and cost overruns. Several studies have conducted a detailed analysis of the factors that lead to cost and schedule overruns in construction and highway projects. The analysis conducted was based on either previous studies or on real projects nationally and globally. The main factors that cause overruns in many projects were Design changes, Design E&Os, inaccurate quantity estimation, poor communication between project stakeholders, lack of proper information exchange, and scope changes. As agreed by most of the previous studies, Design E&Os and design changes were the most contributing factors.

Design E&Os are one of the main factors that lead to severe consequences if they are not discovered during the early project phases (design phase). Many interrelated causes contribute to highway project E&Os. Knowing the reasons will help to avoid or lessen the impact of similar problems in future projects. Causes of design E&Os can be summarized as follows:

a) The project complexity, where highway projects involve multiple stakeholders, can lead to lack of communication and information transformation.
b) Scope: inadequate scope or plans lead to incomplete project requirements; Key features may be missed during the design phase if the scope is not clearly defined.
c) Schedule pressure and cost constraints: Design E&Os are more probable when there is a lot of pressure to complete the project on time and budget is tight.
d) Inexperience of the design team: Design errors can occur when inexperienced designers or designers without relevant skills neglect significant aspects.
e) Inadequate review and quality control: poor quality control process and inadequate reviewing of the design documents lead to undiscovered errors.
f) Non-compliance with the regulations: due to the changed regulations and standards that lead design noncompliance.
g) Poor communication between project stakeholders leads to misunderstanding and missing information leading to errors.
h) Inadequate risk assessment: Failure to identify and address potential risks during the design phase can lead to design E&Os.

Design E&Os in highway projects can have significant consequences, impacting various aspects of the project, the environment, and public safety. Key consequences include costly reviews, rework, and delays during construction caused by these design issues. Discovering design errors after construction has begun results in much higher costs compared to identifying them during the design phase. Additionally, poorly planned highways can endanger drivers and passengers, as accidents and injuries can increase due to inadequate intersection design, insufficient signage, and poor sight distances. Furthermore, design errors that lead to accidents or property damage may create legal liabilities for the responsible parties, resulting in expensive lawsuits and reputational harm.

Mostly, the impact of design E&Os is assessed through the quantification of reworks, cost overruns, and schedule overruns. However, by going through the previous studies and governmental documents, it was found that most of the studies (Hwang et al., 2019; Shrestha & Maharjan, 2018) focused on using different statistical and systematic models for analyzing the costs and delays caused by reworks from previous projects. Only a few studies have developed models to be utilized for predicting the project performance using system dynamics (Han et al., 2013; Li & Taylor, 2014) and ANN models (Pewdum et al., 2009; Trach et al., 2021). Different practices for reducing rework were proposed by (Love et al., 2004) and (Safapour & Kermanshachi, 2019)

Also, it was observed that BIM adoption in the construction industry was less than that in highway projects. However, BIM has the potential to greatly improve the efficiency, waste reduction, and sustainability of infrastructure projects throughout their lifecycle. Few studies have examined the application of BIM to highway construction projects. Such as: (Fanning et al., 2015; Hwang et al., 2019)) have compared the impact of BIM in two highway projects, and it was found that it can yield cost savings from reducing change orders and rework. Moreover, as reported by (Mitchell et al., 2019). The utilization of BIM was included in the MDOT project delivery system, and the report stated the cost benefits and recommendations for including BIM in the contractual documents. Furthermore, a report by Reeder & Nelson (2015) enumerates design and employment needs that agencies must address while employing 3D engineered modeling. The chapter mentions insights gained by the Iowa DOT during its endeavor to fully integrate 3D technology in the design and construction phases of highway infrastructure.

Researchers have recommended different practices to mitigate the consequences of design E&Os in highway projects, such as conducting thorough design reviews, investing in experienced and qualified design teams, using advanced design software and tools, and prioritizing collaboration and communication among all stakeholders. Early identification and rectification of design issues can significantly reduce the impact of errors on the project's overall success and public safety. Moreover, the most recommended practices involved the contractor through the early design phase and conducting a formal review process, which could be a design review or a constructability review.

As for dealing with Design E&Os, it was found that most of the issued DOT documents were stating the procedures for dealing with design E&Os and cost recovery practices from the legal aspect only. There was a lack in including new practices that involve new technological aspects.

CHAPTER 3: METHODOLOGY

This chapter presents an overview of the methodology employed in the study, which is structured into four distinct phases as illustrated in Figure 25. The phases include:

1. Literature Review: To find out what the current studies suggest and what is the need for conducting the study.
2. Change Order Data Analysis: To quantify the frequency, impact, and types of design E&Os in the department records.
3. Surveys and Interviews with WYDOT Personnel: To capture the engineers' perspectives on the design E&Os.
4. National Survey with State DOTs: To assess what the DOTs across the US are doing for their quality control measures, their policies and procedures, and design checklists, and compare them with the WYDOT data, and gain recommendations from it.

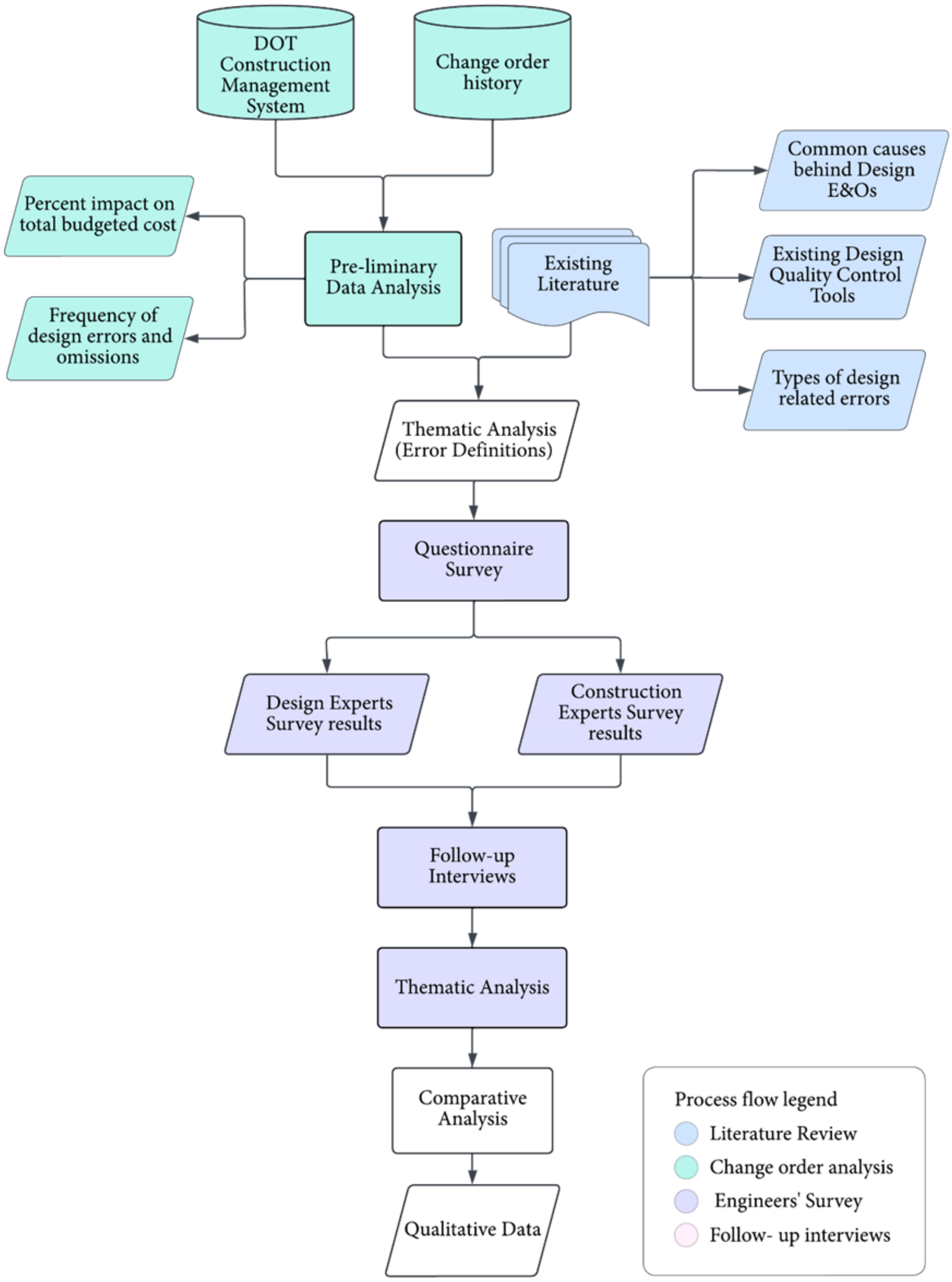

Figure 12: Process Flowchart

To achieve the research objective, a systematic approach was adopted, which involved analyzing change order data from WYDOT, conducting a questionnaire survey, and conducting interviews. The literature review played a crucial role in shaping the questionnaire's development, ensuring that it was informed by existing knowledge in the field.

At the core of this methodology is an initial analysis of change order history, which provided valuable quantitative data on prevalent types of design E&Os, the underlying reasons for these errors, and their overall impact on project budgets. This analysis involved a detailed examination of the total change orders associated with specific contracts, as well as the frequency of the identified errors, all of which are depicted in Figure 25.

The comprehensive change order records were categorized into two main groups: those resulting from design E&Os and those unrelated to them. Further, the shortlisted design-related change orders were further classified into five major design E&Os-related changes.

Each documented change order included an explanation of the associated costs, detailing why the change order was initiated and describing the project. The research team categorized the change orders based on the cost justifications and existing literature regarding common patterns observed in previous studies. These patterns were assessed to determine whether they were related to errors and omissions during the design phase. The Construction Management System (CMS), which records project details, was used to extract and populate the spreadsheet with the change order records and to analyze the impact of the change orders. The project details extracted included the original project/contact amount, the revised amount, the actual cost for the project, the cost associated with the change order, the total change order cost corresponding to the project, the number of change orders in the project, and other relevant information.

To quantify the impact, we calculated the change order percentage (Eq. 1) and cost deviations (Eq. 2) using specific formulas. The interrelationships among these phases, as outlined in Figure 25, provide a clear visual representation of how each component contributes to the overall understanding of the impacts of design E&Os in construction.

$$Change\ Order\ \% = \frac{Change\ Order\ Amount}{Original\ Contract\ Amount} * 100 \ldots\ldots \text{(Eq.1)}$$

$$Cost\ deviation\ \% = \frac{Revised\ Amount - Original\ Amount}{Original\ \ Amount} * 100 \ldots \text{(Eq. 2)}$$

The reasons and cost justifications behind the studies were thoroughly studied to identify the reasons behind the change order and classified accordingly. The study's foundation was built on curated definitions from the change order analysis and their corresponding results, which were essential for developing the surveys in subsequent phases. A structured approach was employed to cross-validate findings and results through a combination of surveys and interviews, carried out in two distinct stages for comprehensive examination and validation.

Stage 1: Construction/ Field Engineers

1. **Survey Development:** The survey was designed based on findings from the change order analysis. It assesses the perspectives of construction personnel regarding change orders and their cost impacts due to design errors and omissions (E&Os). The survey examines the phases of projects where these errors have been identified, the schedule impacts resulting from them, the personnel's familiarity with and effectiveness of various quality control tools, their involvement in project reviews, and the sufficiency and effectiveness of the DOT's EDMS.
2. **Survey Distribution:** The survey was administered to construction and field engineers.

3. **Follow-up Interviews:** Follow-up interviews were conducted based on the survey responses to gather additional insights. These interviews included questions about the lessons learned from the participants' projects, their success stories, as well as common errors they encountered and the reasons behind them.

Stage 2: Design Engineers

1. **Survey Development:** The survey was specifically refined for design engineers, incorporating relevant findings and insights. This comparative study focused on the causal variables of DQC tools, including Falcon and other DOT's EDMS.
2. **Survey Distribution:** This refined survey was distributed to design engineers.
3. **Follow-up Interviews:** Additional interviews were conducted to obtain clarification and validate findings.

This two-stage approach ensured that insights from both construction and design perspectives were systematically validated, as shown in the method flowchart in Figure 25.

The surveys were created using the Qualtrics online survey platform, informed by analyzed change order data and a review of existing literature. The literature review highlighted available tools and identified some perceived causal factors and intended impacts. The change order analysis informed us of the effects of design E&Os on cost and their frequency, which was validated in the survey with DOT personnel. The primary goal was to capture respondents' experiences related to E&Os, exploring the causes, effects on cost and schedule, and the effectiveness of existing DQC tools in addressing these issues. Each survey was organized into specific sections that focused on different aspects of the research objectives. The results were thoroughly analyzed, leading to the generation of follow-up questions for semi-structured interviews in both phases.

To delve deeper into the survey results and obtain feedback from the engineers, the research team conducted semi-structured interviews. These interviews aimed to gather rich, detailed insights into the engineers' experiences and perspectives on E&Os, ensuring consistency while also allowing flexibility to explore unique responses.

The interviews were conducted via Zoom, each lasting approximately 30 minutes. Participants were well-informed about the study, as the interview questions were included in the invitations, and an overview was provided at the start of each conversation. The interviews were transcribed and analyzed using thematic analysis with Atlas.ti, focusing on recurring themes from the discussions. Thematic analysis, a qualitative research method, is outlined in Braun and Clarke (2006), which includes a step-by-step process of understanding the studied data, generating initial codes, identifying common themes, grouping codes into themes, and defining and naming the themes (Bowen et al., 2012). The transcripts were assigned codes based on the identified themes during the conversations, informed by the change orders and the literature.

During the analysis of the interviews, the transcripts were thoroughly reviewed to identify key points, with appropriate codes assigned to significant statements. Related codes were then grouped together to identify broader themes, as defined for the change order data and the literature. Each code group included subcodes based on relevant phrases that contributed to the development of these themes. These codes were subsequently exported and used to analyze interviews with design personnel, facilitating a comprehensive comparison of the results.

Infographics based on the findings from the change orders and the surveys are in **Appendix BI**. Insights gained from the interviews were used to develop a design checklist. Before creating this tool, an additional survey was conducted to identify trends among state DOTs across the United States regarding their collaboration, data management practices, and the use of design checklists. This effort aimed to enhance understanding of industry-wide practices and challenges related to E&Os in checklists.

The design checklist was developed using references from other state DOTs, as detailed in Chapter 7. The development of the checklist incorporated insights from engineers at the DOT, as well as a national survey that informed us of the practices used by other state DOTs. The first step of the process involved gathering WYDOT Design Standards & Guidelines and identifying key design checks. The survey conducted with various state DOTs provided insights into their approach to design reviews, focusing on their quality control processes, key checks, and document management platforms. The results revealed that many DOTs utilize structured platforms for document reviews, with ProjectWise being the most commonly used platform for document management and design reviews. Additionally, there is a focus on incorporating practices from other DOTs to enhance overall effectiveness; these were then used to structure the checks in the updated checklist, including automation of the task using Excel Visual Basic for Applications (VBA).

CHAPTER 4: CHANGE ORDER DATA ANALYSIS

The initial task of this research project was to evaluate change order data. This evaluation utilized WYDOT's Construction Management System (CMS) and an Excel sheet detailing the records of the change order data from WYDOT to collect records of change orders. The comprehensive process documented 960 change orders from mid-2016 to late 2023. Each change order was detailed in the document, including the project/contract number, description, and cost justification. Based on the cost justification and the definitions provided in Table 11, the change orders were classified into two main categories: design E&O-related changes, as well as others. There were a total of 960 change orders recorded, of which 138 were classified as change orders related to design E&Os. The design errors category was further divided into five subcategories: estimate errors, omissions, plan errors, existing utilities, and misinterpretations/misrepresentations, drawing from Markow (Markow, 2009) and various state highway agency websites.

The analysis utilized a systematic inductive approach to organize and define themes that highlighted concepts related to design errors. For example, two locations of the HDPE liner pipe in the project were mistakenly marked as being 36 inches in size; however, the change order description revealed that they were forty-two inches and 48 inches. Consequently, a keyword was assigned to indicate the discrepancy between the site conditions and the plans. Similar issues were grouped into sub-themes, which were then arranged into broader themes informed by insights from existing literature, as illustrated in Table 11.

4.1 Error Types and Examples

Table 11 presents the definitions of these errors used in the survey, along with generalized examples derived from the actual change order data. A combination of Grounded Theory (Brodsky, 1968), and Thematic Analysis (Braun & Clarke, 2006) were utilized to systematically analyze and categorize design errors. Grounded Theory involves developing insights directly from the data through a process of constant comparison, where different data points are examined for similarities, differences, and patterns. In this study, this approach is used to assess change orders and their cost justifications, allowing for a structured evaluation of recurring issues. This was followed by thematic analysis, which was used to identify and categorize recurring patterns within the data.

Table 11: Examples of Design E&O and Definitions

Design Errors (Themes)	Definition	Keywords	Sub-themes	Sample Example from DOT Data
Estimate Error	Error resulted from a massive variance between the estimated quantity of materials, components, or work items and the actual quantity required in construction, which resulted in change orders.	Plan quantity overrun/ underrun.	Error in quantity estimates.	More unclassified excavation was required than initially estimated to construct lateral support.
		Increase/decrease in item quantities.		
		Error in quantities		
		Miscalculation of plan quantities.		
		Addition/deletion of items due to incorrect estimates.		
		Wrong estimates.	Error in estimates during design.	
Misinterpretations/ Misrepresentations	Mistakes or inaccurate interpretations of existing site conditions.	Wrong recorded distances, placements, and item quantities.	Differing conditions from as-constructed plans.	Misidentification of the size and location of existing pipes.
		Incorrect identifications of structures.		
		Misidentification		
		Missed site condition recordings.		
		Different site conditions to mentioned in the plans.		
			Degradation on site not recorded.	
			Misidentification	
Plan Error	Inaccuracies, discrepancies, or mistakes in the	Wrong plan notes	Plan errors	Construction documents
		Plan errors		
		Shelving of plans,		

	engineering or construction plans.	Incorrect dimensions shown.		call for incorrect plant mix depth or incorrect dimensions.
		Wrong specifications shown on the plans.		
		Inconsistency across plans.	Wrong alignments, depiction, notes.	
		Wrong ground levels shown.	Misses out significant details.	
Omission	Essential elements, details, or requirements that were unintentionally left out or not adequately addressed in the plans and specifications.	Missing from plans.	Inadvertently left out.	Missing project features/scope (e.g., fencing, signage, etc.) That must be included per standard specifications.
		Missing rebar quantities.		
		Summaries omitted.		
		Missing bid items.		
		Mistakenly omitted.		
		Inadvertently left out.	Summaries omitted.	
		Missing temporary elements.	Missing items.	
Unknown third party/ utilities	Unknown/unforeseen site conditions or existing utilities that might lead to modifications in the design or relocation, eventually causing a change order. Example: Relocation of service points on the new interchange road due to existing power lines.	Changes in project limits.	Existing lines.	Relocation of service points on the new interchange road due to existing power lines.
		Incompatible existing utilities.		
		Existing pipelines.		
		Unforeseen utility issues.		
		Design changes due to existing elements.		
		Private irrigation lines.	Project limit changes due to utilities.	
		Changes in quantities due to existing structures.	Design change due to existing utility.	

Below is a description of each error category and a real-life change order project example to help better understand each error type.

4.1.1 Omission

Omissions represent elements, details, or requirements that were unintentionally left out or not adequately addressed in the plans and specifications (MCDOT, 2021; ADOT, 2019). Of the sample size of 138 design errors and omissions-related errors, 24, almost 17 percent of them, were omissions. Examples**:** Missing project features/scope that must be included as per WYDOT specifications that will lead to a change order (i.e., fencing, signage, etc.).

Sample change order project: SIB-ACNHPP-N104066 (Guernsey - Fort Laramie (Guernsey East)

Contract description:

- Bituminous pavement surfacing, traffic control, bridge rehabilitation, grading, fencing, milling, signing, and miscellaneous work on approximately 4.60 miles on US 26, beginning at RM 15.50 between Guernsey and Fort Laramie.
- Addition to the contract value for the necessary fence over the large culvert location that was omitted in the contract.
- Change order amount: $26,087.50
- Original contract amount: $3,733,917.00
- Total of all change orders in this project: $37,333.00
- Percentage (percent) change in change order due to this change: 69.88 percent
- Percentage (percent) change in total contract amount: 0.7 percent

4.1.2 Estimate Error

Errors resulted from variances in the estimated quantity of materials, components, or work items and the actual quantity required in construction, resulting in change orders (Lewis Jr & NSPE, 1999; Vashishtha et al., 2020). An example of estimate error is more unclassified excavation was required than originally estimated to construct lateral support.

Sample change order project: STP-RF-W352008 (District 3 R/W Fence (Cora North)

Contract description:

- Removal and replacement of right-of-way fence and miscellaneous work at various locations in Transportation District 3.
- Significant increase in the number of brace and end panels from the one stated in the plans.
- Change order amount: $47,168.12
- Original contract amount: $767,692.00
- Total of all change orders in this project: $42,168.12
- Percentage (percent) change in change order due to this change: 111.86 percent

(111.86 percent because some change orders also lead to a decrease in the overall cost.)

- Percentage (percent) change in total contract amount: 6.14 percent

4.1.3 Plan Error

Plan errors are inaccuracies, discrepancies, or mistakes in the engineering or construction plans may lead to change orders (MoDOT, 2002; TxDOT, 2000). An example of plan errors is construction documents call for incorrect plant mix depth or dimensions that may lead to a change order.

Sample change order project: NHPP-N403007 (Lusk - Van Tassell (West Section)

Contract description:

- Grading, draining, milling plant mix, placing blended base, bituminous pavement surfacing(recycle), chip seal, electrical and miscellaneous work on approximately 21.50 miles on US 20 beginning at RM 41.74 between Lusk and Van Tassell.
- The existing plant mix depth was around 9" as opposed to the 3"-7" as mentioned in the plans.
- Change order amount: $48,140.00
- Original contract amount: $13,413,396.28
- Total of all change orders in this project: $48,140.00
- Percentage (percent) change in change order due to this change: 100.00 percent
- Percentage (percent) change in total contract amount: 0.36 percent

4.1.4 Misinterpretations/ misrepresentation

Misinterpretations/misrepresentations are the mistakes or inaccurate interpretations of existing site conditions that lead to change orders or schedule overruns (FHWA, 2022). An example of this error is the misidentification of the size and location of existing pipes.

Sample change order project: HSIP-200057(Jackson - Wilson (WYO 22 & WYO 390)

Contract description:

- Electrical systems and miscellaneous work on WYO 22 & WYO 390 at RM 4.06 between Jackson and Wilson.
- Under the item Traffic Control Signal, the subsidiary item was listed as a quantity of four when it should have been five.
- Change order amount: $17,265.75
- Original contract amount: $99,051.30
- Total of all change orders in this project: $17,265.75
- Percentage (percent) change in change order due to this change: 100.00 percent
- Percentage (percent) change in total contract amount: 17.43 percent

4.1.5 Existing Utilities

Unknown/unforeseen site conditions or existing utilities that might lead to modifications in the design or relocation, eventually causing a change order. An example of this error is the relocation of service points on the new interchange road due to existing power lines.

Sample change order project: STP-2000048 (Wilson - Idaho State Line (Vehicle Arrestor System)

Contract description:

- Grading, draining, placing crushed base and bituminous pavement Surfacing, plant mix wearing course, precast wall component system, electrical and miscellaneous work on 0.26 mile on WYO 22 beginning at RM 7.57 between Wilson and the Idaho State Line.
- The barrier wall profile was found to be incompatible with the crash attenuator. WYDOT Bridge Dept. designed a new section of barrier wall to accept the attenuator and have it function properly.
- Change order amount: $74,651.07
- Original contract amount: $3,587,530.20
- Total of all change orders in this project: $65,071.32
- Percentage (percent) change in change order due to this change: 114.72 percent
- Percentage (percent) change in total contract amount: 2.08 percent

4.2 Change Order Analysis Results.

Out of the extensive dataset of 960 change orders, 138 were identified as design-related errors for in-depth analysis. This analysis included details regarding the change order costs, original budget, revised costs, actual costs of the projects, and contracts from the CMS. The analysis yielded the following results:

1. Less than 15 percent of the change orders were due to errors and omissions, amounting to a total of $7,560,137.40 positive and $194,350.67 negative change order values.
2. The study found that certain projects experienced up to ten change orders, with causes ranging from design errors to other factors. Out of 960 change orders, roughly 25 percent had no cost impact, 58 percent resulted in increased costs, and 15 percent led to decreased costs.
3. Cost deviation from the original estimated budget of the projects due to design errors and omissions ranged from not significant at all (<1 percent) to extremely significant at the staggering change in the original bid amount of as much as 10 percent of the budget. This sampled data result was verified from the survey results, which indicated that the change orders due to design errors and omissions mostly ranged from 0 to 1 percent of the original budget.
4. The change order records analysis showed that out of the 138 change orders related to design errors, 56 percent were due to plan and estimate errors (28 percent each), while the remaining 40 percent were caused by other factors (7 percent misinterpretation or misrepresentation of job site conditions, 17 percent omissions, and 20 percent existing utilities).

The figures below differentiate between change orders caused by design E&Os and those that are not. Figure 13 shows an increase in change orders in 2019 compared to previous years; however, this increase is not significant when considering the dollar amounts relative to the projects awarded that year, as illustrated in Figure 14. 2019 shows a significant rise in dollar amount because of change orders, while the following years weren't as affected, resulting in a linear trend in change orders.

The data in Figure 13 shows a fluctuating trend in change orders related to design E&Os from 2016 to 2023, with a significant peak in 2019, reaching $2,408,239.76—markedly higher than any other year. Prior to this peak, costs varied considerably. In 2016, the costs were high at $1,650,478.75, followed by a sharp decline in 2017 to $376,383.92. There was a moderate increase in 2018, with costs rising to $883,919.38, leading up to the 2019 surge. After 2019, a clear downward trend emerged, with costs falling to $631,340.63 in 2020 and stabilizing between $588,293.41 in 2021 and $701,833.61 in 2023. This indicates that although change orders related to design E&Os have decreased since 2019, they have not been eliminated, and they have settled into a relatively stable range over the past three years.

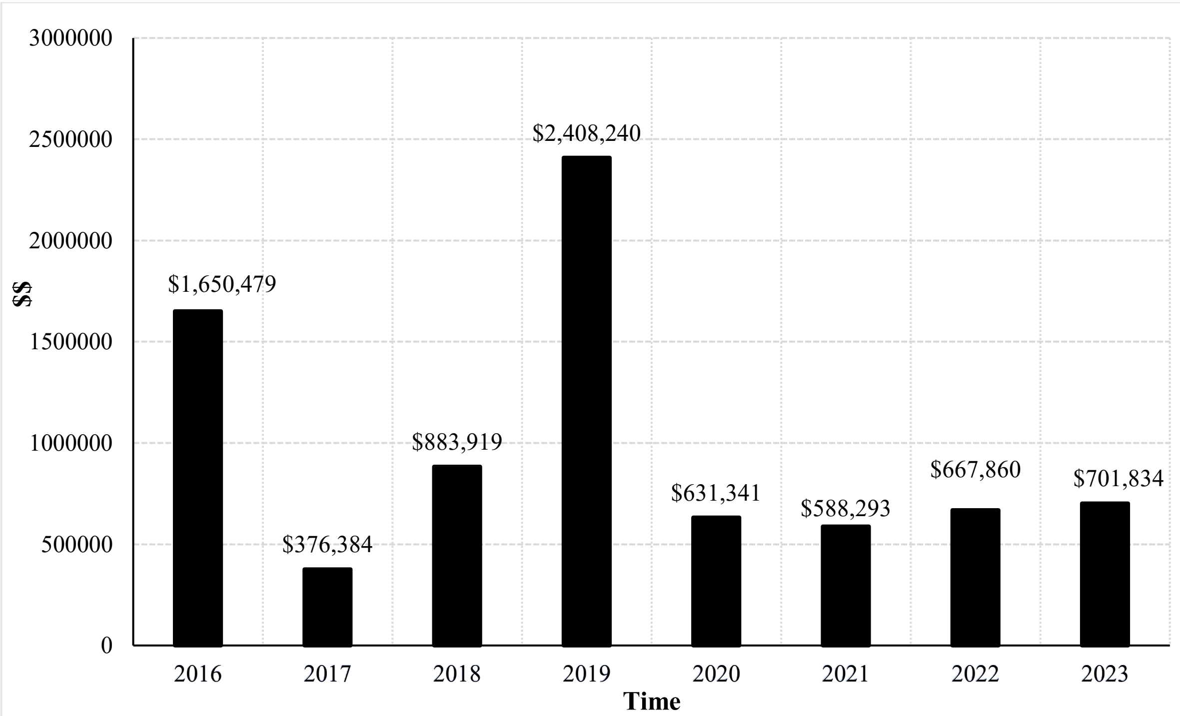

Figure 13: Trend of change orders due to design errors and omissions

Building upon the previous analysis, Figure 14 continues to illustrate the financial trends in project expenditures while providing a direct comparison of change order values over the year against the Original, Revised, and Current Amounts. As observed earlier, project costs have seen significant fluctuations, with a sharp increase starting in 2019 and peaking in 2020 and 2021. This trend remains consistent in the current figure, where the original amount serves as the baseline, while the revised and current amounts reflect cost adjustments over time. The change order values, shown separately, highlight their contribution to these increases, reinforcing their role in project cost escalation. In several years, particularly 2020 and 2021, the change orders align closely with the difference between the Original and Revised amounts, suggesting that these modifications were key drivers of cost changes. While 2022 shows a slight decline, the 2023 increase suggests continued financial adjustments or new project phases. This comparison underscores the significant impact of Change Orders on project budgets and the ongoing challenges of cost control in large-scale projects.

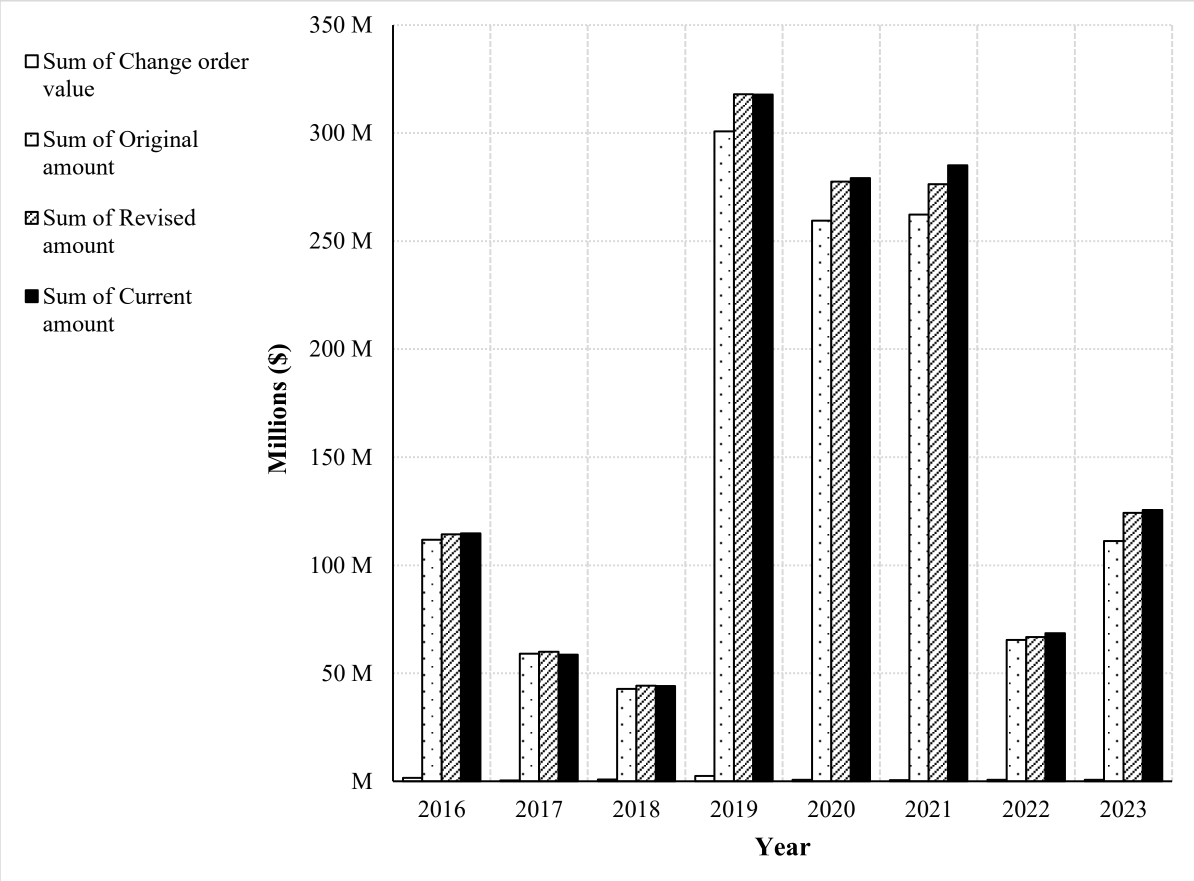

Figure 14: Trend of original budgets, revised and actual dollar value of projects per year

Figure 15 shows the trend of change orders unrelated to design errors over 8 years. The graph shows a linear uphill increase in the dollar amount resulting from change orders unrelated to design errors, which peaked at $7.3 million in 2022 before experiencing a sharp decline to $586,560.46 in 2023. This pattern differs significantly from change orders associated with design errors, highlighting key distinctions. The overall magnitude of non-design-related change orders is considerably higher, with certain years, particularly 2022, exceeding $7 million, while design-related change orders have remained within a lower range. Moreover, the fluctuations in costs reveal contrasting types; design-related change orders have shown steady increases followed by stabilization, whereas non-design-related change orders peaked sharply in 2022 and then drastically dropped in 2023. The significant reduction in 2023 for non-design-related change orders may indicate improved project controls, fewer unforeseen conditions, or enhanced initial planning. In contrast, design-related change orders showed moderate fluctuations, indicating a persistent challenge over the years, which highlights the need for action to mitigate the impacts. Initially, from 2016 to 2019, costs for non-design-related issues rose steadily. The years 2020 and 2021 saw notable fluctuations, with a dip in 2020 followed by a sharp increase in 2021. Overall, while non-design-related change orders have exhibited greater financial impact and more extreme fluctuations, design-related change orders have followed a more predictable trajectory. This highlights the varying nature of project uncertainties, suggesting that while design errors contribute to predictable cost overruns, external and operational factors can lead to even larger and more unpredictable changes in construction project costs.

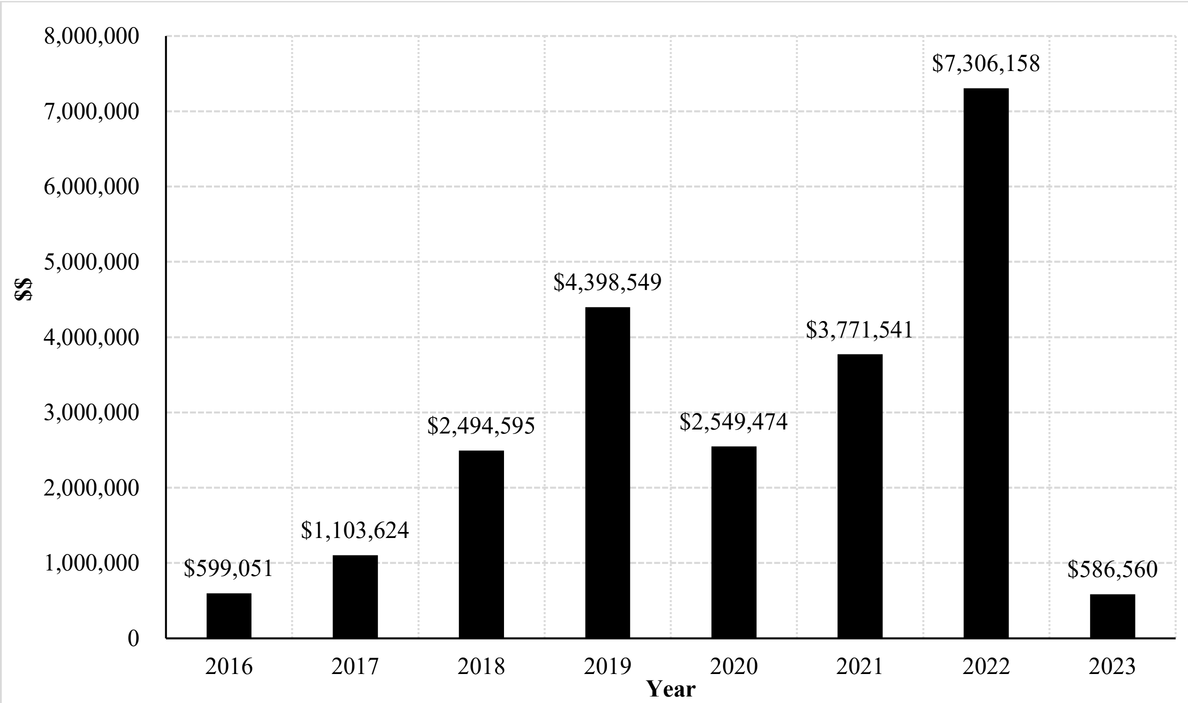

Figure 15: Trend of change orders unrelated to design error

Figure 16 illustrates the frequency of design-related errors among the 960 analyzed change orders, revealing a total of 138 cases linked to design errors. The most common issues were Plan and Estimate Errors, each occurring 38 times and representing 28 percent of the total cases. Existing Utilities Errors accounted for 28 occurrences (20 percent), while Omissions contributed to 24 cases (17 percent). Additionally, misinterpretation or misrepresentation of job site conditions was noted in 10 cases (7 percent). This analysis underscores the critical impact of inaccurate cost estimations, flawed planning, and oversight in design documents on project costs. The data shows that estimation errors and planning errors are the primary causes of cost overruns, indicating that enhancing estimation techniques and planning accuracy could mitigate financial impacts.

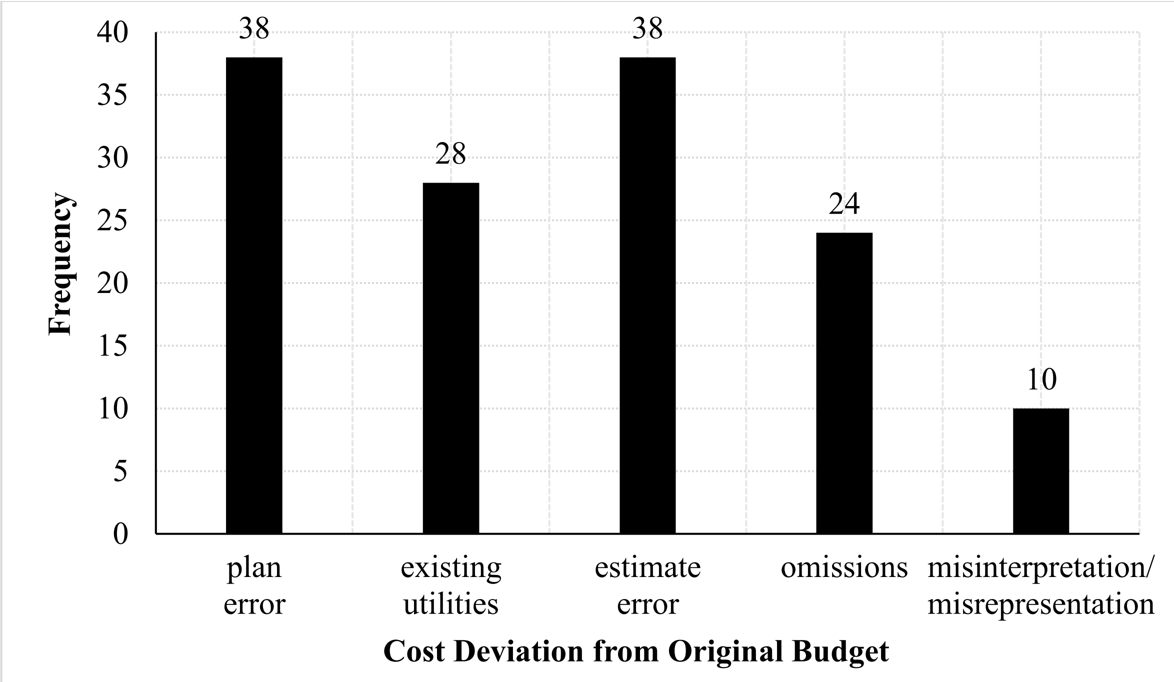

Figure 16: Frequency of design-related errors

Figure 17 presents the frequency distribution of cost deviations from the original project budget that occurs due to design errors and omissions. This visualization highlights the range and frequency of cost impacts across 138 projects, offering valuable insights into budget management. On the x-axis, we see the various ranges of cost deviations from the original budget, while the y-axis indicates the frequency of occurrences within each deviation range. The analysis reveals that the majority of cost deviations—71 occurrences—fall within the 0–1 percent range. This suggests that while design errors are commonplace, they typically result in only minor increases to the budget. A smaller yet noteworthy portion of deviations—21 occurrences—falls between 1–3 percent, indicating a moderate impact on the budget. Furthermore, 10 occurrences are documented in the 3–5 percent range, and 16 instances surpass the 5–10 percent threshold. These figures highlight that some design errors can lead to significant budget overruns. Interestingly, there are only 3 cases where deviations exceeded 10 percent, underscoring the rarity of extreme budget overruns due to design flaws. Additionally, the analysis includes 17 instances of negative deviations, reflecting situations where actual costs were lower than anticipated. These cases may result from budgeting overestimations or successful cost-saving strategies. Overall, this distribution of cost deviations offers crucial insights into the impact of design errors on financial planning and project management.

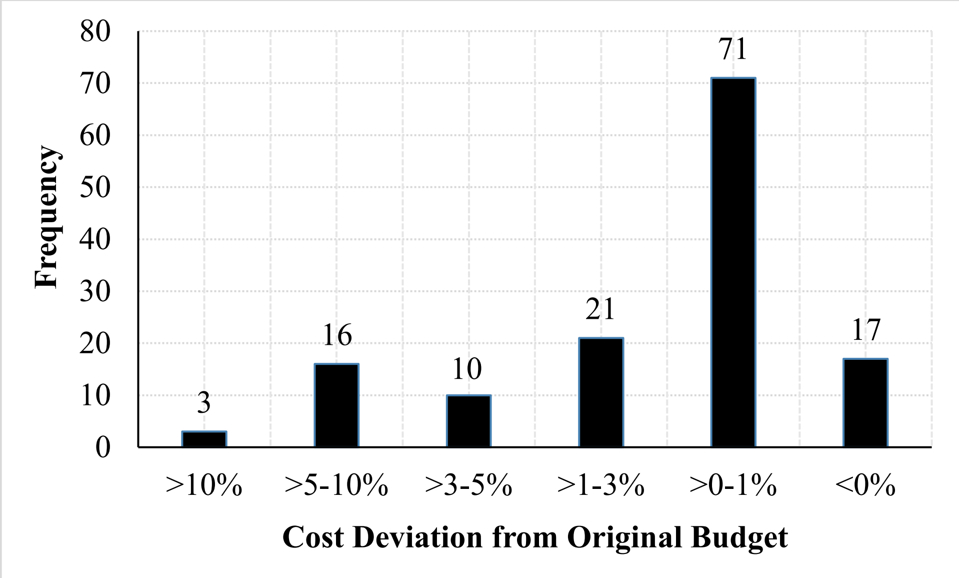

Figure 17: Cost deviation from the original budget

Figure 18 outlines the maximum and minimum change order values resulting from estimate errors, plan errors, omissions, misrepresentations, and errors caused by existing utilities. The highest change order is due to estimate errors, shortly followed by plan errors. Estimate errors present the highest cost impact in project management, with a maximum of $520,408.20 and a mean of $115,338.85, highlighting the severe consequences of inaccurate cost estimates. Omission and planning errors also significantly affect costs, but tend to lead to lower average impacts compared to estimated errors, with mean values of $50,572.98 and $32,820.87, respectively. Misinterpretations and conflicts with existing utilities result in relatively lower financial repercussions, with maximum values of $119,667.80 and $131,950.00, respectively. Notably, the negative minimum values across these categories indicate instances where adjustments allowed for cost recoveries, underscoring the potential for project optimizations. Overall, the substantial gaps between maximum and minimum values illustrate the high variability in the financial impacts of different errors, emphasizing the importance of accurate planning and cost estimation in projects.

The mean change order values serve as a more reliable indicator of typical costs, providing a clearer picture than the extreme values alone. This illustrates that while some error types carry a higher risk of incurring significant costs, the mean values help to understand what expenses can generally be expected. Overall, implementing effective mitigation strategies could significantly reduce the variability and help manage costs associated with high-risk errors.

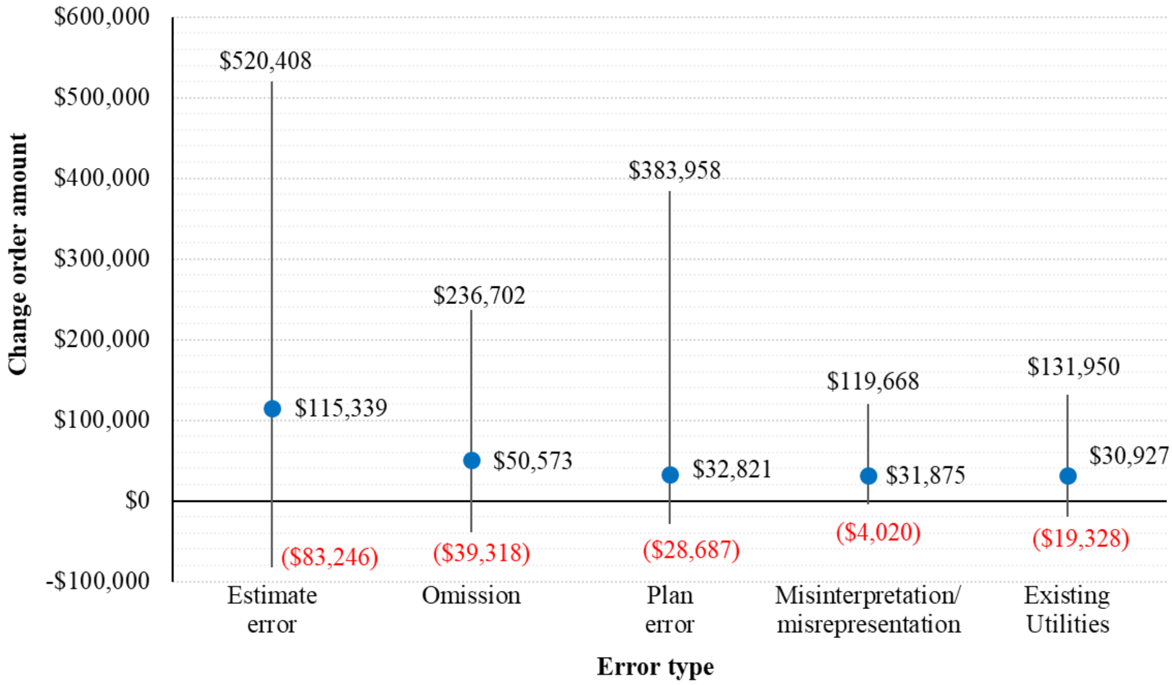

Figure 18: Maximum and minimum change order values due to Design E&Os

4.3 Chapter Summary

The analysis of change order data from WYDOT's Construction Management System, covering mid-2016 to late 2023, has uncovered crucial insights into design-related errors in construction projects. By categorizing these errors into design errors and omissions, and further identifying subcategories like estimate errors, misinterpretations, and plan inaccuracies, the research pinpointed key areas for improvement.

Out of a dataset of 960 change orders, 138 were linked to design-related errors, with 56 percent resulting from inaccuracies in plans and estimates, each contributing to 28 percent of the total. Other causes included misinterpretations of job site conditions (7 percent), omissions (17 percent), and issues related to existing utilities (20 percent). Notably, less than 15 percent of the change orders were due to design errors and omissions (E&Os), accounting for approximately one million dollars in positive change order values, with negative values totaling around two hundred thousand dollars. The study also found that some projects experienced up to ten change orders, which were not directly tied to design E&Os. Interestingly, nearly 25 percent of the change orders showed zero change order values, indicating contractual or schedule modifications unrelated to costs. Overall, 58 percent of the change orders had positive values, while only 15 percent led to minor negative impacts of about 2 percent. The most common cost deviations fell between 0 percent and 1 percent, although a few projects faced cost changes affecting their budgets by as much as 16 percent.

Utilizing Grounded Theory and Thematic Analysis, the research provided a structured framework for understanding these recurring issues. The findings highlight the necessity for improved planning accuracy, thorough documentation, and communication of site conditions.

By addressing these identified error types, future construction projects can benefit from more efficient execution and better cost management.

CHAPTER 5: SURVEY AND INTERVIEW INSIGHTS FROM WYDOT CONSTRUCTION PROFESSIONAL

5.1 Introduction

Construction projects are complex activities that require thorough planning and execution to ensure success. Despite meticulous planning, design flaws and pre-construction concerns develop, resulting in schedule delays, cost overruns, and poor project quality. Recognizing the importance of detecting and mitigating these difficulties and evaluating the impacts of these errors on schedule and project cost, a comprehensive approach was taken to gain insights from industry specialists on frequent design flaws, scheduling consequences, and best practices for error prevention through both a survey and qualitative interviews.

The survey, developed based on the trends of the change orders in closed and active WYDOT projects from 2016 to 2023, acted as a foundational element in understanding the occurrence and severity of design errors encountered in construction projects in the field. The change order history allowed the research team to identify the common design E&Os and their relative impacts on the project cost; analysis of structured data revealed significant trends and patterns in the type and frequency of design errors, including their underlying causes and effects. The approach provided the research team with a solid framework for further investigation, which allowed them to create groundwork for further exploration.

The survey responses shed light on several errors besides the ones shortlisted from the change order history. This chapter comprehensively examines design flaws, their impact on cost and schedule, and common DQC tools currently used, incorporating data from surveys and interviews with construction personnel. The chapter also provides recommendations from the construction engineers, integrating insights into concrete ideas for improvement.

5.2 Objectives

The major objectives of the construction engineers' survey were:

a. To identify the common design E&Os and when they are encountered in the construction process.
b. To evaluate the impact of the errors on the project budget and schedule.
c. To analyze the DOT's data management and record-keeping practices.
d. To evaluate the role of construction engineers in resolving design E&Os.
e. To analyze the construction, bidding, and design review processes.
f. To analyze the familiarity and effectiveness of some of the prevalent DQC tools.

The major objectives of the construction engineers' interviews were:

a. To gain insights into the problems highlighted in the surveys.
b. To get recommendations based on the need for improvement.
c. To highlight strategies to mitigate design E&Os through lessons learned and past success stories.

5.3 Construction Personnel Survey Structure

The first section assessed the usage and effectiveness of the department's electronic document management system (EDMS), asking respondents about the frequency of contractor use, the sufficiency of data records, and whether other platforms were used for data management. The second section addressed design E&Os during the construction phase, exploring when these errors were noticeable, their frequency, and their impact on costs and schedules. Respondents rated the effect of different design-related errors on cost overruns and schedules and shared their involvement in resolving these issues. The third section evaluated the effectiveness of AGC-DOT meetings and the design review process before letting the construction documents for bidding. The final section examined the familiarity and effectiveness of tools available to mitigate design E&Os, such as BIM and independent design reviews. The overall structure of the survey is outlined below:

1. **Welcome Message**: This section presents the survey and offers participants crucial details regarding the research project. It outlines the importance of the survey, highlights confidentiality, and motivates individuals to take part.

2. **Data Management & CMS:** This block consisted of 5 questions focused on assessing the effectiveness of data management systems like the department's CMS. It aimed to identify the challenges faced in managing design documentation and collaboration during construction. The discussion revolved around the challenges faced in managing design documents and data, along with an exploration of how these systems facilitate communication and collaboration among team members. Additionally, it assessed the impact of data management on identifying and resolving design errors, highlighting the importance of effective organization and sharing of information in the design process.

3. **Design Error and Omission during the Construction Phase:** This section included 15 questions targeting experiences with design E&Os that occur specifically during construction. It sought to understand common issues faced by engineers and the impact these errors have on project timelines and costs. Specifically, it requested examples of these errors along with their specific impacts on timelines and budgets. It also inquired about the frequency of such errors and explored whether communication gaps may contribute to them. Furthermore, the survey sought to understand the methods engineers employ to address or rectify these errors once they are identified, as well as an assessment of the effectiveness of existing processes in preventing or managing these issues.

4. **Construction, Bidding, and Design Reviews:** This section consisted of four questions related to the processes involved in construction, bidding, and design reviews. It aimed to understand how these stages may contribute to design E&Os and the effectiveness of current review practices. Additionally, the research team inquired about the effectiveness of feedback mechanisms during the bidding and construction phases. The survey aimed to assess the perceived quality and thoroughness of design reviews while also exploring the level of collaboration among different stakeholders involved in these critical processes.

5. **Tools to Mitigate Design E&Os:** The research team focused on identifying potential tools and methods that could reduce design E&Os in future projects in this section. The questions asked about familiarity and the effectiveness of existing quality control tools.

In addition to the main blocks, the survey collected some contact information from participants (name and job title) for future follow-up and interviews, ensuring that all responses will remain confidential and only used for research purposes.

5.4 Timeline

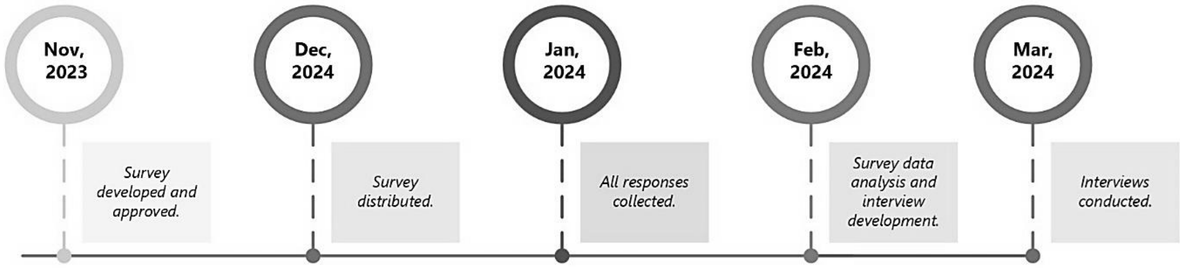

Figure 19: Survey and interview timeline for Construction Engineers' Survey.

The project's data collection phase began in early November, with the research team gaining access to the change order history spreadsheet and the CMS. Based on data analysis and literature review, a list of questions was developed to capture the field engineers' experience regarding design E&Os, which went through several reviews and final approval. The developed Qualtrics survey was sent to the construction professionals in December. By January, the research team had collected enough responses, which were analyzed and studied for follow-up interview questions conducted in the month of March.

Throughout the survey, Likert scale questions were utilized to gauge frequency, agreement, and perceived effectiveness of various practices and tools, providing a nuanced understanding of respondent perspectives. Each section employed a mix of multiple-choice questions, rating scales, and open-ended questions to gather comprehensive insights. The survey included open-ended sections for the engineers to elaborate on any aspects omitted from the study that they believed should have been addressed. The surveys were distributed using QR codes and emails to all the state districts.

5.5 Survey Results

The outcomes of the survey conducted have been compiled and are presented in detail below. This section aims to provide a comprehensive overview of the key findings and insights derived from the data collected.

5.5.1 Participants involved

The survey was circulated to the field and construction engineers through emails, and a total of 25 responses from engineers around the state, including District Construction Engineers, Resident Engineers (REs), Project engineers, etc., from both highway and bridge development programs were obtained. The survey included responses from construction engineers with 4 to

41 years of experience in all five districts. A total of 25 survey responses were obtained from REs, district construction engineers, and bridge engineers. Nineteen of the 25 survey participants agreed to participate in follow-up interviews, while the remaining six declined. Table 12 shows the number of participants in the survey from all five districts of the state of Wyoming.

Table 12: Distribution of participants from 5 districts in WY.

District	Region	Count
District 1	Southeast	5
District 2	Central	5
District 3	Southwest	4
District 4	Northeast	1
District 5	Northwest	7
Unspecified	—	3
Total	—	**25**

5.5.2 Data Management and CMS

During the initial research on the document recording system and management used by the DOT, the CMS developed and customized for WYDOT by iPD Web was found to be the primary resource for construction documents. The survey results revealed Falcon as another source for plan distribution and management. According to the responses, 52 percent of the participants agreed that the contractors used CMS most of the time for data updates. In comparison, 8 percent of the participants mentioned that contractors do not use CMS for updates at all, as shown in Figure 20.

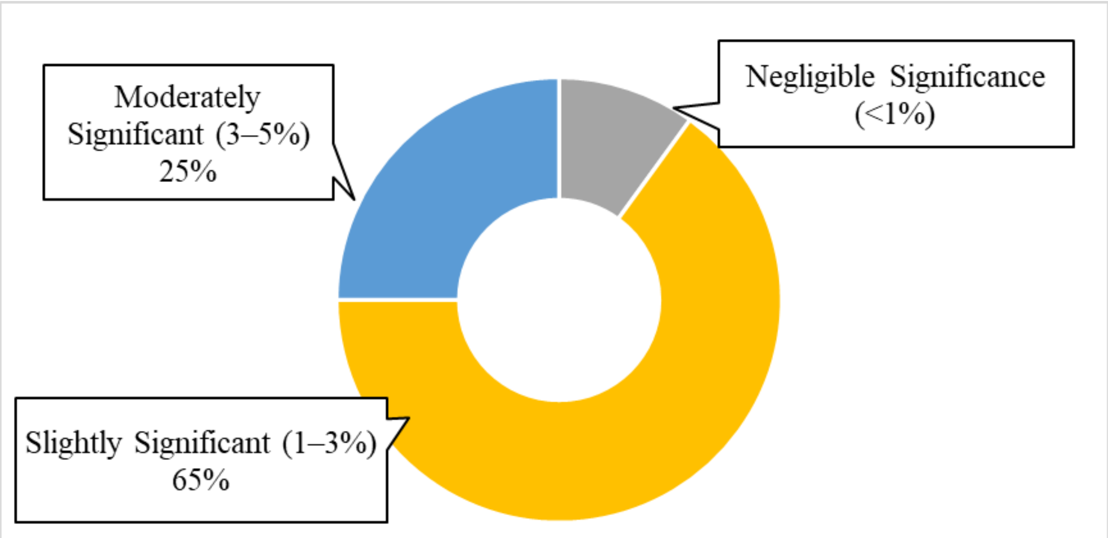

Figure 20: Frequency of contractors using CMS for data updates.

Among the construction engineers surveyed, 90 percent believed the CMS records were enough for data management, while two disagreed. 16 of the 25 participants used other platforms used by the engineers for data records and management, some of which are listed below:

1. Safety Portal
2. Bridge Management System
3. Pavement Management System
4. Agile Assets
5. SPOD
6. Safety Management System (SMS)
7. Google Suite
8. AASTHOWare BrM
9. Trimble Business Center
10. Excel

5.5.3 Identification of Design E&Os across Project Phases

Design E&Os can be encountered in any phase of construction and lead to cost overruns or schedule delays. The survey participants navigated through a section that delved into identifying the specific locations and instances where these errors occur and their impacts. All participants agreed that design errors were most prominent during the construction phase, with the contract-letting phase closely behind in identifying errors. Figure 21 shows the participants' responses about identifying design E&Os in different project phases. During the construction phase, errors were identified and documented using a Likert Scale of frequency. The results of this analysis are presented in Figure 21.

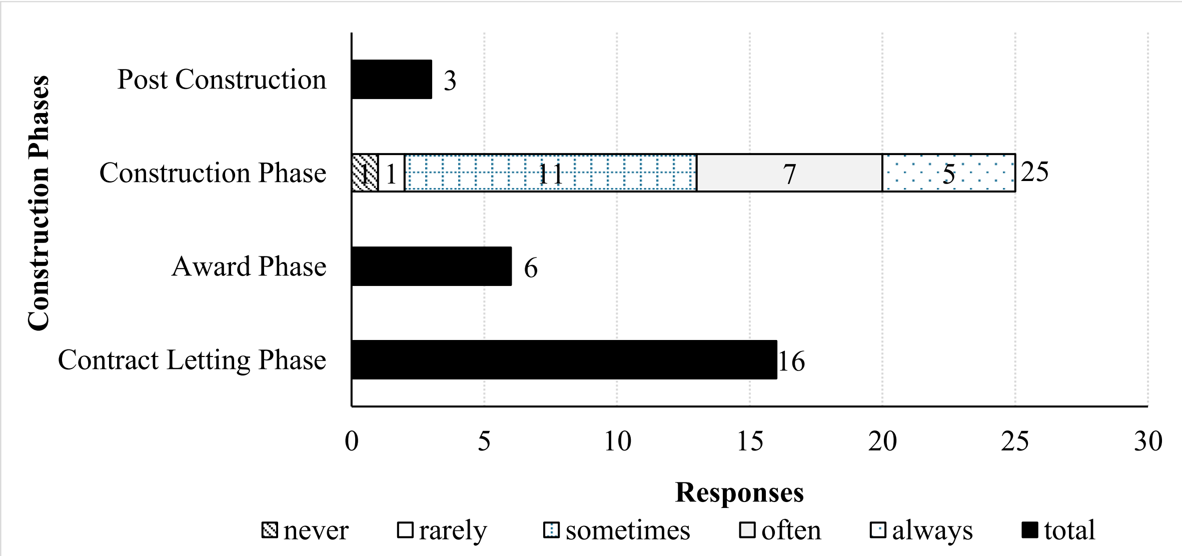

Figure 21: Identification of Design E&Os in project phases.

5.5.4 Impact of Design E&Os on Project Cost and Schedule

Design E&Os represent significant challenges in construction projects, frequently resulting in unforeseen costs and delays in project schedules. This section critically examined the frequency of such occurrences and their subsequent implications on cost overruns and schedule delays. Moreover, the team explored the involvement of construction engineers in rectifying the design E&Os to limit their impact on project cost and schedule, the results of which are visualized in Figure 22 and Figure 23. The figure below shows the statistics from the survey. WYDOT has established general requirements for its design plans that outline the criteria to be met during each project phase. According to feedback from engineers, adherence to these requirements varies: 20 percent of engineers follow them occasionally, 20 percent do so about half the time, and 60 percent adhere to them most of the time. However, there have been no cases of engineers consistently following the criteria at all times.

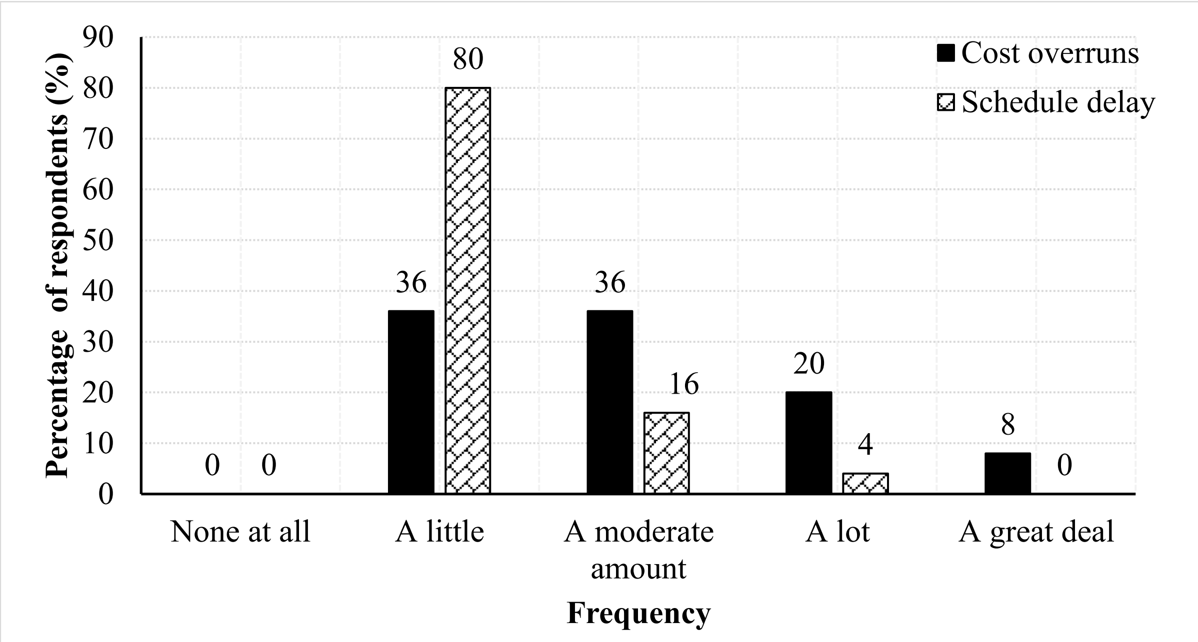

Figure 22: Frequency of cost overruns and schedule delays due to Design E&Os.

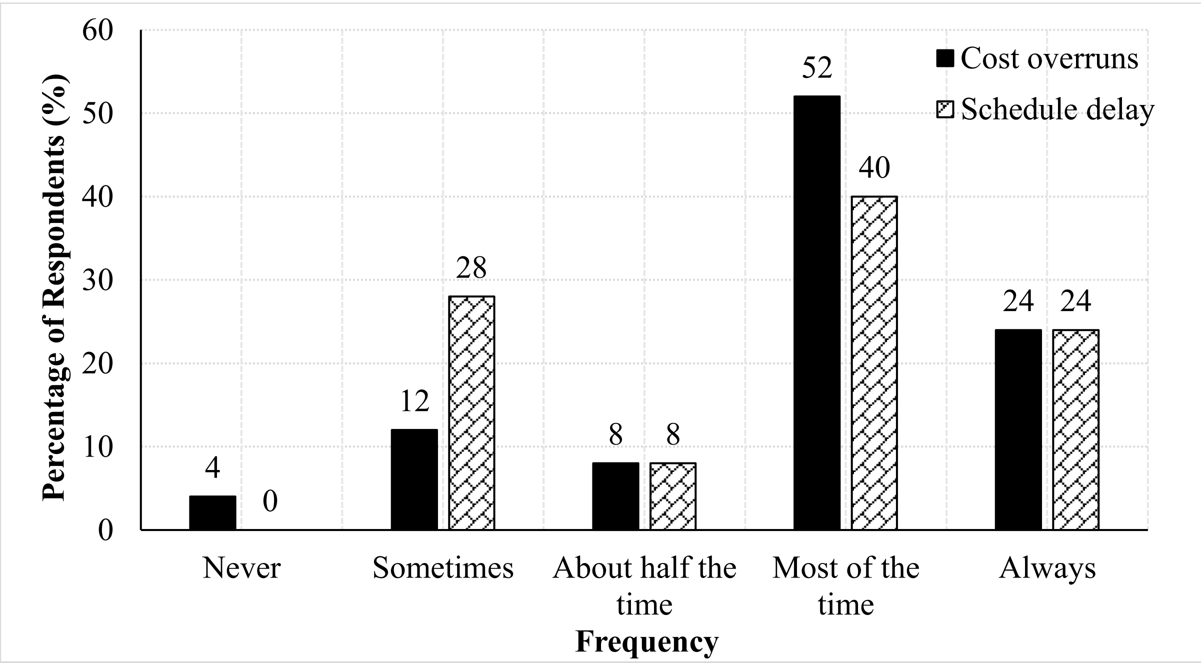

Figure 23: Involvement of construction engineers to resolve the design E&Os leading to cost and schedule overruns.

As per the responses, plan error has the maximum impact on cost overrun and schedule delays, with omissions just trailing behind. The average impact of omission on cost and schedule ranges from least significant to the most, as depicted in the Table 13 and Table 14.

Table 13: Impacts of Design E&Os on Project Cost

Field	Min	Max	Mean	Median	Standard Deviation	Variance	Sum
Estimate Error	6	90	38.08	33	22.69	514.63	952
Misinterpretation/ misrepresentation	6	80	30.16	25	19.79	391.49	754
Plan Error	20	100	55.44	52	22.62	511.85	1386
Omission	10	93	55.56	62	24.91	620.41	1389
Unknown third party/utilities	0	90	28.88	24	20.95	439.03	693

Table 14: Impacts of Design E&Os on Project Schedule

Field	Min	Max	Mean	Median	Standard Deviation	Variance	Sum
Estimate Error	0	60	24.14	20	16.47	271.3	531
Misinterpretation/ misrepresentation	7	81	28.25	20	19.05	363.02	678
Plan Error	7	100	44.64	40	24.32	591.67	1116
Omission	9	90	45.28	41	26.13	682.76	1132
Unknown third party/utilities	5	80	34.91	31	21.82	476.26	768

After an initial analysis of the data, it was found that different design errors had varying impacts on the total cost. These impacts were categorized into five levels: negligibly significant (less than 1 percent change in the original budget), slightly significant (1-3 percent change in the original budget), moderately significant (3-5 percent change in the original budget), very significant (5-10 percent change in the original budget), and extremely significant (more than 10 percent change in the project budget). Figure 24 shows the participants' views on the significance of design E&Os on change orders and project budgets.

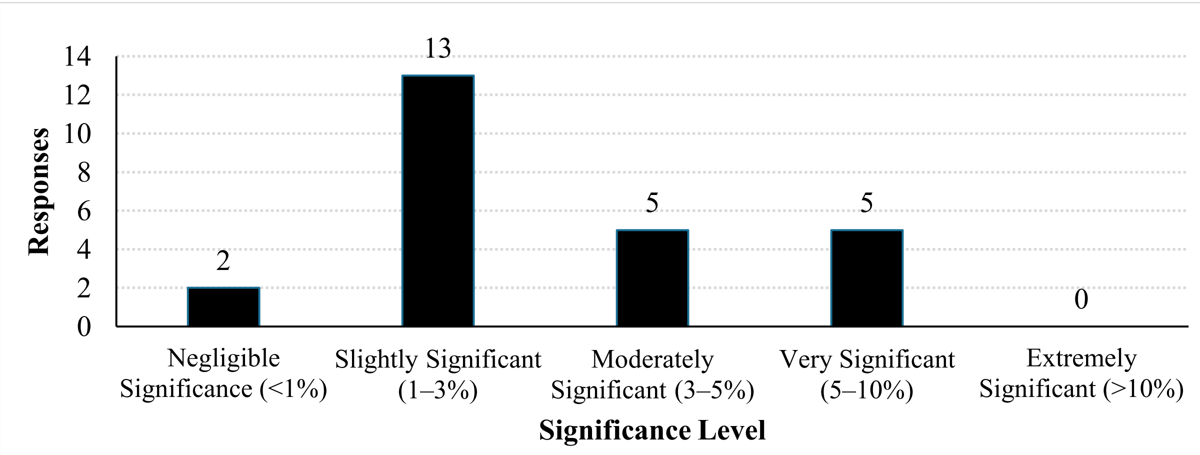

Figure 24: Impacts of Design E&Os on Project Budget.

5.5.5 DQC Tools.

The research team asked the participants to rate the currently available tools and their effectiveness in addressing design E&Os. Approximately 70 percent of participants believe that the AGC-WYDOT meetings are effective in addressing design errors and quality issues in construction documents, while 12 percent feel that the meetings are not effective at all as reflected in Figure 25.

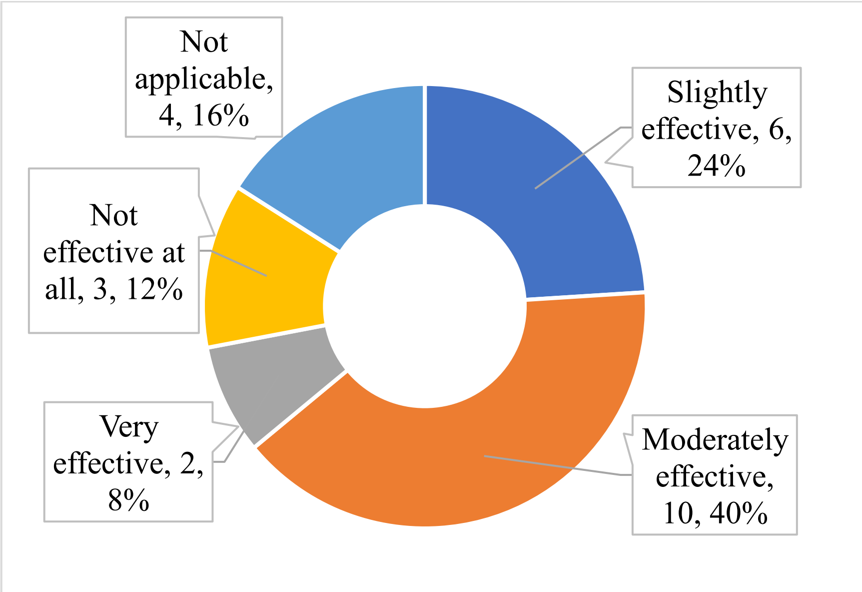

Figure 25: Effectiveness of Collaboration meetings

To assess the frequency of involvement of REs in reviewing construction documents prior to the bidding process, the team asked respondents to rate their level of participation. The results (Figure 26) indicated that nearly all engineers are actively engaged in the document review process before bidding. This involvement not only ensures the quality of the bid documents but also helps minimize the need for addenda or change orders later in the project. Such proactive engagement contributes to smoother project execution and enhances overall efficiency.

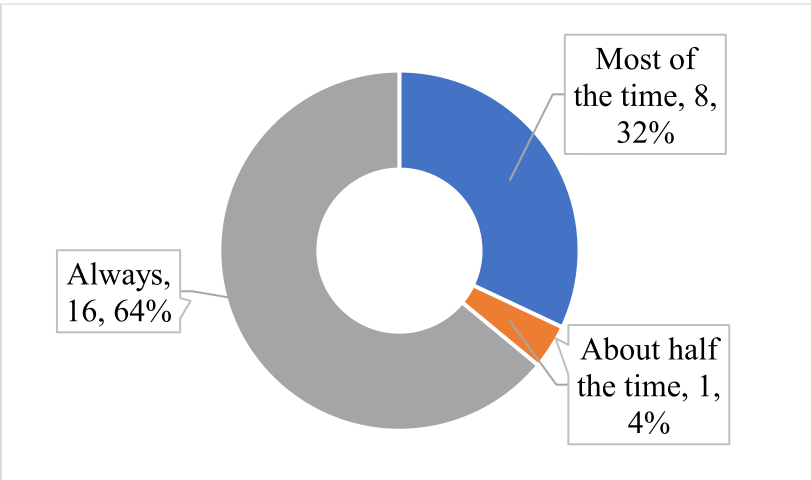

Figure 26: Frequency of Involvement in Construction Document Review

The REs provided ratings on the effectiveness of the current design review process in limiting design E&Os. The majority indicated that the process was mild to highly effective, with only one respondent expressing that it was not effective at all. This feedback highlights a generally positive perception among engineers regarding the design review process, suggesting it plays a significant role in minimizing design-related issues in construction projects. There is a place for improvement in implementing new tools to limit design E&Os in WYDOT. The team reviewed the familiarity and effectiveness of some of the existing DQC tools, and Figure 27 shows the results from the observation.

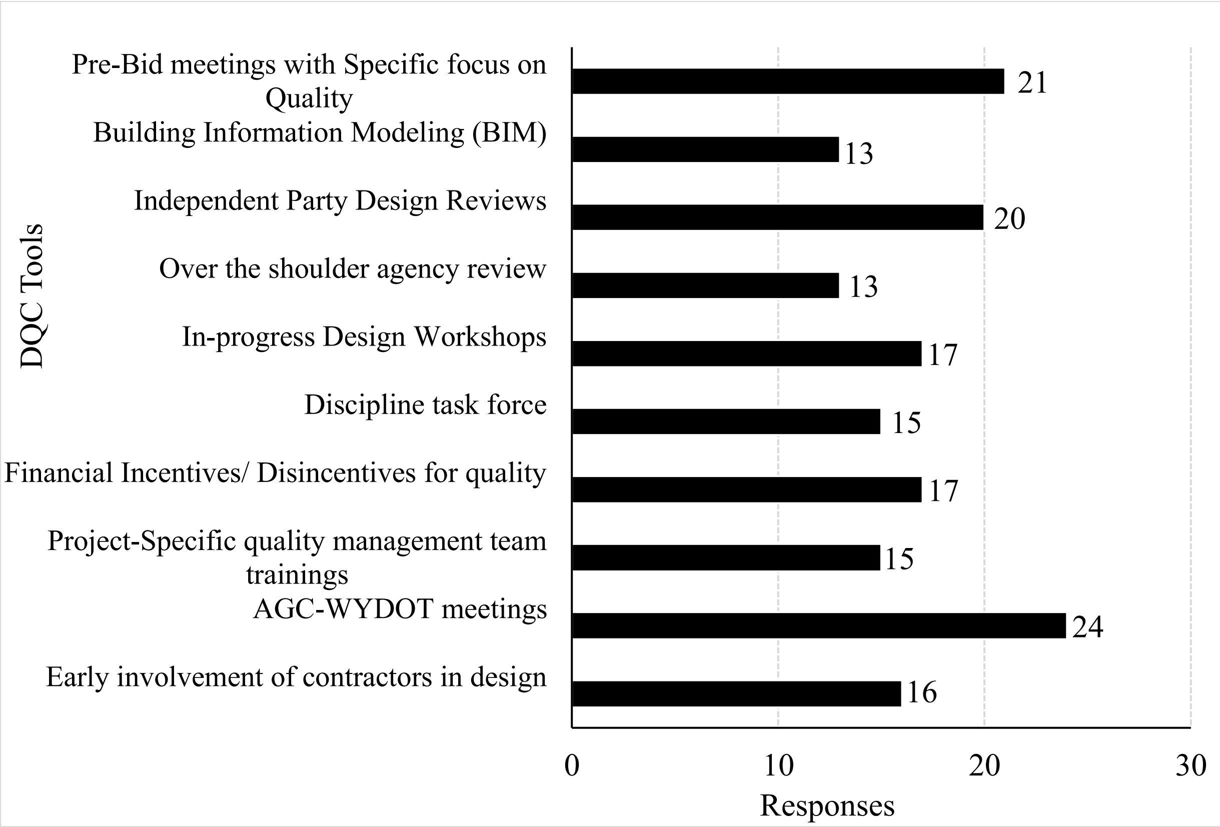

Figure 27: Frequency of responses on DQC tools familiarity.

The two datasets (Familiarity and Effectiveness) measure different but related aspects of various DQC tools:

- Familiarity – How well respondents (likely construction and design personnel) are acquainted with each tool.
- Effectiveness – How respondents perceive the impact of these tools in practice.

Comparing mean values, standard deviations, and ranges (Min-Max values) across both datasets, alignment and discrepancies in the familiarity and effectiveness of these tools were accessed and evaluated.

As shown in Figure 28, overall, the comparison of mean ratings reveals that Familiarity ratings tend to be higher for some tools and lower for others, indicating varying levels of awareness across the industry. In contrast, Effectiveness ratings (Figure 29) are more evenly distributed, which suggests that even lesser-known tools may still be perceived as effective. "Pre-Bid

Meetings with Specific Focus on Quality" was rated higher for familiarity, a rating of 53.10 but a lower effectiveness rating of 46.11. Similarly, "AGC-WYDOT Meetings" had a relatively high familiarity mean of 56.00 while its effectiveness rating dropped significantly to 30.9, implying that respondents are aware of the tool yet do not find it particularly useful in practice.

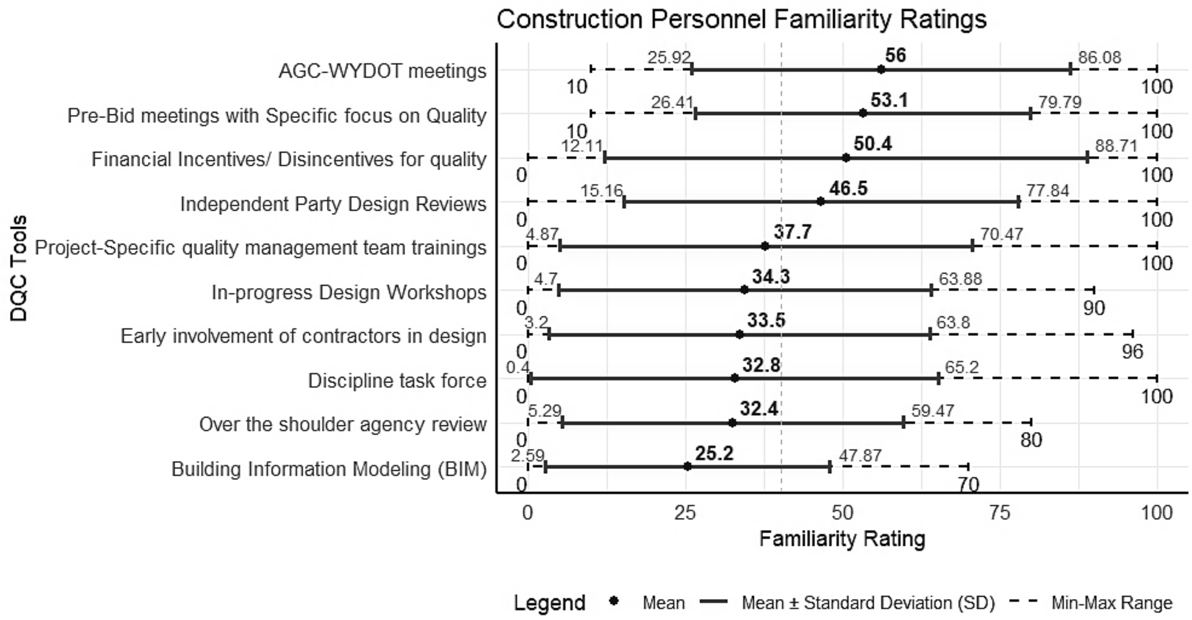

Figure 28: Familiarity of Construction Personnel with DQC Tools

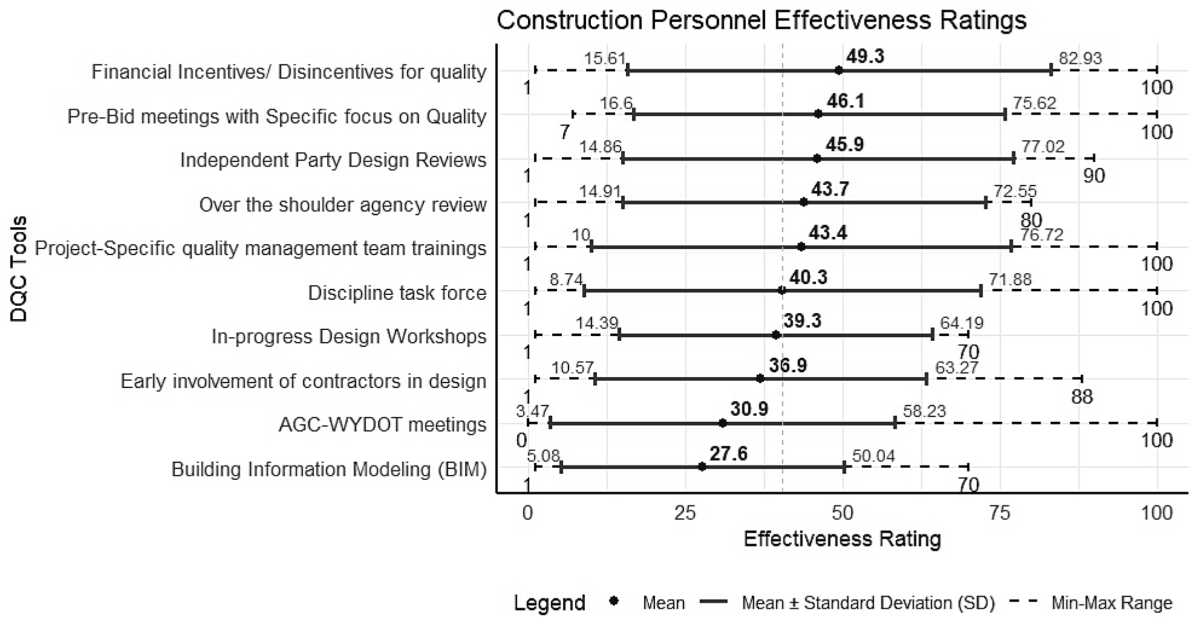

Figure 29: DQC Tools effectiveness ratings by Construction Personnel

The survey was sent a few days after the AGC-WYDOT meeting in 2024, which may have impacted survey respondents' perceptions. Nevertheless, since people attended the meeting, it can still be regarded as a good rating method. This could be one of the reasons for the spike in familiarity ratings on WYDOT meetings.

The Min-Max ranges of the tools show broad discrepancies in opinion. Tools such as Financial Incentives for Quality and Independent Party Design Reviews possess wide ranges (from 0 or 1 to 100) in both datasets, revealing that while some find these tools essential, others see little to no value in them. Conversely, tools like "AGC-WYDOT Meetings" and "In-Progress Design Workshops" exhibit narrower ranges, indicating more consistent responses among respondents. Additionally, the standard deviation analysis reveals that effectiveness ratings have slightly lower values than familiarity ratings, suggesting more agreement among respondents regarding which tools are effective. In contrast, a higher standard deviation in Familiarity indicates that some tools are widely known by certain groups but unfamiliar to others, possibly correlating with job roles or organizational contexts.

Key insights from the comparison reveal specific categories of tools based on their familiarity and effectiveness ratings. Tools that are widely recognized, such as "AGC-WYDOT Meetings," have high familiarity but moderate effectiveness. This indicates that while respondents are aware of these meetings, they do not view them as highly effective. This situation suggests a need to reassess how these meetings are conducted or how their impact is evaluated. In contrast, tools like "Financial Incentives/Disincentives for Quality" exhibit moderate familiarity (mean of 50.41) combined with high effectiveness (mean of 49.27). This implies that increasing awareness of these financial incentives could lead to greater adoption and utilization.

Additionally, tools with both low familiarity and low effectiveness, such as "Building Information Modeling (BIM)," record low values, indicating gaps in training, adoption, or implementation barriers. The survey allowed manual text entry as well, some of which suggested there is a gap between the use of BIM tools by the DOT and the contractors. There is still a huge learning curve for the implementation of BIM tools. With the department transitioning to AutoCAD from Bentley MicroStation, this might increase the time for familiarity with the tools. But once the tools are implemented, there could be a smoother transition into the 3D designs.

In contrast, tools with high effectiveness and high familiarity, like "Pre-Bid Meetings with Specific Focus on Quality," may benefit from refinement rather than an increase in awareness.

From a broader perspective, it is evident that construction professionals do not always correlate high familiarity with high effectiveness. Some widely recognized tools, such as "AGC-WYDOT Meetings," have low effectiveness scores, indicating that mere familiarity does not guarantee success. Tools like Independent Party Design Reviews and Pre-Bid Meetings score high in both categories, underscoring their importance in quality control. Furthermore, opportunities exist to promote tools with high effectiveness but low familiarity, such as "Financial Incentives for Quality," through enhanced education and implementation strategies.

To improve the overall awareness and effectiveness of DQC tools, several recommendations arise from the analysis. First, tools like Financial Incentives for Quality and Discipline Task Forces should be promoted, as they are perceived as effective despite low familiarity.

Implementing training sessions, sharing case studies, and launching pilot projects could enhance their visibility. Additionally, it is critical to re-evaluate familiar yet low-impact tools, such as AGC-WYDOT Meetings, to determine whether modifications, better implementation strategies, or potential replacements are necessary. Lastly, tools like BIM, which have low familiarity and effectiveness, may require identifying and addressing barriers such as lack of training, cost concerns, or resistance to change to improve their adoption and success.

This section presents some of the general views and ideas the REs presented in their responses. The common knowledge was if the reviews are skipped due to rushed schedules and are dived straight to final plans, these designs seem to be the ones with the most E&Os, meaning fewer plans and fewer reviews, meaning fewer chances to make corrections. The analysis highlights several critical challenges in project design and construction, primarily caused by incomplete plan reviews and insufficient field involvement. Projects that bypass essential parts of the schedule, such as moving straight to final plans, often face more E&Os due to reduced oversight, resulting in costly mistakes during construction, such as a field engineer incurring over $10,000 in additional costs because a designer overlooked guardrail slope details. Enhanced field engagement by designers can lead to clearer plans with fewer errors, yet a disconnect remains between design teams and field engineers. Pre-design meetings and ongoing collaboration are suggested improvements. There are mixed experiences concerning third-party plan reviews, with some engineers feeling these reviews introduce unnecessary changes that compromise project functionality, as seen when narrowed shoulder widths negatively impact a roadway project's effectiveness. Additionally, the organizational structure within WYDOT is described as "too departmentalized," resulting in a lack of coordination and accountability, as multiple departments work in isolation. The retirement of experienced personnel and the influx of less experienced hires exacerbate these issues. Furthermore, rushed timelines and diminished project review periods, especially for traffic and bridge projects, have increased the likelihood of design errors. The absence of clear drafting standards leads to inconsistencies across projects, and the pressure to finalize plans during peak construction season decreases review quality. While the Associated General Contractors (AGC) group is seen as valuable, its influence is limited for engineers working with out-of-state contractors who may be more flexible. To mitigate these challenges, stakeholders advocate for more structured plan reviews prior to finalization, increased field involvement during the design phase, better communication between districts and design teams, consistent drafting standards for improved clarity, and ensuring that changes requested during reviews are implemented effectively. Addressing these interconnected issues is crucial to reducing avoidable construction errors and controlling associated costs.

5.6 Follow-up Interview Insights

Following up on the survey results and comments from the engineers, the research team conducted 11 semi-structured interviews to gather in-depth insights from construction engineers regarding their experiences and perspectives on design E&Os. This approach allowed the research team to maintain consistency across the interviews while also providing the flexibility to explore individual responses. Over the course of two weeks, the research team interviewed one engineer from District 1, three from District 2, three from District 3, one from

District 4, and one from District 5. These participants, representing all districts, shared their views, which supported the findings from the data analysis and surveys. The interviews were conducted via Zoom and lasted approximately 30 minutes each. To keep everyone informed about the study, the interview questions were sent along with the invitations to the participants, and the background of the study was explained at the beginning of each conversation. Additionally, the findings from the survey were analyzed and categorized to present the requirements and recommendations from field engineers regarding the errors identified in the literature reviews. Transcripts of the interviews were prepared and analyzed using thematic analysis with Atlas.ti, focusing on the common themes noted during the discussions.

5.6.1 Common Design Errors and Pre-Construction Issues

During the study's interviews, it became clear that the most common reasons for design E&Os revealed by industry professionals were strikingly comparable to those described in existing literature. This further emphasizes the prevalence of the errors and, despite their identification, how they still need to be addressed. The following explanation builds on these shared observations, diving deeper into the core reasons and implications of these widespread design E&Os, as revealed by the interviewees.

5.6.1.1 Plan error

The data observations revealed that plan errors are the most common design errors encountered in the field sooner or later. The process of plan handling, from initial design to final implementation, involves multiple parties, including designers, District Construction Engineers, and REs. However, despite the collaborative efforts, several critical issues contribute to the occurrence of plan errors throughout various project phases. Plan errors range from minor mistakes in the plans to omissions of entire components of the project, leading to inconsistencies between the understanding of the projects between the parties involved and ultimately to graver schedules and cost overruns. The change order history analysis and the survey responses put forward plan errors that have significant impacts on both cost and schedule. The cost impact due to plan errors ranged from $300,000 to nil.

5.6.1.2 Quantities/ Estimation error

The high incidence of errors in amount estimations presents a substantial obstacle in construction projects. These errors manifest in several ways, such as inaccuracies in summaries, illogical quantities, and frequent disparities between estimated and real quantities. Concrete and reinforcing steel, two critical construction components, are especially vulnerable to missing quantity predictions, which can result in underrun and overrun scenarios. One of the engineers interviewed mentioned that the missing quantities are compounded in bridge projects, where significant uncertainty exists between the Project Development (PD) and the bridge development program, creating an environment favorable to errors.

One root problem discovered is the District's dependence on field engineer estimates in its smaller-scale projects, which sometimes rely entirely on experience rather than comprehensive secondary evaluations. This technique has resulted in costly oversights, as proven by inconsistencies in quantity, such as 27,000 yards of asphalt pavement instead of the 2,000 yards needed.

5.6.1.3 Omissions

Omissions in construction project plans pose significant challenges and can lead to costly repercussions if left unaddressed. One common issue highlighted in interviews is the omission of critical notes during different plan phases, where essential details are missed, potentially leading to misunderstandings or errors during project execution. Additionally, missing quantities due to inexperienced staff can result in inaccurate estimations and subsequent budgetary discrepancies. Similarly, the absence of bid items and overlooking the inclusion of rebars in bridge designs can compromise the integrity and safety of the structure. Moreover, incomplete or outdated information in general notes or special provisions has hindered project clarity and regulation compliance. These omissions lead to tangible financial impacts, as evidenced by examples where missed notes resulted in substantial change orders for District 1 projects. Furthermore, the lack of experience among field teams and designers may exacerbate the problem, as they may overlook critical issues or fail to identify potential problems, leading to further complications during construction.

5.6.1.4 Misrepresentation/ misinterpretation

Various obstacles develop due to faults and discrepancies discovered during construction project evaluations, hindering the execution process. Errors resulting from surveys or other sources that cannot be easily detected during reviews provide substantial challenges, potentially leading to design inconsistencies and performance problems. Furthermore, mistakes in standard sections have been observed, leading to misinterpretations and departures from intended specifications, upsetting project timelines and budgets. Furthermore, meeting subsurface conditions that differ from those identified during initial studies has presented unexpected obstacles.

5.6.1.5 3D models

As highlighted during interviews with industry professionals, the absence of 3D modeling support from the WYDOT poses significant challenges for construction projects. Unlike private consulting firms with advanced design software, as per a few interviewees, WYDOT relies on field engineers to manually create 3D models, while designers lack access to the necessary software. This disparity in technological resources creates inefficiencies and increases the likelihood of errors in project designs.

One notable challenge arises from the discrepancy between 3D modeling capabilities and project requirements, particularly regarding grading and Americans with Disabilities Act (ADA) compliance. While contractors increasingly demand 3D designs for accuracy and efficiency, WYDOT's current practices often provide 2D curb ramp ADA designs instead.

3D designs are still a learning process for WYDOT, which has led to more errors being encountered just because of the lack of proficiency in using the software or the new technology.

Efforts to standardize software usage between field engineers and designers, such as the recent collaboration with the survey department, have shown promise in reducing errors and improving project outcomes. However, further investment in training and expertise is recommended to elevate WYDOT's design standards and align with industry best practices.

5.6.2 Common Factors Leading to Design E&Os

In conversations with the engineers, common patterns emerged regarding the types of errors they encountered in the field and the possible reasons for these errors. The wide range of areas mentioned was categorized into common themes, which were later evaluated in the design team surveys, where the team rated the impacts of the said factors on the occurrence of design E&Os.

5.6.2.1 Comments from REs Ignored

One prevalent issue is the failure to address comments and feedback provided by REs during the review process. Often, these valuable insights are not incorporated into the final Plans, Specifications, and Estimates (PS&E) documents, perpetuating E&Os.

Some interviewees mentioned that their comments and recommendations are sometimes deemed insignificant and overlooked during the plan revision process. This oversight diminishes the effectiveness of quality control measures and perpetuates errors in project documentation.

5.6.2.2 Poor Communication

There is a notable absence of reviews and effective communication with field personnel between the issuance of PS&E plans and their implementation. This disconnect between design teams and field engineers often results in overlooked discrepancies and missed opportunities for error correction.

Communication issues were one of the major problems highlighted during the interviews. The DOT still relies on emails, phone calls, and other communication methods to convey the issues encountered in the field. There is no standard method of addressing the issues through the departments. Responders claimed that about 95 percent of the errors were due to the lack of proper communication. The lack of in-person meetings, which typically encourage interaction further compound the communication issues. Since field meetings are not as frequent, new engineers often struggle to determine when to ask questions or whom to direct their inquiries to when they do arise.

5.6.2.3 Errors Carried Forward

Errors in the project plans often result from mishandling plans and human errors carried forward from previous phases. These errors occur when corrections from previous versions are omitted, leading to discrepancies between the revisions and the plans ultimately issued. This results in compromised corrected plans, which are replaced by outdated versions instead of being revised and scrutinized. The result also stems from a lack of reviews and communication between the departments.

5.6.2.4 Time Constraints

Time constraints between the issuance of final plans and PS&E documents exacerbate the likelihood of errors. Designers face pressure to rush the process, leading to rushed reviews and inadequate scrutiny of plan details, particularly during peak construction periods. The same is the issue encountered by the field; the field engineers do not get enough time to review the plans during peak construction and often only get a day or two to review the plans as per some of the interviewees. The projects with shorter design periods to get the designs out as early as possible limit the number of reviews, leading to fewer eyes on the design and hence the missed-out issues.

5.6.2.5 Shelving of Plans

The shelving of plans, often for extended periods, poses significant challenges. Changes in field conditions and outdated data can render initial designs obsolete, necessitating extensive revisions and rechecks to avoid costly errors during construction.

One of the responders mentioned that critical details, such as changes in pavement conditions, were overlooked, leading to subsequent rework and additional costs because core cutting for the project was done five years before the plans were issued.

5.6.2.6 Employee turnover and lack of experienced designers.

Over the past five years, the field personnel and the design team have experienced turnover and changes within their respective roles. Experienced designers are retiring, leading to a gap in knowledge and ease of asking questions when they arise. These turnovers and a shortage of experienced designers were highlighted as contributing factors to design errors. New engineers recruited do not have a review checklist, recommendation, or manual to develop or check the plans.

Experienced engineers have emphasized the necessity for guidance for the incoming generation, highlighting instances where newer professionals may not always know when questions should be asked and, if so, what inquiries to make.

5.6.2.7 Outdated document management system; Falcon

WYDOT relies on Falcon as its EDMS for handling a majority of its plans and document submissions. However, the system does not facilitate updates regarding the review status, which means that communication about changes to the plans often depends on traditional methods such as emails and phone calls. This creates a significant need for real-time comment and revision tracking, as well as a collaborative platform that would streamline the review process and enable efficient teamwork among stakeholders involved in plan assessments.

5.6.2.8 Lack of standards in drawings.

Each drawing sheet produced is different according to the squad it comes from or the engineer who prepared it. There are no set standards for the prepared drawings leading to different units being used at times with different engineers, which could lead to confusion at times. A common example of this is the inconsistent use of tons instead of cubic yards. While there is a design checklist available, it requires updates, and it would be beneficial to start using it. Currently, many people rely on their experiences or past projects to identify potential errors in the designs, rather than following a consistent checklist.

5.6.2.9 Poor scope definition and lack of proper planning during design

Lack of proper briefing on what the project holds and what the specifications should have been leads to details being left out or assumed at times. This also includes cases when notes are left out of the plans for specifications that lead to changes later.

Some of the other issues mentioned in the interviews were:

5.6.2.10 Lack of accountability

This issue arises when plans are circulated across departments. Once the plans are issued and released, a few feedback mechanisms are in place to inform designers about how the plans are performed. Specifically, designers lack insight into which elements of the designs were effective and which parts were difficult to understand. Addressing constructability issues during design reviews and field meetings may help to resolve this problem; however, accountability of the issues remains important because there is no standardized process for critiquing the efficiency of the designs.

5.6.2.11 Lack of training in the organization

Employee turnover is closely related to this issue. New engineers often lack proper onboarding training, and existing engineers, being overworked, cannot dedicate sufficient time to train their new hires. Without adequate training, errors are more likely to occur when engineers are responsible for generating plans. Additionally, the lack of a structured onboarding process leads to frustration among new hires, affecting morale and potentially resulting in further turnover, as mentioned by one of the engineers. This situation underscores the need for standardization in certain practices, as noted by the engineers interviewed.

5.6.2.12 Rounding up quantities.

Rounding up to the nearest whole number without further exploration leads to overruns and underruns. One of the participants raised an issue regarding calculations in the department. They noted that while the department typically uses at least three decimal places, rounding numbers up for unit calculations can lead to problems when these values are multiplied for larger quantities. This rounding can result in overestimations.

5.6.3 Evaluation of Schedule Impacts and its Assessment

Effective schedule management is critical for the successful execution of construction projects, yet challenges persist in tracking and addressing schedule delays, as revealed during interviews with industry professionals. There are no formal tracking mechanisms for schedule delays, and documentation is primarily confined to internal records. However, internal communication between designers and project stakeholders remains essential, fostering collaboration without using accusatory practices. To address schedule-related issues, industry professionals advocate collaborating with the Project Control System (PCS) for comprehensive information and analysis.

A notable example provided during the interviews involved a project in District 3, where consultants were engaged to expedite project completion within a shortened timeframe. Unfortunately, the consultants could not make the planned deliverables on time, undermining the complexities inherent in schedule management. Despite these challenges, efforts are made to rectify errors and mitigate schedule impacts through quality control measures and meticulous estimation practices.

Furthermore, interviews also revealed that the schedules are changed almost once every month and made available to the REs, but the changes are neither always justified nor self-explanatory.

5.6.4 Data Management & CMS Practices

From the initial survey responses, 50 percent believed that CMS is sufficient for data collection, while participants also revealed using platforms like safety portals, bridge & pavement management systems, Agile Assets, SPOD, Google Sheets, SMS, Google Suite, AASTHOWare BrM, Trimble business center, excel, Trello and a bunch of other databases for records.

Falcon, the primary platform for communicating plans and updates, was pictured as outdated and cumbersome. Almost all the interviewees suggested Falcon needs updating, and a real-time comment and revision tracking platform would greatly help. Respondents discussed their personal approaches to data archiving for design E&Os compared to WYDOT processes. While some emphasized the importance of standardized record-keeping, others highlighted the need for flexibility to accommodate diverse project requirements and services to cater to specific project needs. The opinions on standardizing record-keeping and software usage varied among respondents.

5.6.5 Success Stories and Best Practices

Respondents shared success stories and best practices for mitigating design E&Os from previous projects. These strategies included proactive communication and interdisciplinary collaboration, such as holding active on-site meetings prior to finalizing designs. This approach facilitated interaction among all parties involved, enhancing communication between departments regarding what has worked in the past and what has not, thus preventing the repetition of past mistakes. By implementing these practices, teams were able to minimize errors and optimize project schedules and budgets.

5.6.6 Lessons Learned Influence on Future Projects

Lessons learned from past design E&Os have significantly influenced future project planning and execution. By documenting and disseminating these lessons, teams can avoid repeating similar mistakes and improve overall project performance. Incorporating feedback mechanisms and conducting post-project reviews facilitates continuous improvement and enhances project outcomes.

5.6.7 Strategies to Reduce Design E&Os

Throughout their work, field engineers have encountered various challenges and inefficiencies that hinder project progress, impact overall outcomes, and develop strategies to minimize the impact of design E&Os. Their recommendations hold significant weight in this context, offering valuable insights into potential improvements and strategies to enhance project efficiency and effectiveness. This section presents a compilation of recommendations provided by field engineers derived from interviews.

5.6.7.1 Checklists

The current situation regarding the design review checklists is that there are existing checklists, but they are outdated and in need of revision. The construction staff recommends developing a more comprehensive and generalized checklist that covers common design checks applicable across various projects. Additionally, the bridge department has an internal checklist to help new engineers and designers review and develop plans in a more systematic way. To maintain consistent quality across all design projects, it's crucial to create a universal checklist that sets a standard baseline. This checklist should include important elements like traffic design needs, safety measures, structures, and environmental considerations. It must comprehensively cover all project components, including bridges, roads, and right-of-way (ROW) compliance. Each department, such as the bridge department, should create internal checklists tailored to their needs. Furthermore, the general checklist should be divided into specialized groups for different project types, such as preservation projects, mill & overlay projects, bridges, and roads, addressing the unique requirements and challenges of each category. It's important to involve a knowledgeable and experienced team to develop the checklist and encourage collaboration among various departments and stakeholders to incorporate diverse perspectives and expertise.

5.6.7.2 Better communication

Complaints about communication were the most common ones throughout the interviews, whether about not hearing back from the design team about the changes the REs suggested or the changes made in the plans after the plan review meetings and before the project is let. Sometimes, the REs only learn about the project changes after the final plans are issued for bidding. There is a clear communication gap between the field and the project development at times, either because of staff turnover and new employees not having an idea about whom to go with the questions they have or simply because of the peak construction periods.

5.6.7.3 Review tracking/real-time revision tracking on changes made to the plans.

Real-time collaboration platforms are essential in today's environment. Delays in communication or information sharing between teams have led to the continued use of outdated plans, as updates are not communicated quickly enough. Transitioning from traditional platforms to interactive tools like BlueBeam or developing department-centered collaboration tools could help address this issue.

5.6.7.4 In-field meetings

There was a practice in place where designers and REs would conduct field visits alongside experienced designers and relevant departments such as geology, survey, hydraulics, and bridge engineering, as needed. This approach promoted collaboration and knowledge sharing in real-world settings. Additionally, prior to the COVID-19 pandemic, there was a policy governing in-field meetings, which established a framework for these interactions. However, the pandemic disrupted these practices due to restrictions on travel and large gatherings. As a result, many meetings have moved to online formats. While this shift has been helpful in some instances, it also has its disadvantages. To address this, the department has initiated some pre-construction field meetings, which could aid in visualizing the designs and improving communication. The use of virtual plan reviews has also proven to be beneficial, allowing for broader participation and more efficient collaboration across different teams.

5.6.7.5 Peer-review process for design and plans.

A more structured peer-review process can help identify errors and inconsistencies in design plans before they reach the construction phase. Adjusting the schedules, if possible, to allow longer review times might help reduce costly mistakes. It was mentioned that the REs used to get about a week for design reviews, but in 90 percent of the projects, they only get about a day for the reviews. Additionally, having reviewers who were not directly involved in the planning process can provide a fresh perspective and catch issues that might have been overlooked by the original designers. Adding peer reviews along with the integration of other design squads to review, designs from one squad might help lead to higher-quality designs and fewer errors in execution.

5.6.7.6 Strengthening Internal Quality Assurance (Q/A) and Quality Control (Q/C)

A more structured internal Q/A and Q/C process is essential to minimizing errors in design and construction. This can be accomplished by setting realistic milestones that provide sufficient time for thorough reviews at each stage, establishing clear review timelines, and ensuring that all team members adhere to these schedules. Moreover, fostering collaboration between design teams and field engineers can help identify potential construction issues early in the process. Additionally, implementing standardized spreadsheets and checklists can assist in tracking materials, procurement, and compliance with CMS requirements.

5.6.7.7 Enhancing the Plan Review Process

Plan reviews are crucial for identifying design issues before construction begins, and enhancing their effectiveness can significantly reduce costly changes later. To achieve this, it is essential to conduct reviews either in person or through virtual meetings, ensuring the participation of all key stakeholders. The department already had a check squad for design reviews, but including more thorough reviews could benefit and limit the process. Involving field engineers can help align design recommendations with on-site realities. By increasing both the depth and frequency of these reviews, the construction process can become much smoother and more efficient.

5.6.7.8 Feedback loops

Closing feedback loops is crucial for fostering continuous improvement in design processes. Teams can effectively capture lessons learned from completed projects by implementing a structured post-construction review. This process ensures that any issues encountered during construction are documented, allowing for better-informed decisions in future designs. It also creates a platform for collaboration among field engineers, designers, and project managers to discuss successes and identify areas for enhancement. Furthermore, this review helps to highlight recurring errors, enabling teams to systematically refine design manuals, standards, and workflows for future projects. Overall, such a feedback mechanism enhances both the efficiency and quality of design outputs. This approach ensures continuous improvement in project planning and execution.

5.6.7.9 Updating Manuals and Standards for Consistency

A robust and regularly updated set of design manuals and standards is crucial for maintaining consistency and quality in design plans. The department should ensure regular updates to manuals to reflect evolving best practices and lessons learned from past projects.

5.7 Chapter Summary

This chapter provides a comprehensive overview of the complexities involved in construction projects, particularly focusing on the significant challenges arising from design errors and pre-construction issues. The REs highlighted several reasons for the high prevalence of design E&Os, primarily citing poor communication and the failure to consider their comments. Additionally, there was concern regarding the shelving of plans. When projects are delayed over the years, it can lead to outdated plans, as site conditions may have changed by the time construction begins, resulting in discrepancies between the site and the plans. The engineers ranked the impact of plan errors on cost overruns as significant. They discussed several issues, including the carrying over of errors through updates, time constraints, employee turnover, and the pressure engineers face due to being overworked.

Despite thorough planning, these issues often lead to schedule delays, cost overruns, and overall compromised project quality. To address these challenges effectively, REs suggest the use of post-construction reports and feedback mechanisms. Some other recommendations from their side included the use of checklists, improved collaboration and communication platforms, and a review tracking mechanism. They also suggested incorporating in-field meetings, introducing peer reviews for the design process, strengthening internal quality assurance, and updating manuals to ensure they remain current.

In addition to quantitative findings, the qualitative insights gathered from interviews with construction personnel provide valuable information about practical experiences and recommendations for improving design processes. The perspectives shared by these construction professionals are crucial for enhancing the overall quality control process. By incorporating the views of construction engineers, this chapter presents tangible ideas for improvement and emphasizes the importance of ongoing evaluation and adaptation of strategies to effectively mitigate design errors. Overall, this chapter lays a critical foundation for understanding the relationship between design quality and construction efficiency, paving the way for future research and practical advancements in the industry.

CHAPTER 6: DESIGN PROFESSIONAL SURVEYS AND INTERVIEWS

6.1 Introduction

Understanding the insights of key contributors in a project, the research team planned to gather insights from both construction and design. The next stage of the project involved the participation of design engineers and their perspectives. The design squad surveys included responses from different departments, incorporating insights from materials, bridge program, principal engineers, design squad leaders, quality control review/ check squad, geologists, and project engineers. A comparative study was conducted for the design engineers, mirroring key areas related to cost impacts and overruns, while also incorporating an additional section focused on the causal factors leading to design E&Os. A diverse team across project development gave a diverse range of responses from the design team, building on the responses and issues addressed by the construction team prior. Design personnel assessed the impacts and the reasons behind the design E&Os as mentioned in the construction team's surveys and interviews. The findings and structure of the design teams' surveys and interviews are discussed in this section.

6.2 Objectives

The major objectives of the design squad engineers' survey were:

- To identify the common design-related E&Os and their impact on project cost.
- To identify the most common high-risk areas during the design phase that might lead to project cost overruns or schedule delays.
- To analyze the DOT's data management and record-keeping practices.
- To analyze the effectiveness of the current design review process and available design review checklists.
- To analyze the common reasons behind design E&Os and their impact.
- To evaluate the role of construction engineers in resolving design E&Os.
- To analyze the familiarity and effectiveness of some of the prevalent DQC tools.
- To analyze and back up the recommendations made by the construction engineers.

The major objectives of the design squad engineers' interviews were:

- To gain insights into the problems highlighted in the surveys.
- To get recommendations based on the need for improvement.
- To highlight strategies to mitigate design E&Os through lessons learned and past success stories.

6.3 Design Personnel Survey Structure

This survey included five main sections, beginning with evaluating the effectiveness and usage of the department's EDMS. The second section explored various aspects, including construction, bidding, and design reviews, as well as the effectiveness of design checklists and AGC-DOT meetings. The next section examined the impact of causal factors on the occurrence of design errors, and the final section gathered insights from the design team regarding the recommendations made by construction field engineers. The general structure of the survey followed the following structure:

1. **Welcome Message:** The survey introduced its objectives, highlighting the importance of gathering information on the impacts of E&O design on WYDOT projects. Participants were thanked upfront for their involvement.
2. **Challenges Faced:** This section focused on data management and collaboration practices within WYDOT. Respondents were asked about the sufficiency of current systems, such as the CMS and Falcon, and expressed their need for better tools to track design changes. Additionally, the section identified common issues arising from design E&Os and discussed their effects on project costs and schedules.
3. **Construction, Bidding, and Design Reviews:** The section addressed the effectiveness of AGC-WYDOT meetings in tackling design-related issues and assessing the quality of construction documents. It evaluated professionals' perceptions regarding the meetings' ability to resolve design E&Os. Key areas of focus included construction, bidding, and design reviews

5. **Quality Control Mechanism:** This section focused on evaluating the quality control processes that were in place to identify design errors before they impacted projects. It addressed the use of design review checklists, assessed the effectiveness of these checklists and inspections in minimizing design E&Os, and offered recommendations for structuring the review process more effectively.
6. **Design Error Causal Variables:** This section explored the underlying causes of design E&Os, their frequency, and their impact on project cost overruns. These variables were identified through interviews with construction personnel and existing literature.
7. **Tools to Mitigate Design E&Os:** This section focused on identifying existing tools and practices that help minimize the occurrence of design E&Os. It assessed familiarity with various industry tools and gathered input on specific risk analysis methods utilized during the design phase. Additionally, it evaluated the effectiveness of key recommendations from the perspectives of construction engineers.
8. **Thank You Message & Contact Information:** This section of the survey expressed gratitude to participants for their valuable input and invited any additional comments or feedback that may not have been addressed. It collected personal information from participants, including their full name, job title, years of experience, and contact details. The survey also inquired whether respondents were willing to be contacted for follow-up interviews.

Overall, this survey aimed to gather comprehensive insights into the factors contributing to designing E&Os, improving practices, and minimizing their impact on WYDOT projects.

6.4 Timeline

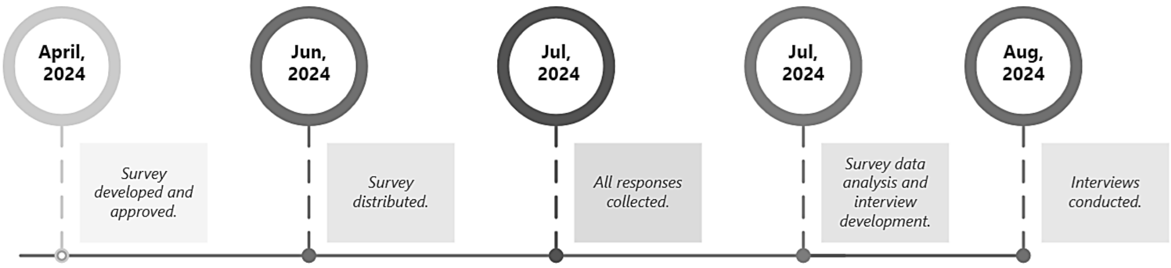

Figure 30: Survey and interview timeline for Design Teams' Survey.

Following interviews with the construction staff, the research team analyzed the data and began the construction of the design squad interview based on the change order data analysis, literature review, and suggestions from the field engineers. The aim was to capture the design team's experience regarding design E&Os. The questionnaire was developed and transformed into a Qualtrics survey using the Likert scale for quantitative data. The survey was distributed to the design team in June using QR codes and emails. By the end of July 2024, responses were collected from 38 engineers in the design team. These responses formed the basis of a comprehensive survey, which was meticulously analyzed and transformed into solid quantitative data.

Following this, a final draft of interview questions was developed, reviewed, and distributed to engineers who volunteered to participate in the interviews. In August 2024, 13 semi-structured interviews were conducted, yielding rich qualitative data that provided deeper insights into the engineers' perspectives and experiences. The insights are discussed below alongside the survey results.

6.5 Survey Results

The survey results have been compiled and are presented in detail below. This section aims to provide a comprehensive overview of the key findings and insights derived from the collected data.

6.5.1 Participants involved

A total of 60 responses were received from the design team, out of which 38 full responses were utilized for the analysis. Of the 38 respondents, with experiences ranging from two to 37 years in road design, 18 agreed to follow-up interviews, of which 13 were interviewed. The participants held roles such as project engineers, engineer II, design specialists, materials staff engineers, project engineers, geologists, bridge engineers, operations technicians, and design quality reviewers.

6.5.2 Challenges faced

The research team asked the engineers whether they think the current data management and records system needs improvement or is sufficient for records. Almost 38 percent of the engineers agreed that the CMS and Falcon are sufficient for records, while 10 percent strongly believed there is a need for updates. 33 percent of the respondents had neutral responses, as shown in Figure 31.

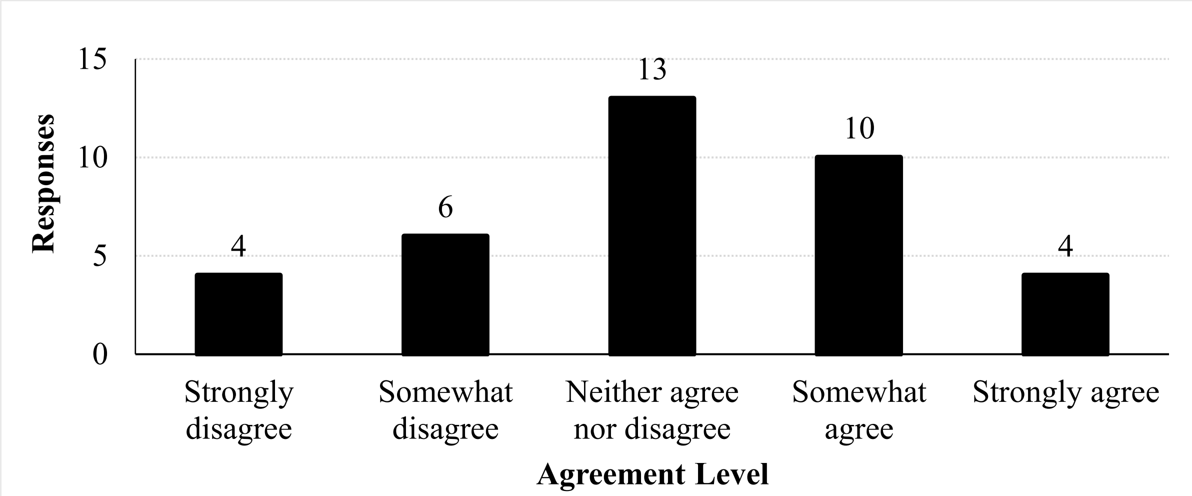

Figure 31: Sufficiency of CMS for data records

Respondents were asked how frequently they encountered specific types of errors to assess the prevalence of various design E&Os. Among the 36 design professionals who participated, seven reported experiencing estimation errors, while eight identified misinterpretations and misrepresentations. Additionally, seven noted errors in the plans, and nine experienced omissions in design. Eight respondents encountered issues related to existing utilities, and nine mentioned other errors, which included insufficient drainage evaluations, difficulty in obtaining accurate estimates from the field, and a lack of communication and accountability that led to items being overlooked or omitted from plans. Other challenges included data arriving late, design errors necessitating redesigns that caused schedule constraints, and delays in fabrication and shop plan reviews.

These responses as shown in Figure 32 indicate that omissions and other errors were the most frequently encountered issues, followed closely by conflicts with existing utilities and misinterpretations/misrepresentations.

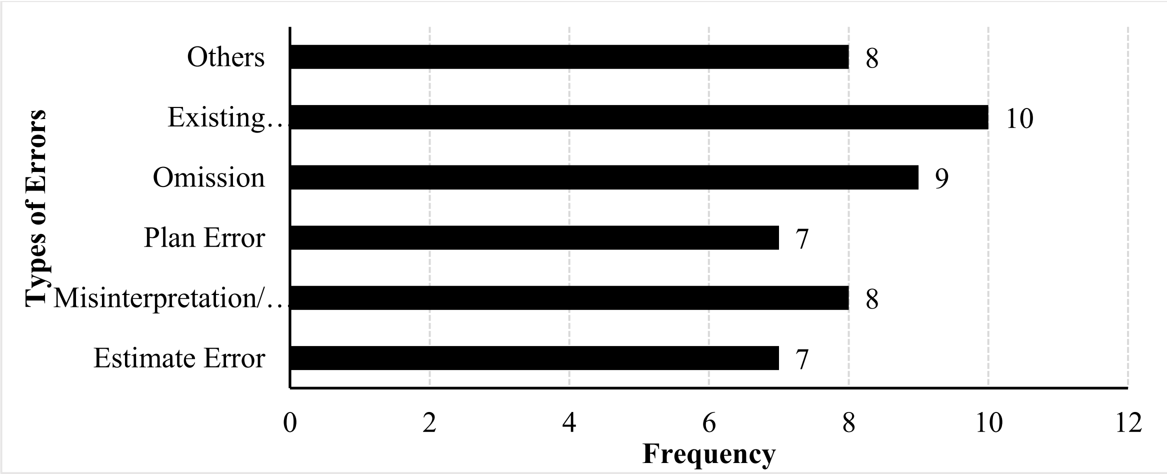

Figure 32: Prevalence of Design E&Os in projects as per Design Personnel

The design engineers assessed the impact of various types of errors on project costs. They found that omissions had the greatest effect on expenses, followed closely by misinterpretations and misrepresentations. Estimate errors, issues with existing utilities, and plan errors had a lesser impact, in that order.

Table 15 summarizes the responses from 34 participants who evaluated the impact of various field-related errors in highway construction. Omission emerged as the most significant issue among the categories assessed, receiving the highest mean rating of 48.88. Following Omission, participants perceived Misinterpretation or Misrepresentation of field data as a critical error, which garnered a mean score of 46.47. Other notable categories included Estimate Error, Unknown third party/utilities, and Plan Error, which recorded mean values ranging from 36.24 to 41.44. The variation in participants' responses highlighted a range of perceptions regarding the severity and frequency of these issues, reflected in the standard deviation values that spanned approximately 21.9 to 31. Overall, the data indicated that omissions and misinterpretations of field data were regarded as the most impactful errors encountered. The effects of the identified design-related errors are outlined in Table 15.

Table 15: Cost Impacts of Design E&Os as per Design Personnel

Field	Min	Max	Mean	Median	Standard Deviation	Variance	Responses	Sum
Estimate Error	0	90	39.55	30	31.04	963.5	31	1226
Misinterpretation/ misrepresentation	0	83	46.47	50	26.95	726.3	30	1394
Plan Error	3	83	36.24	30	21.92	480.5	29	1051
Omission	0	90	48.88	50	28.83	831.2	32	1564
Unknown third party/utilities	3	89	41.44	45	24.88	619.2	27	1119
Other	0	80	38.92	37	28.02	785.2	12	467

Engineers identified several other issues affecting project success. Key challenges included insufficient drainage evaluation, difficulty obtaining accurate field estimates, and poor communication between designers and field teams. In one project, guardrail replacement encountered problems, such as shortened guardrail lengths, missing end terminals, and incorrect guardrail layouts that impacted safety and project timelines. Additionally, the lack of communication and accountability contributed to mistakes in plans, which should have been identified during project development. Engineers emphasized the importance of design personnel making site visits to enhance understanding and effective collaboration. Late information and rushed processes hindered thorough reviews, resulting in potential design rework and suboptimal outcomes. Overall, while many issues were interconnected, misrepresentation of field data was highlighted as a more significant contributor to design errors than the errors themselves.

6.5.3 Additional High-Risk Areas Identified by Respondents

Respondents identified various recurring challenges that contribute to project risks beyond the typical design errors. These challenges can be organized into three main categories: communication issues, process inefficiencies, and external constraints.

a. Communication and Coordination Issues
    - Failure to communicate changes to other departments
    - Delays in receiving necessary information
    - Lack of accountability in the design and review processes
b. Process and Planning Challenges
    - Incomplete data from surveys or geological assessments
    - Timing of reviews: Conducting them during the initiation of grading plans would be more beneficial than waiting for the final plan issuance
    - Pressure to complete plans quickly due to time constraints
    - Scope creep impacting project development
c. External and Financial Constraints
    - Rising inflation affecting overall project costs
    - Delays in right-of-way (ROW) acquisition and project shelving hinder progress
    - Insufficient force account work to manage unforeseen issues

These insights reveal that while design E&Os are significant concerns, broader challenges related to project management and communication also play a crucial role in increasing project risks. The focus on delayed reviews, incomplete data, and tight timelines underscores the need for improved coordination and better early-stage planning to mitigate these risks effectively.

6.5.4 Construction, Bidding, and Design Reviews

The research team assessed the effectiveness of the AGC-WYDOT meetings to limit the occurrence of design E&Os. A significant portion (33 percent) did not find these meetings relevant to their role. While 30 percent found them moderately effective, 24 percent (Slightly Effective + Not Effective at All) did not see much value in them, as shown in Figure 33. The absence of "Extremely Effective" ratings shows how these meetings may lack strong, tangible benefits for many participants. The data suggests that there may be room for improvement in structuring or facilitating these meetings to make them more useful.

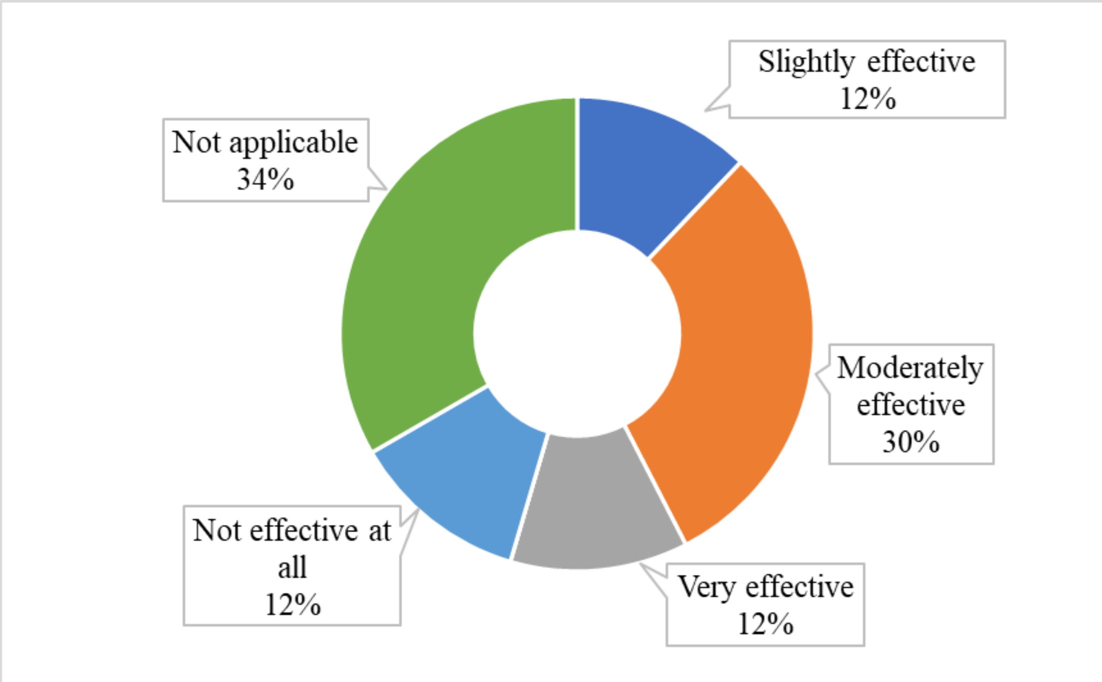

Figure 33: Effectiveness of AGC-WYDOT meetings

When assessing the effectiveness of the current design review process, the significant results in Figure 34 suggest that the majority (89 percent) of respondents rated it as at least moderately effective. Among these, 54 percent (categorized as Extremely Effective and Very Effective) believe that the process plays a crucial role in minimizing errors. In comparison, 35 percent (Moderately Effective) recognize its value but see opportunities for improvement. Only 11 percent rated it as Slightly Effective, indicating that it has minimal impact, and no respondents found it to be completely ineffective. In comparison to Figure 34 (AGC-WYDOT meetings), the design review process is perceived as more effective overall, as no participants dismissed its impact entirely. This data indicates that while the design review process is largely effective, there are still areas that could be refined to further reduce design E&Os.

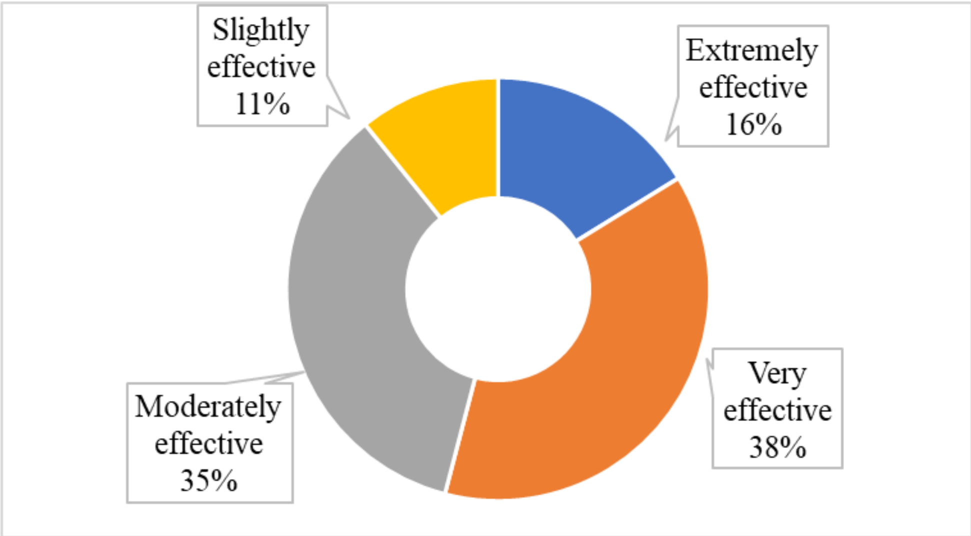

Figure 34: Effectiveness of the design review process to limit Design E&Os

6.5.5 Quality Control Mechanism

The current design review process includes several checks that are conducted whenever plans are issued. The research team asked the design personnel if they followed all the steps in the review process in each stage. Figure 35 illustrates the likelihood of the design team using all the steps in the review process. Nearly all respondents indicated that they used the review steps; however, around 60 percent of them used the checks most of the time, while 44 percent stated they only used all the steps sometimes or about half the time.

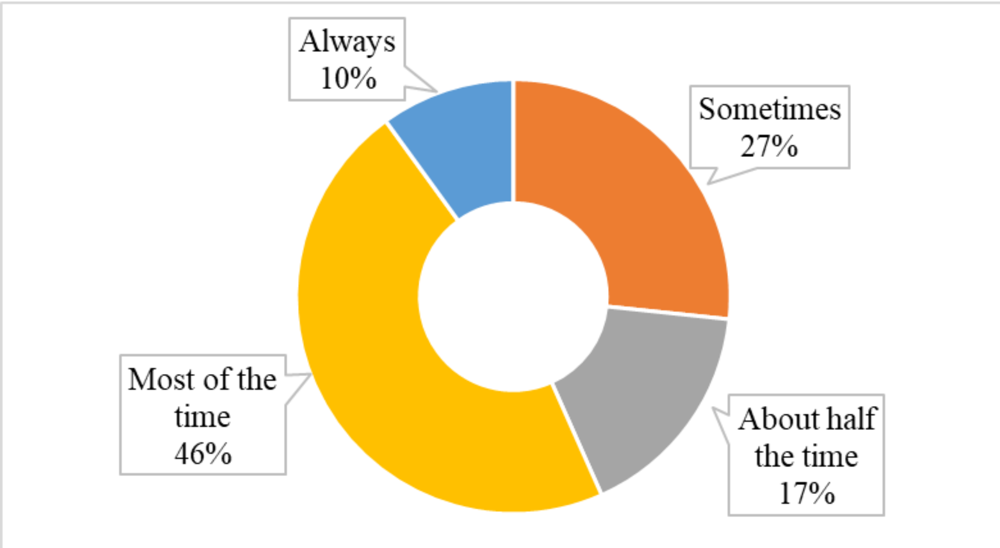

Figure 35: Likelihood of using all the steps in the review process

When asked about the effectiveness of the current design review checklists, the majority of design personnel indicated that they are moderately effective. However, many of the design personnel mentioned that they tend to rely more on their personal experiences for thorough checks rather than strictly following every step in the checklist. Most respondents noted that the checklists are only helpful for identifying omissions and ensuring that the design components are not overlooked. Figure 36 shows the ratings on the effectiveness of the current design review checklist; the responses highlighted the need for improvement in the current checklist.

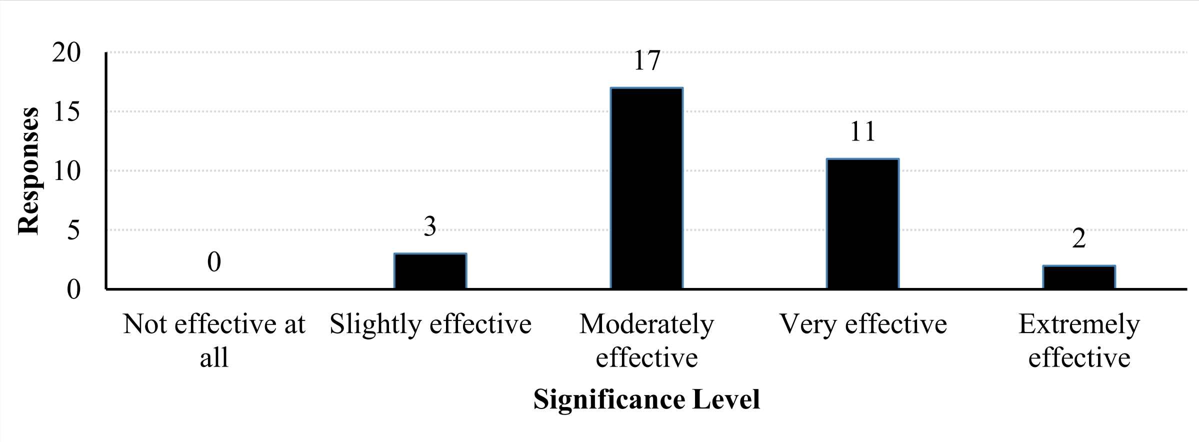

Figure 36: How effective are the current design review checklists?

6.5.6 Design Error Causal Factors

Based on surveys and interviews conducted with construction engineers, a list of common causal factors was compiled. This list was incorporated into the survey and sent to design personnel, asking them to identify the most common factors they have encountered. The results of the survey are presented in Table 16. Eighty percent of respondents identified employee turnover as the most pressing issue, closely followed by communication problems, which were reported by 75 percent of respondents. Schedule pressure and accountability issues were noted by eight out of the 36 respondents. Table 16 illustrates the rankings of these factors as reported by the respondents.

Table 16: Causal factors and their Prevalence

Rank	Factors	Count [N=36]	Percent [N=36]
1	Inexperienced staff / Employee turnover	29	80.56%
2	Poor Communication	27	75.00%
3	Schedule pressure	16	44.44%
4	Lack of proper planning during design	13	36.11%
5	Lack of training, strategy, and leadership	10	27.78%
6	Discrepancy in design checks and audits	10	27.78%
7	Poor scope definition	9	25.00%
8	Lack of accountability	8	22.22%
9	Rounding up quantities	0	-

The identified causal factors were analyzed in collaboration with the design team to comprehend their frequent occurrence and their effects on the design process. The design team provided ratings for these impacts, as illustrated in Figure 27. Employee turnover and inexperienced staff were recognized as the most significant contributors to design errors, receiving 25 percent of the votes, while poor communication followed closely with 21.71 percent. Schedule pressure and inadequate planning were rated at 13 percent and 10 percent, respectively. The survey indicated that inexperienced staff had the most profound effect on design while rounding up the estimates was seen as having a minimal impact. Figure 25 presents the survey results regarding the influence of causal variables on design E&Os. The variability in the impact of factors such as lack of training, planning, and accountability suggests that their effects can vary significantly between different projects.

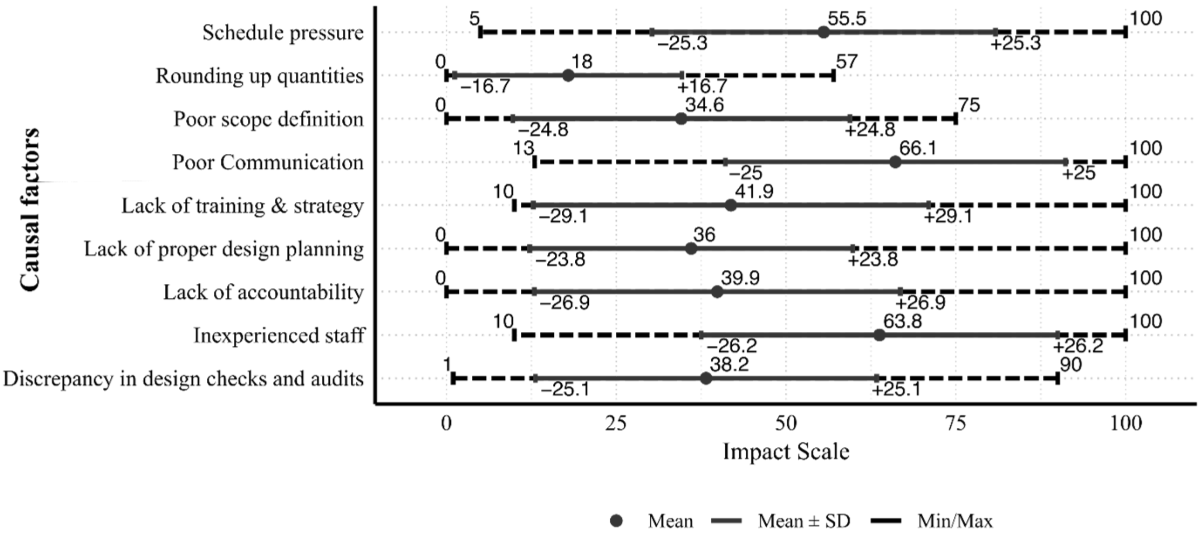

Figure 37: Impacts of Causal Variables on Design E&Os.

Some additional reasons behind the Design E&Os, as chaptered by the design personnel, are as listed below:

- Software changes and debugging issues
- Poor document management practices
- Use of common sizes instead of using true dimensions
- Changes in budget allocations
- Designers are being overworked due to staffing shortages
- Use of outdated material specifications
- Last-minute change requests and interference from higher authorities.

6.5.7 Design Quality Control Tools Familiarity and Effectiveness

The design engineers provided ratings on the effectiveness of the current design review process in limiting design E&Os, which was used as a comparative analysis between the two sides. The research team reviewed the familiarity and effectiveness of some of the existing design quality control tools. Figure 38 shows the results from the observation on how the

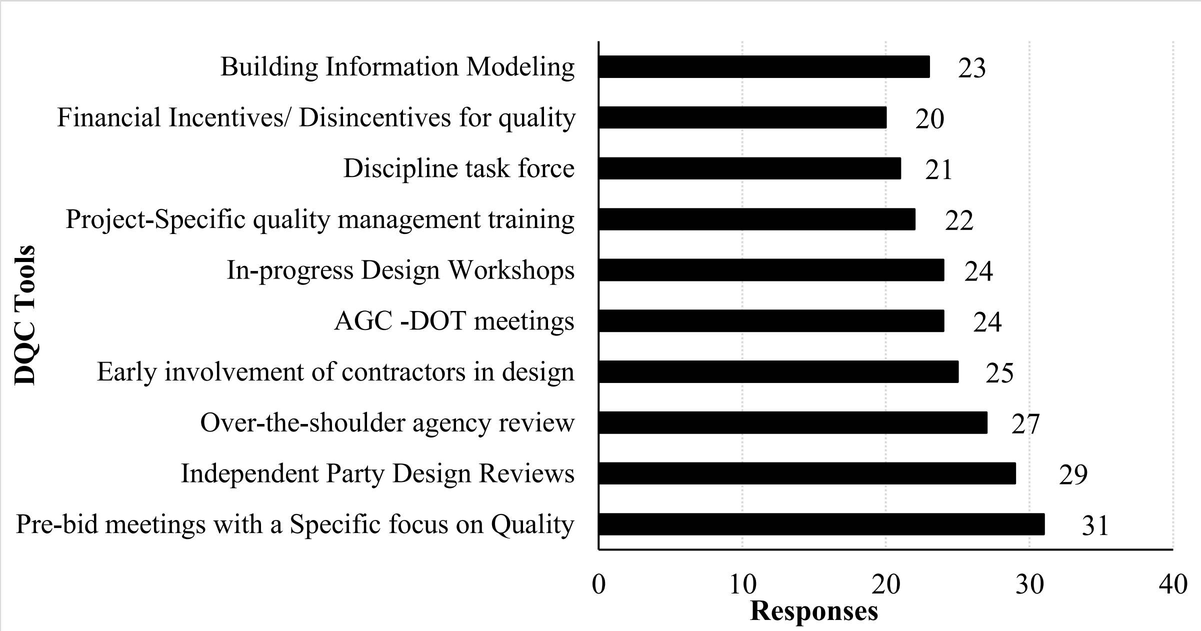

Figure 38: Frequency of responses for DQC tools familiarity among Design personnel

The survey data from the design engineers, like the Construction personnel data, represent the familiarity and construction personnel with the DQC tools and how effective they believe the tools are in mitigating the occurrence of Design E&Os or their impacts.

Most tools run higher in effectiveness ratings than familiarity ratings, as shown in Figure 39 and Figure 40**.** This indicates that even tools that may not be as well-known are still seen as valuable when put to use. Interestingly, the AGC-WYDOT Meetings stand out, as it has a familiarity rating of 47.88, which surpasses its effectiveness rating of 39.10, suggesting that while people are familiar with this tool, they don't find it to be especially effective. Early Contractor Involvement had the largest positive difference (+19.32), indicating that while it is not as well known (29.68), those familiar with it recognize its effectiveness (49.00). Like the construction personnel survey findings, the Financial Incentives/Disincentives for Quality show moderate familiarity (38.65) and high effectiveness (47.47), indicating that these tools have strong potential. Increasing awareness could enhance adoption and utilization.

The AGC-WYDOT Meetings received the highest familiarity rating at 47.9, highlighting their prominence among design personnel, followed closely by Independent Party Design Reviews at 39.8 and BIM at 39.2, indicating a reasonable level of recognition for these tools. In contrast, Project-Specific Quality Management Team Trainings and Early Involvement of Contractors received the lowest ratings at 28.0 and 29.7, respectively, suggesting they are less well-known or utilized within the organization. Furthermore, the significant standard deviation across most tools reflects a wide variability in responses, with the Min-Max ranges highlighting extreme differences, some respondents rated their familiarity at 0, while others approached 100. This notable spread, particularly for BIM and the Discipline Task Force, suggests that familiarity varies greatly among different groups, likely due to factors such as job roles and levels of project involvement.

Most personnel have different levels of familiarity with the tools. Some are very familiar, while others have little or no experience. This high variance shows the difference in familiarity. In contrast, the effectiveness ratings are more consistent, indicating that people generally agree on how well the tools work when used. The BIM and Discipline Task Forces have the most significant gap in familiarity, with some members knowing the tools well while others do not. Quality Management team training had the lowest effectiveness variance, suggesting strong agreement among the respondents on its perceived impact.

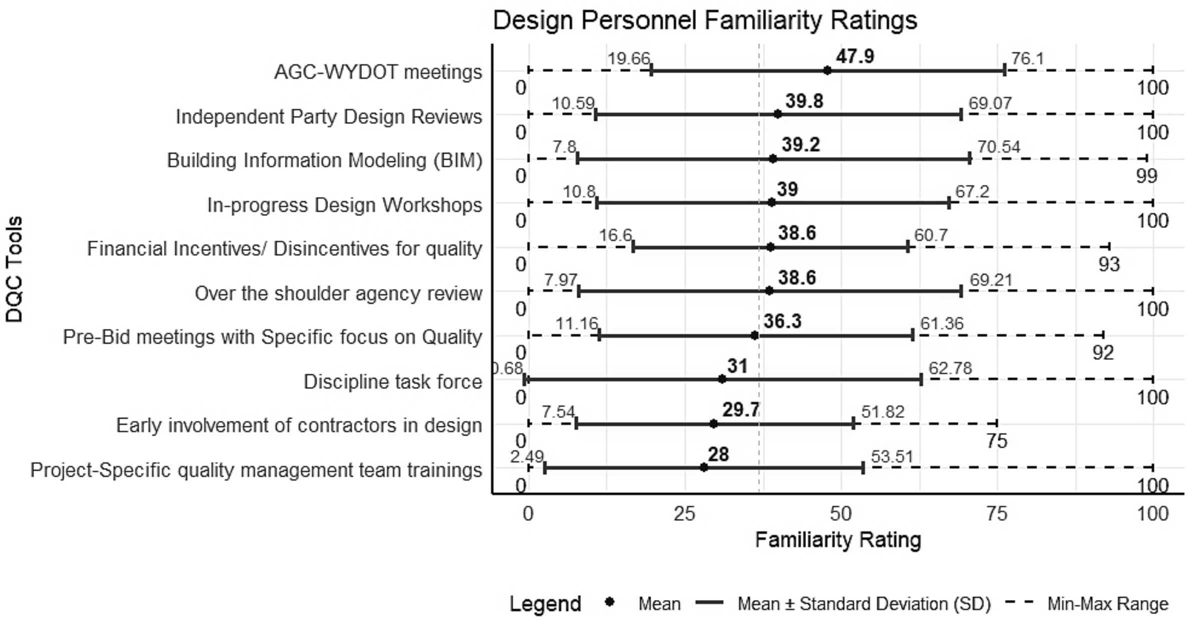

Figure 39: Familiarity of Design Personnel with DQC tools

By examining the relationship between familiarity and effectiveness, several noteworthy patterns emerge. For instance, the AGC-WYDOT Meetings exhibit high familiarity (47.9) yet low effectiveness (39.1), indicating that while these meetings are well known, their impactful execution may require reevaluation. Similarly, Pre-Bid Meetings, though somewhat familiar (36.3), do not rank highly in effectiveness (42.5), suggesting potential gaps in their implementation. Interestingly, the Early Involvement of Contractors stands out with low familiarity (29.7) but high effectiveness (49.0), signaling that even with limited awareness, this approach holds significant potential for impact, hinting at a need for greater advocacy and training. Project-Specific Quality Management Team Trainings also show a disparity, with familiarity at 28.0 and effectiveness at a moderate 40.2, suggesting that increased adoption could enhance design quality. Conversely, Independent Party Design Reviews and BIM demonstrate a strong alignment between familiarity and effectiveness, with ratings of 39.8 and 44.9, and 39.2 and 44.6 respectively. This indicates that these tools are not only recognized but also valued by industry professionals. However, BIM's substantial standard deviation highlights the variability in experiences among users, pointing to an opportunity for further development and consistency in its application.

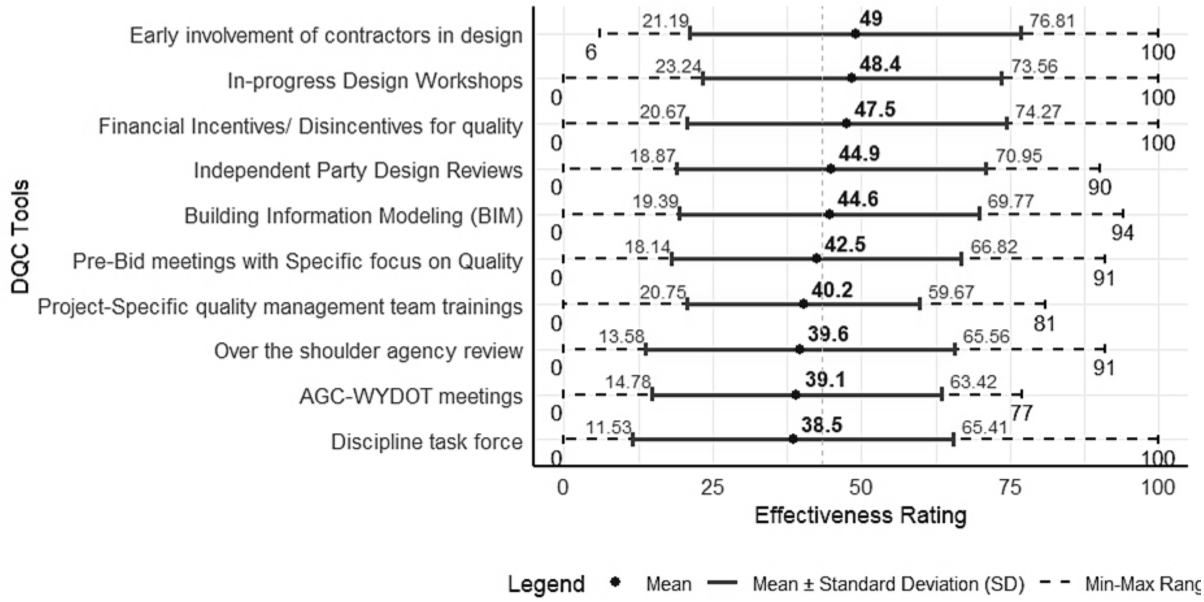

Figure 40: DQC tools effectiveness ratings by Design Personnel

Tools with lower familiarity but higher effectiveness can be promoted further to maximize their impact. Like the responses from the construction team, tools like BIM had inconsistent familiarity and effectiveness ratings, suggesting the implementation challenges and the gap in knowledge and usage.

6.5.8 Recommendations on limiting Design E&Os

The recommendations gathered from construction engineers were evaluated in collaboration with the design engineers. The design engineers rated the effectiveness of the recommended tools on a scale of 0 to 100, where 0 represents the least effective and 100 represents the most effective. Communication was identified as the primary reason behind the occurrence of design E&Os. The engineers rated improved communication as the most effective solution, closely followed by in-person or online design reviews, which foster better collaboration and enhance the quality of the produced designs.

Post-construction reviews ranked third. During discussions with the engineers, they mentioned being aware of post-construction reviews but expressed that they had not participated in this process previously. To better understand the process, the research team scheduled a brief interview with the project closeout staff. The findings from this interview are described in detail in the following sections of the chapter.

In-field meetings were mentioned shortly thereafter, and a proper guideline for new hires received a rating of 65.19. The design review checklist and peer reviews were rated at 62.81 and 62.68, respectively, as shown in the Figure 29**.** Post-construction reviews (67.8) and in-person/online plan reviews (67.5) demonstrate high effectiveness, although there's moderate variation in responses. Most participants found these reviews to be useful, but opinions do vary somewhat. On the other hand, real-time review tracking (51.7) shows significant variability in feedback, with ratings ranging from 24.74 to 78.68. This suggests mixed perceptions regarding its usefulness among respondents. These insights highlight the importance of evaluating and potentially enhancing the real-time tracking process to better meet participants' needs and expectations. Even though the recommendations show varying response rate in effectiveness perception, all of them are still rated effective overall, most recommendations were perceived positively.

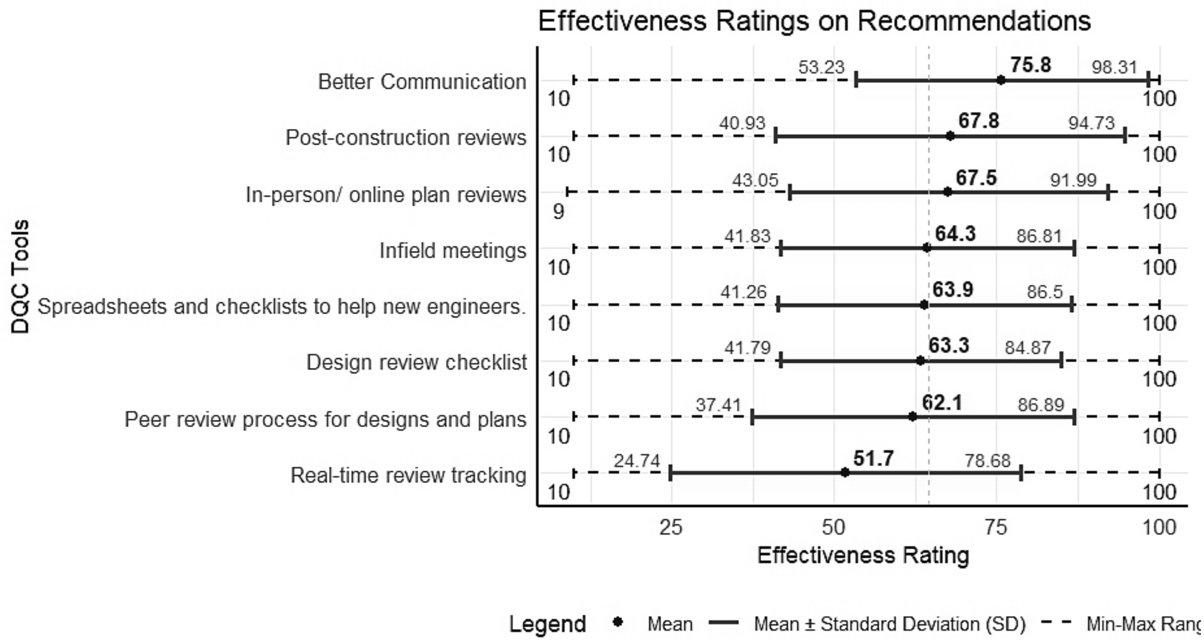

Figure 41: Design personnels' effectiveness ratings on recommendations

In the open-ended sections of the survey, the research team received some detailed information on the design sides' views and recommendations. Several respondents highlighted challenges with the design review checklist, including its limited effectiveness due to reviewers' lack of project familiarity. One suggestion was to implement a deep-dive review where one or two dedicated reviewers become highly familiar with each project, improving the accuracy and effectiveness of the review process. The following suggestions were made by the survey respondents:

- Educating newer employees on the importance of using checklists.
- Updating and modernizing the checklist on an annual basis to keep it relevant.
- Dividing the checklist into structured sections, such as:
    - Ensuring the full project intent is met.
    - Performing a constructability check.
    - Verifying the accuracy of the plans.
- Digitizing the checklist and storing it in a shared drive, enabling designers and project stakeholders to access and update it in real time.

- Expanding checklist categories include new design types (e.g., new bridge designs) and updates to align with specification changes.

While checklists are useful for catching omissions, some respondents emphasized that they cannot prevent all design errors and should be used in combination with a structured review process to minimize risks.

6.6 Interview Insights

In response to the survey findings and feedback from the engineers, the research team conducted 13 semi-structured interviews to gain deeper insights from design engineers about their experiences and perspectives on design E&Os. Over two weeks, the team interviewed design staff from various departments, including the check squad, project engineers, bridge program specialists, materials engineers, CAD engineers, and principal engineers. These participants, who had between two and 37 years of experience in the highway industry, represented all relevant disciplines and shared their unique perspectives, which reinforced the results obtained from our data analysis and surveys.

The interviews were conducted via Zoom, with each lasting approximately 30 minutes. To keep all participants informed, the research team included the interview questions in the invitations and provided an overview of the study at the beginning of each session. Additionally, the team analyzed and classified the survey findings to outline the requirements and recommendations from field engineers regarding the errors identified in the literature review. Transcripts of the interviews were created and examined using thematic analysis with the help of Atlas.ti, highlighting the recurring themes that emerged during the discussions. The findings from the interviews are detailed in this section.

The interviews touched on specifics with the design engineers, the basic flow of which consisted of the following:

- Current Design Review Process.
- Constructability Review Process and Involvement.
- Procurement Changes and Addendums.
- Change Order Review Tracking.
- Post-Construction Closeout.
- Other Issues and Recommendations.

6.6.1 Current Design Review Process

As per the interview discussions, the current design review process varies among different design squads. Some designers strictly follow a set process for the checks, while others rely on their experience. However, as the department has lost experienced employees in recent years, the need to establish a standard review procedure has become more apparent. Additionally, the design squad reviews conducted within a group differ from one another; some design squads conduct individual reviews of other designers' work, ranging from simple summaries and calculations to detailed checks of the design components. Presented are the insights from the interviews into the positive and the negative aspects of the current design review process.

6.6.1.1 Positives

When asked about the engineers' experiences with the design review process currently laid out, both positive and negative aspects were revealed. The engineers pointed out that the design process flowchart is meticulously laid out, encompassing all necessary steps in the design flow, including stages of review and critical checkpoints during these evaluations. The check squad, serving as quality reviewers, keep detailed records of all addenda, tracking amendments throughout the year while identifying errors and the responsible parties. Any modifications made to the plans prior to issuance are systematically documented in accordance with established procedures. Additionally, other designers may review plan sets from their colleagues if time permits. At every stage of the project, the plans are subjected to reviews by all personnel involved, including the Bridge program, which conducts its internal evaluations. Special provisions undergo a rigorous three-stage review: first by project development, followed by construction field staff, and concluded with a mass review. Although the five to six phases of plan issuance and review are beneficial, the actual number of reviews varies depending on the project's scope, as not every project will adhere to the same review standards, influenced by the development timeline. Some designers and design squads utilize both an internal schedule for their design development and design reviews, along with the PCS schedule, to ensure adequate time is allocated for these activities. Feedback varies among departments, with some providing extensive input while others may refrain from participating in the feedback process altogether. Moreover, certain designers meticulously check every calculation produced during quality checks, a practice deemed highly useful and essential for the overall integrity of the project.

The Bridge Program incorporates a collaborative and iterative approach to enhance its fabrication and constructability reviews, particularly in complex projects. Initially, these reviews are based on the individual experience of engineers and designers, as there is currently no formalized procedure in place. Each project begins with a preliminary evaluation by the engineer or designer, followed by a thorough review conducted by the squad leader, ensuring a robust oversight process. To further improve practices, the program has established a dedicated team tasked with updating its design and application manual. This team facilitates periodic meetings where lessons learned from past projects are discussed, allowing for the standardization of procedures based on collective insights from bridge engineers, technicians, and others involved. However, a notable gap remains in monitoring the implementation of these updates, as there is no formal process to ensure the newly revised manual or design standards are actively utilized.

In conjunction with the Bridge Program, the Bridge Analysis Software (BRASS-DIST) plays a critical role in maintaining the quality of designs. The software specifications are routinely updated to reflect the latest standards, ensuring the tool remains effective and relevant. Developed in collaboration with the University of Wyoming, BRASS is designed with a focus on quality control within the engineering process. Any modifications to specifications and standards are meticulously managed through coding, and engineers utilizing this software are kept informed about pertinent updates through comprehensive reviews and chapters. To uphold the integrity of the software's output, calculations performed by the program are routinely hand-checked against manual calculations. This multi-tiered approach to quality assurance has evolved; the previous practice of a single programmer check has been expanded to include peer reviews, followed by checks from the programmer and the squad, thereby enhancing the overall reliability and accuracy of the analysis conducted through BRASS.

6.6.1.2 Areas of Improvement

The design process often encounters significant challenges, primarily due to a lack of adherence to established steps by all participants involved. Particularly during emergency projects, such as the recent Jackson landslide repair, time constraints frequently lead to a hurried process where not all steps are followed. This urgency can result in fewer reviews, which increases the likelihood of errors, compounded by human mistakes. Moreover, some engineers arrive unprepared for plan review meetings, relying heavily on the design team, while certain designers resist delegating tasks, leading to burnout and overwork, exacerbated by low staffing levels within the department. Additionally, many projects experience delays in receiving materials and rate recommendations, typically arriving only two weeks prior to final plan issuance, which forces late design changes and leaves insufficient time for reviews. The issues are further complicated by staffing shortages, limiting the field's ability to thoroughly evaluate plans and provide timely updates on necessary changes, often resulting in last-minute adjustments that are inadequately reviewed. Construction staff also face time constraints, creating an unpredictable environment where reviews may or may not catch errors. During the summer months, field engineers are particularly busy, which diminishes the likelihood of adequate pre-checks of plans. Moreover, checklists are utilized only by the project Development (PD), and there is a notable lack of involvement from the PD and design teams after a project has been awarded, contributing to the overarching inefficiencies in the design and review process.

Monthly meetings are held with the design team leaders to discuss ongoing projects and progress checks. During these sessions, design reviews are conducted informally. A Word document is utilized to compile questions related to the project, which are then discussed during calls or sent to the field personnel and all parties involved in project development. Additionally, plan reviews are conducted with the construction staff. While contractors have access to the plans before project letting, they seldom perform reviews, possibly due to a lack of incentives.

6.6.1.3 Consultant Projects

Reviews for all projects handled by the DOT follow the same steps and criteria, with no exceptions; thus, Consultant projects are reviewed in the same manner as in-house designs, and addendums are tracked accordingly. However, there are some inconsistencies in the oversight of consultant reviews; while some individuals perform well, others do not uphold the same standards, leading to varying quality in design accountability. Several engineers have raised concerns about the lack of accountability for designs created by consultants, noting that these designs do not undergo the same rigorous checks as in-house projects, which can result in more errors and frequent change orders. This perspective appears to contradict previous statements from interviews suggesting that consultant designs go through the same number of reviews and adhere to the same rigorous processes as in-house designs, raising questions about whether there is truly a standardized approach to quality reviews or if the process varies by department and development location. Additionally, conflicting opinions emerged during discussions: one interviewee observed that the design team was often unaware of changes made to their projects post-design, as they received no feedback on change orders. In contrast, a materials engineer asserted that all changes are tracked and communicated. One of the engineers further noted that when he was part of the team, change orders were addressed with the designers, indicating that the current lack of communication may differ from past practices.

6.6.2 Constructability Reviews

There is no formal process for constructability reviews from the field. There are some engineers who have worked in the field before joining the design side. Their previous experience has helped them work better on the designs in general, and they have relied on that experience for the constructability questions that arise in the designs, which is not always the case for all designers. There are some kickoff meetings that happen from time to time, but they are not mandated for all the projects.

There are also project engineers and designers who have active communication with the construction staff and the resident engineers responsible for the project through either emails or phone calls about the constructability of their designs and with any questions that needs to be addressed by the field for their recommendations which makes the designing process a lot more smoother and everyone stays onboard on the changes happening on the design and the reason behind them.

One of the interviewees mentioned, "It might be beneficial for designers to spend some time in the field before beginning their careers to gain a better understanding of construction processes and perspectives."

The current constructability review process lacks formality, relying instead on calls, emails, or informal meetups, which diminishes the opportunity for meaningful communication. Although engineers occasionally raise project-related issues during these informal interactions, the absence of a structured feedback loop often leaves designers in the dark regarding the strengths and weaknesses of their designs. This missed communication hinders potential learning that could lead to improved designs in the future. Even if a project closeout and constructability review are included in the design manual, these processes are not consistently carried out. While the bridge program does hold informal discussions with fabricators to assess design feasibility and gather field insights, such practices are predominantly reserved for complex projects and are not standard for all designs. Furthermore, construction field engineers have limited involvement in the review stages, contributing to communication gaps. Although some designers take the initiative to consult directly with REs about constructability, this informal approach heavily relies on individual initiative. Ultimately, discussions around constructability are infrequent during the design process and tend to arise only when prompted by field personnel during plan reviews.

6.6.3 Post-Construction Closeout

Designers and operations engineers are generally aware of post-construction reviews, but many have never participated in one. The research team conducted a brief interview with the closeout analyst to gain a deeper understanding of the post-construction closeout process, which revealed:

In each state district, one person is responsible for construction and documentation, overseeing all projects within the district. This individual keeps track of construction updates provided by the construction engineers and monitors the projects' budgets, progress, and schedules in collaboration with the field engineers. Construction documents are reviewed and updated monthly, with the updates published on the CMS and distributed to all relevant parties via email threads.

The design process in engineering projects, particularly during emergencies like the Jackson landslide repair, faces significant challenges due to non-adherence to established steps by participants. Time constraints often lead to hurried processes with fewer reviews, increasing the likelihood of errors due to human mistakes. Engineers frequently arrive unprepared for plan review meetings, and some designers resist delegating tasks, resulting in burnout amid low staffing levels. Delays in material and rate recommendations often force late design changes, making timely reviews difficult, especially during summer months when field engineers are particularly busy.

While monthly meetings with design team leaders involve informal design reviews and discussions using a Word document for questions, construction staff typically do not have adequate time for thorough plan reviews. Although contractor access to project plans exists, a lack of incentives often results in minimal review activity.

For consultant projects, the review process follows the same criteria as in-house designs; however, inconsistencies in oversight lead to variable design quality. Concerns have been raised about the lack of accountability for consultant designs, which may have fewer rigorous checks, resulting in errors and change orders. Moreover, communication issues regarding post-design changes hinder collaboration between design teams and project engineers.

The constructability review process is informal and varies by project, lacking a standardized approach. While some engineers leverage their field experience to address constructability questions, kickoff meetings are not mandated for all projects. Active communication between project engineers, designers, and construction staff can enhance the design process, but a structured constructability review process is lacking. Some interviewees suggest that designers would benefit from field experience to better understand construction processes.

Details on the project, including the change orders, timeline, and schedule changes, are updated on the CMS every month during the project closeout process. Some updates might be late when several projects are going on simultaneously, but the updates are published to the CMS, and all possible parties involved have access to the files.

Design engineers typically have limited involvement during construction unless significant changes occur. This limited involvement can lead to challenges, mainly when unexpected issues require design modifications or adjustments. The separation between design engineers during the construction phase can create gaps in communication and understanding of the project's evolving needs. This disconnect can result in mishandling design errors or omissions that could have been avoided with better collaboration and continuous engagement throughout the project lifecycle.

The interview reveals that there are flow charts and checklists for project closeouts designed to assist project engineers, but these tools can be complex and require detailed documentation. Documentation mainly occurs during meetings with the district construction engineer, where ongoing challenges and areas for improvement are discussed. The construction finals analyst keeps a record of these discussions, although awareness of specific issues may sometimes be limited. The district construction engineer helps document any problems that arise during contractor interactions. This collaborative effort fosters alignment in addressing challenges. Documenting lessons learned is crucial as it improves future project execution and promotes a culture of continuous improvement, allowing teams to avoid repeating past mistakes.

Overall, the district construction engineer and the finals engineer share the responsibility for documenting lessons learned. This emphasizes the importance of communication and collaboration in project management. Ultimately, this practice contributes to better project outcomes and more effective management strategies for subsequent projects.

The team mentions that the CMS is designed effectively to track changes related to change orders and schedule delays. Notifications are received whenever a change order is issued, allowing for a review of the impact of these changes on project quantities and bid items. This review process is crucial to ensure that the changes do not negatively affect the overall scope or budget of the project.

One significant challenge mentioned is when a change order alters the completion date for a portion of the project while leaving other portions unchanged. This situation can complicate project management, as it requires careful coordination to ensure that all aspects of the project remain aligned and that delays are managed appropriately.

The construction finals analyst also emphasized the importance of tracking overtime days related to liquidated damages. This tracking is essential for maintaining transparency and accountability, as it informs the contractors and the district construction engineer about the project's status and any delays that may have occurred. While monitoring change orders and delays is not a daily task, it is a frequent part of the project management process, indicating that these issues arise regularly and require ongoing attention.

The reasons behind change orders can vary widely. Recently, many change orders have been driven by rising material costs, making it difficult for contractors to adhere to their original bids. Other common reasons for change orders include the need for project extensions or additional excavation hours. The decision to issue a change order often depends on the specific circumstances of the project and the extent of the changes required. In some cases, costs can be managed through a force account, allowing for payment without a formal change order and provided adequate documentation, such as invoices.

6.6.4 Issues and Recommendations

Most of the recommendations from the design team closely resembled those provided by the construction team. However, there were some differing opinions and additional suggestions from the design team during their interviews. These insights could be considered to enhance the design review process and reduce the frequency of design E&Os.

6.6.4.1 Infield meeting

Following the onset of COVID-19, the design team, like the construction engineers, saw a decrease in in-person meetings. While many engineers worked from home during the pandemic, there was an increase in online meetings. Even after the pandemic, this trend continued. Although engineers have begun to go to the field for larger projects, smaller, faster projects with limited design time and lower budgets tend to overlook on-site visits. Sometimes, the only form of communication for these projects is through email exchanges between the field workers and designers.

According to the engineers, the infield meetings provided a better perspective from the parties involved in the design. Also, they forced every individual in the project to look at the plans together. Due to low staffing and turnover and the high construction period, it's difficult to conduct in-person reviews.

6.6.4.2 Design checklists

Discussions with the design engineers and the compilation of information from the team involved in preparing the design checklists have highlighted the importance of their experience. Engineers with over 30 years of experience can help develop a more effective design checklist. This resource will serve as a valuable guideline for new team engineers, ensuring that essential knowledge is preserved even when experienced members retire. By retaining this knowledge, the department can maintain continuity and support ongoing projects, even after seasoned professionals move on.

6.6.4.3 Time constraints

The design team in conversation mentioned how the construction letting in WYDOT is first quarter heavy, usually October through February, meaning most of the project designs are finalized around the end of summer for letting, which is the peak construction period in the state. Most of the field staff are the busiest during this period, which leads to skipped design review phases on their part. This might not be an easily solvable problem, as it was set up as per the requirements of the contractors in the state to accommodate their plans as well.

The department's quality review team consists of two people and handles four to 12 projects per month. Each project can have up to 100 pages to review. The quality control team's main focus is to review summaries and calculations to ensure that nothing has been missed or miscalculated. This is particularly important because contractors rely on these quantities when bidding. This process helps to ensure that the design team and contractors are aligned.

Rushed projects like the ones with government pressure must be handled early, which leads to compromised schedules and steps during the design. The messed-up schedules due to the rush, then miss out on the standard process of reviews for quality checks of the designs.

Field engineers often encounter difficulties with tight review periods and their demanding schedules during construction. The typical two-week review period frequently proves insufficient for a thorough assessment of final plans, potentially hindering their ability to provide meaningful feedback. This underscores the need for better alignment between design schedules and construction timelines to improve the effectiveness of reviews.

6.6.4.4 Peer reviews

As most designs are centralized in the Cheyenne office, different design squads are accessible in the same office. Having a fresh set of eyes that have not worked on the project, go through the plans and be responsible for the plan reviews might help catch some errors that might have been missed in the internal design audits. This process will also provide a broader perspective to the design squads about how the other teams have been handling the designs and take notes on either improvements they can make in their designs or pinpoint inefficiencies in their design process.

A fresh set of eyes on the project might provide a broader perspective on different kinds of projects and involvement in a broad area.

6.6.4.5 Construction Experience Before Joining the Design Team

The design team emphasizes the experience of a young designer in the field before getting into design. The design team in Laramie usually allows the students to work in the field for at least one summer before joining the design squad, which makes them visualize their designs better and analyze the constructability of the design.

6.6.4.6 Importance of Structured Review Processes

A structured review process is essential for ensuring comprehensive plan evaluation and communication among stakeholders. Utilizing flow charts and plan issuance distribution charts facilitate the inclusion of all programs, including construction, in the review process. These tools will help ensure that every program has the opportunity to review plans, including final versions, enhancing communication and involvement in the design process.

6.6.4.7 Addressing Experience Gaps Among New Employees

To address the experience gaps among new employees, implementing checklists or procedures can guide them through design checks. Such tools help new designers understand critical aspects of the review process, improving their learning curve and overall design quality.

Detailed checklists are crucial for navigating the review process and enhancing the quality of designs produced.

6.6.4.8 Independent Design Checks for Quality Assurance

Informal independent design checks, where experienced designers review the work of their peers, provide an additional layer of quality assurance. This practice ensures that designs meet required standards before finalization and leverages the expertise of senior designers to enhance overall design quality.

6.6.4.9 Openness to Learning and Improvement

A commitment to continuous improvement is reflected in the willingness to learn from other states' quality control practices. Embracing insights and adopting new methods can enhance design processes and deliver better outcomes. Staying informed about best practices and innovations is key to refining processes and achieving superior results.

6.7 Comparison between Construction and Design Perspectives

The field and design engineers, while agreeing on several common points of errors and recommendations, had differing opinions on some issues. One interesting topic that emerged was their contrasting views on the major types of Design E&Os that led to the most significant cost impacts or change orders.

As shown in Table 17, the analysis of change orders indicates that plan errors have the most significant impact on cost overruns, according to field engineers. In contrast, design engineers rated plan errors as having the least impact on costs, highlighting a substantial difference in perception between the two groups. Estimate errors followed closely in their impact on cost. Additionally, design engineers noted that omissions are one of the most common reasons for change orders and their associated cost impacts on projects. There have been instances where inadequate communication regarding updates or missing notes in the final plans led to the issuance of change orders. The change order data shows the frequency of each of the listed errors on the change orders initiated across the

The rankings derived from the three types of data analysis are presented in the table below:

Table 17: Comparison of the ranking of Design E&Os based on Cost Impacts

Rank	Change Order	Field Personnel	Design Personnel
1	Plan Error	Plan Errors	Omissions
2	Estimate Error	Omissions	Misinterpretation
3	Existing Utilities	Estimate Errors	Estimate Errors
4	Omission	Misinterpretation	Existing Utilities
5	Misinterpretation	Existing Utilities	Plan Errors

The study revealed a statistically significant difference in average responses related to plan errors and their impact on project costs, as indicated by the t-test. This highlighted a notable discrepancy between the design and field perspectives, as shown in Figure 42. Specifically, the design perspective underestimated both the frequency and severity of plan errors compared to the field perspective, which characterized these issues as more prevalent and severe.

Design personnel perceive misinterpretations and errors related to existing utilities as having a greater impact than field personnel do. This may be because these issues originate during the design phase but become apparent later during construction. While there is some agreement between the two groups regarding estimated E&Os, there are significant differences in perception concerning other categories.

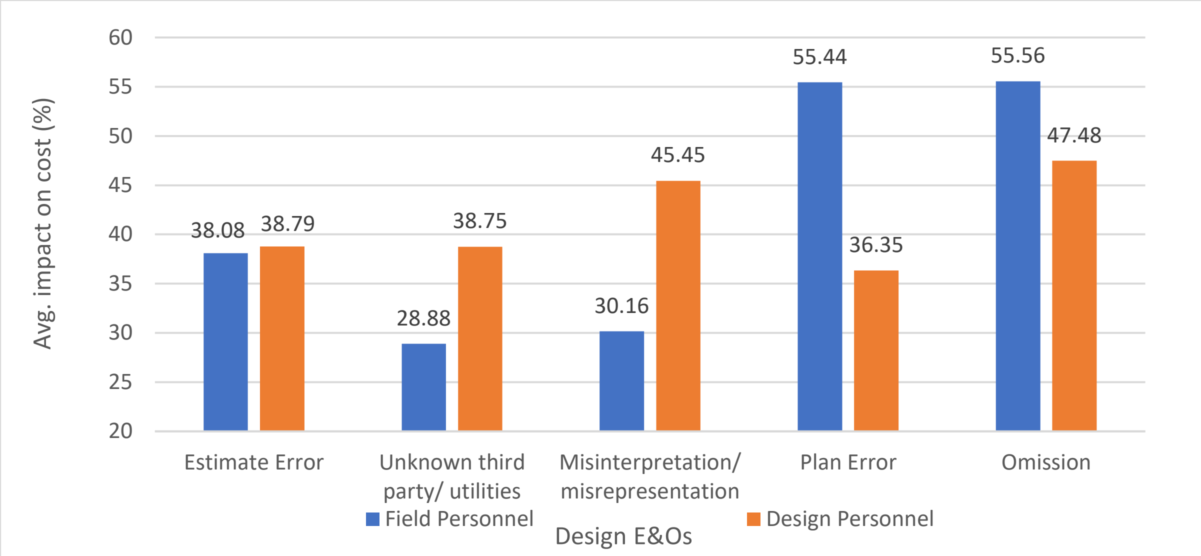

Figure 42: Cost Impact on due to Design E&Os.

The findings from the survey were analyzed and organized to present the requirements and recommendations from construction personnel regarding the errors identified in the literature review. Thematic analysis was conducted using Atlas.ti to systematically review the interview transcripts. The transcripts from the construction engineers' surveys served as the foundation for developing the initial codes for analysis. Codes were used as labels or keywords to help the research team highlight key pieces of information from the responses. For instance, if a response discussed communication problems, it was assigned a code such as "communication issues." The purpose of coding was to summarize the content of each data segment with a relevant term.

During the analysis of the survey responses, the transcripts were read thoroughly to identify important points, and appropriate codes were assigned. Related codes were then grouped together to identify themes, like the ideas discussed in Table 11. Each group of codes included subcodes based on relevant phrases that contributed to the development of these themes. Finally, these codes were exported and applied to analyze the interview transcripts from the design personnel, allowing for a comparison of the results.

Figure 43 is a Sankey diagram illustrating the frequency of codes and the relationship between causal factors (on the right) and errors (on the left) identified from related phrases in two groups of documents: interviews with construction personnel and interviews with design personnel. The findings from these interviews align with the rankings displayed in Table 2, which detail the impact and occurrence of design errors on costs.

On the left side, the themes represent factors contributing to errors, while the right side illustrates the outcomes associated with these errors. The thickness of the arrows indicates the frequency with which each theme was mentioned in relation to the identified errors; thicker arrows signify more frequent mentions, while thinner arrows indicate less frequent associations.

The diagram highlights that construction engineers mention plan errors more frequently than designers do. The frequencies shown relate to terms and codes derived from the interview transcripts. This visual representation of the descriptive data reveals the variation in items mentioned by the two groups.

Sankey diagram showing the flow and frequency of interview-coded causes of design and construction errors, linking sources such as communication and schedule limitations to error types like omissions, estimate errors, and plan errors.

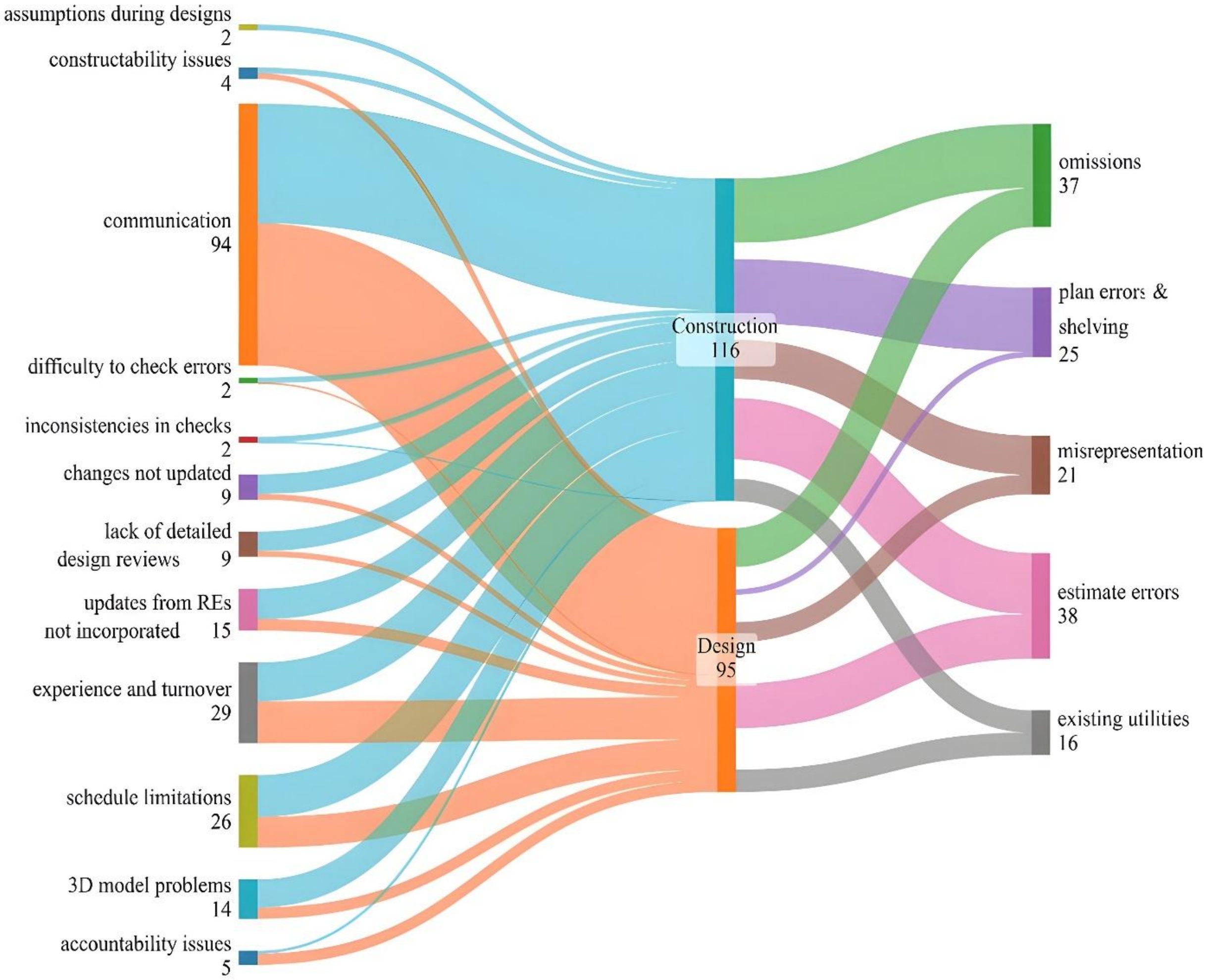

Figure 43: Sankey diagram showing the frequency of common codes in the interviews

In conclusion, the research revealed that design errors frequently arise from discrepancies in estimated quantities, mishandling of plans, and communication gaps between design and construction teams. These errors can significantly impact project timelines and budgets, highlighting the importance of evaluating schedule implications within project management. Although schedule delays often occur due to design errors, the absence of formal tracking tools creates challenges in effectively addressing these issues. The survey indicated that CMS and Falcon are the most commonly used tools for data and record management in WYDOT projects, while other platforms are utilized based on individual needs. The discussion further underscored the relevance of existing DQC tools and the engineers' knowledge and proficiency in using these tools to minimize design errors and omissions. Overall, enhancing communication and tool integration among teams can play a pivotal role in improving project outcomes.

6.8 PCS Scheduling Process

The interviews with the Construction Engineers highlighted the need for a brief discussion with Cheyenne's project control system team to learn more about the scheduling process and tracking. This section explains the findings from the hour-long interview with the PCS staff regarding their overall scheduling process, reviews and comment tracking, current projects, and review times allocated before and post-COVID; a distinct variation highlighted in the Construction Engineers' interviews.

6.8.1 Pre-defined templates

The team mentioned in the conversation that WYDOT uses templates for different scopes of work to assist in project scheduling. These templates contain a string of typical activities tailored to specific types of projects. For example, they have templates for overlay projects and bridge rehabilitation projects.

When a new project is initiated, the team matches the project's scope of work with the appropriate template. As the scope of work becomes more defined through documents like scope statements or Recon, adjustments are made to the schedule by adding or subtracting activities and durations.

The templates serve as a starting point for project scheduling by providing a structured framework of activities and timelines based on the typical requirements of each type of project. This approach helps streamline the scheduling process and ensures consistency in planning across different projects with similar scopes of work. The templates also serve as a communication tool, ensuring all stakeholders understand the project timeline and activities.

The project control system is designed to monitor progress, anticipate and address delays proactively, keep stakeholders informed through regular updates, and enhance coordination among project teams. External influences like time constraints, financial limitations, regulation alterations, and immediate infrastructure requirements can create pressure to accelerate project schedules.

Specific criteria address unforeseen delays or changes in construction or scheduling contingency. These criteria encompass buffer time allocation, regular risk assessments, adaptable resource management, efficient communication protocols, and contingency plans for different scenarios. By integrating these criteria into the project control system, teams can effectively manage unexpected disruptions and maintain project timelines.

Regarding external factors or pressure pushing plans to get out sooner, the team mentioned external pressure on project needs, such as the urgency to spend allocated funds quickly. This pressure can influence the need to expedite project timelines to meet funding requirements or other external deadlines. Additionally, there is an emphasis on projects that require immediate attention due to factors like ADA compliance, right-of-way takings, and weather constraints, which can also create pressure to accelerate project schedules.

6.8.2 Reviews

In the interview, the scheduling staff mentioned that PCS has assigned two weeks each to draft final plans and final plan reviews. At first, the scheduling team had allocated only two weeks for the entire review phase due to the designers' and reviewers' experience and knowledge, which made it seem possible. However, it was soon realized that this review period was insufficient and needed an extension. Hence, an additional two-week timeframe is allocated for the check squad group to review the plans in addition to the initial two-week review period. This extra plan issuance review time ensures quality control and allows stakeholders to review and provide feedback on the project plans.

To manage quality design reviews and meet deadlines, PCS conducts quarterly meetings with design teams to track progress and address issues collaboratively. The PCS also generates documents to monitor project statuses and sends monthly emails to programs regarding projects projected to be behind schedule. These procedures help identify potential delays early on and take corrective actions to ensure timely completion of projects.

The staff mentioned "30-60-90" to track project delays. They monitor projects that are behind schedule by categorizing them based on the delayed days. This method of tracking delays in increments of 30 days provides a clear overview of the project's status and helps manage and mitigate delays effectively. It allows the team to assess the impact of delays on project timelines and take proactive measures to address any issues that may be causing delays in project delivery.

Additionally, the staff highlights the presence of a shelf (typically six to twelve months) in the scheduling system, which allows for allocating additional time for projects if unexpected issues arise or if more time is needed for review or completion. This shelf time has been used as a buffer to accommodate unforeseen circumstances and ensure project timelines can be met effectively. The proactive use of buffer time allocation is a key component of schedule contingency planning in project management. By incorporating buffer time into the project schedule, the team prepares for unforeseen delays or disruptions that could affect project timelines. The buffer time provides flexibility to address unexpected events during project execution and minimizes their impact on the overall project schedule.

The PCS establishes clear timeframes for project reviews, incorporates structured processes for stakeholder engagement, and uses documentation to monitor project progress and ensure prompt feedback and adjustments.

6.8.3 Tracking comments

There was a brief discussion about tracking review comments and the challenge of scheduling staff being left out of review discussions due to their non-engineering background. The project manager mentioned that they often do not get involved in detailed review conversations unless there are issues related to communication, schedule revisions, or significant changes that require their attention.

The team mentioned two sets of project managers within the organization: project scheduling project managers who coordinate project teams but are non-engineers, and project development project managers who oversee the compilation of plan sets and include squad leaders. The project development team, typically led by professional engineers, handles the technical aspects of the projects. This division of roles has resulted in scheduling staff being excluded from detailed review discussions primarily involving engineering-related matters. The control team suggests that process improvements could enhance communication and collaboration between different project management roles to ensure that scheduling staff are more actively engaged in review discussions when necessary.

6.8.4 Common current projects

In the conversation, it is mentioned that the STIP is currently in preservation mode. This means the department primarily focuses on maintaining existing projects rather than initiating new ones. Projects in preservation mode are characterized by fewer changes in course and less frequent additions of review time at the end of the project. While adjustments are still made for new construction as needed, they are deemed infrequent and rare in this phase.

The staff mentioned overlay projects as common within the department's current focus on preservation mode. These projects are typically part of routine maintenance and preservation efforts to enhance roadway durability and safety.

In the context of PCS, overlay projects are mentioned as being prevalent, with many projects falling into this category. Due to their nature as preservation activities, overlay projects often follow a streamlined process that may involve fewer changes in course and a more direct path to final plans without extensive revisions. This streamlined approach is reflected in the scheduling templates used for overlay projects, which contain predefined activities and timelines tailored to this specific scope of work.

6.8.5 Review times before and after COVID.

Conversations with the REs raised concerns about the timeline or duration of the field review of drawings before letting them, indicating that insufficient time has been allocated for this critical review process. This issue has been particularly highlighted in projects proceeding to final plans without adequate time for a thorough field engineer's review.

Before COVID, the timeline for field review of drawings may have been constrained, leading to challenges in ensuring comprehensive feedback and quality assurance before project letting.

However, with the impact of COVID and other factors such as turnover and increased funding, the need for sufficient time for field review has become more pronounced.

The PCS mentioned asking the district construction engineers if they want a field review timeframe built into the schedule for certain activities. The PCS indicates they have repeatedly inquired about providing the field with additional review time during construction seasons. However, the response from higher management suggested that the allocated time frame should be enough for the field.

6.9 Chapter Summary

In summary, the survey findings revealed several critical challenges within the organization, particularly in data management, design review processes, and quality control mechanisms. Many respondents expressed concerns about the sufficiency of current systems for tracking design changes, highlighting a gap in available tools. Mixed responses regarding the effectiveness of design review checklists pointed to limitations in their utility, leading to suggestions for more in-depth, project-specific reviews. Additionally, a clear need for structured quality review processes was identified to prevent design errors that could adversely affect project timelines and budgets. To further explore these issues, 13 semi-structured interviews with design personnel highlighted variability in design review processes across different squads. While some teams adhered strictly to established protocols, others relied on individual experiences, underscoring the need for standardized procedures that capture best practices. Moreover, the departure of experienced staff created a significant knowledge gap, emphasizing the importance of thorough training and better documentation for new engineers. Recurring challenges surfaced, including time constraints that rushed schedules, particularly during peak construction periods, and communication barriers exacerbated by the shift to remote work during COVID-19, which hindered in-field engagement critical for project comprehension. Considering these findings, several recommendations emerged: establishing structured review processes with detailed checklists and peer reviews, implementing continuous training and mentorship for new employees, and enhancing collaboration through more frequent in-person meetings or check-ins. A notable contrast was observed between construction and design teams in their perspectives regarding design errors, highlighting the importance of fostering open communication for mutual learning. The chapter concludes with insights from a construction final analyst, emphasizing the importance of effective project closeout processes. Documenting learnings and conducting systematic reviews of project outcomes are crucial for continuous improvement, preserving valuable knowledge that would otherwise be lost during staff turnover and refining organizational practices moving forward.

In conclusion, Chapter 6 emphasizes the necessity for enhanced collaboration, structured processes, and ongoing education within design and construction disciplines to mitigate design errors. By synthesizing diverse insights from both surveys and interviews, this chapter not only identifies the prevalent challenges but also lays the groundwork for recommendations aimed at fostering a culture of quality, accountability, and continuous improvement in design practices.

These efforts, if adopted, have the potential to significantly reduce the occurrence of design errors, thereby improving overall project efficiency and success.

Chapter 7: Design Review Checklist

Interviews conducted with design and construction personnel, as well as surveys with State DOTs across the nation, highlighted the importance of using design checklists. Conversations with engineers revealed that WYDOT has a design checklist developed in the early 2010s. However, this checklist is outdated, and many engineers are unaware of it or seldom use it. Many personnel are aware of the importance of a checklist, but often overlook it, preferring to rely on their personal experience instead. During discussions with engineers, it was emphasized that having a checklist could greatly assist them in completing checks and design processes. This checklist would also serve as a helpful guide for new engineers, helping them understand the necessary requirements for the design.

Considering the suggestions, an updated design review checklist was developed for WYDOT to serve as a QC tool during the design phase. This design checklist includes elements from various state DOT standards, tailored specifically to meet the needs and standards at WYDOT as per the available specifications. This section provides a brief overview of the current checklist's limitations and identifies areas for improvement. It also summarizes findings from a survey distributed to state DOTs and outlines the structure of the updated review checklist. Additionally, it includes feedback from the pilot study regarding its effectiveness.

7.1 Drawbacks and Areas of Improvement

a. Details and Depth:

Several DOTs shared versions of their internal design checklists as part of this study. While the exact development timelines of these tools are unclear, they remain active components of QC workflows. The existing checklists from other DOTs offer more comprehensive criteria and specific checks tailored to various structures and preconstruction phases, including surveys, roadway hydraulics, and traffic considerations (VDOT, FHWA, MDOT, ODOT, FDOT). In contrast, the WYDOT checklist is not divided into departments and is a generalized check, making it cumbersome to navigate and user-unfriendly. It would benefit from being divided into separate sheets, aligning with the checks relevant to each phase or structure. Additionally, enhancing accessibility through automated spreadsheet functions and integrating direct links to updated specifications could further improve usability.

b. Specificity regarding Regulations:

The current checklist primarily emphasizes the requirements and orientation of the plans, focusing on what is necessary and what may have been overlooked in the compiled final plans. However, it falls short in offering detailed information about design specifications or references to where this information can be found, limiting its effectiveness as a resource for users needing deeper insight into regulatory compliance.

c. User Guidance:

Establishing clear user guidelines is essential for effectively navigating the checklist data and understanding the required spreadsheet entries. The original checklist does not provide sufficient guidance on its use, as indicated by interviews revealing that some engineers do not utilize the checklist, and some are unaware of its existence. Some engineers mentioned they didn't know the checklist was available, while others stated it was not clear what complete QC checks entailed. These guidelines should specify which sections need to be completed and define the responsibilities of every department involved, to promote accountability and enhance usability throughout the review stages.

d. Responsibility and Accountability:

Accountability is crucial for maintaining quality during the design phase. However, the current checklist system only includes the check squad and the design squad leaders in the review process. This limits opportunities for others to provide feedback or critique the designs. To promote a culture of shared responsibility, all team members, regardless of their role, should participate in quality checks by signing off on their sections. This would ensure a more inclusive review process. The new checklist could include specific sections for each department involved in the design process. This would align with the requirements from DOTs such as VDOT, which outlines specific checks for each department, and ODOT, which has a separate designated checklist for geotechnical design.

e. Integration with Other Processes:

Implementing a real-time tracking review process, akin to the approach utilized by certain DOTs, could enhance the efficiency of the checklist system. For example, SCDOT employs Bluebeam alongside regularly updated design review checklists to uphold QC. This integration streamlines the digitization of reviews and allows for consistent monitoring of design checks, thereby enhancing efficiency and accountability within the project workflow. Currently, revisions and checks rely on emails and attachments, which squad leaders use to review the plans. This process is based on their experience and knowledge passed down from their seniors.

f. Flexibility and Customization:

The design checklist must accommodate flexibility and customization, allowing for adjustments to diverse project types or organizational requirements. As indicated in interviews, a holistic approach would enable the checklist to serve as a foundational tool for general assessments while also being adaptable for specific checks relevant to structures within larger projects.

g. Cluttered and Redundant Checklist:

The existing spreadsheet is seen as cluttered and redundant, often prompting users to perform the same checks multiple times for the same design. Streamlining the checklist to eliminate repetitive elements could enhance clarity and reduce confusion during the review process.

h. ***Manual* Errors:**

The current extensive reliance on manual checks increases the potential for oversight and errors in the review process. To mitigate this risk, it is essential to introduce automation for common, repetitive tasks, reducing the likelihood of mistakes and enhancing overall efficiency.

To address the issues, the research team developed an updated QC checklist incorporating best practices from other state DOT agencies. Section 5.2 discusses the results of the survey sent to various state DOTs.

The research team developed and conducted a national study as part of research to document the DQC tools familiarity and effectiveness, review practices, and collaborative methods used by various State DOTs across the United States. The target population for the survey comprised design engineers and project development team members involved in Quality Assurance and Quality Control within their respective departments.

To achieve this, 154 emails were sent to state DOT representatives nationwide, resulting in 25 responses from different DOTs. The aim was to gather insights that could inform the development of tools and strategies to mitigate design errors and enhance design outcomes.

The survey was structured into several key sections aimed at gaining a comprehensive understanding of practices within state DOTs.

7.1 Overview of State DOT Survey

To understand the diverse perspectives within state DOTs, it is important to collect background information from the respondents. This section requests details such as the state DOT represented, the department or division the respondent is affiliated with (for example, Design, Construction, Materials, or Quality Assurance), their role within that division, and their years of experience.

Document Management and Collaboration Tools: The first section investigates the document management and collaboration tools currently employed by DOTs. Participants will be prompted to identify tools they use, such as ProjectWise or AssetWise for document management and collaborative platforms like Bluebeam and email for real-time quality assurance. Additionally, the focus will be on coordination methods among design teams, field personnel, and review staff. By understanding these aspects, the survey aims to assess the effectiveness of these collaborative tools in minimizing design errors, which ultimately enhances project outcomes.

Consistency and Coordination Practices: In this segment, respondents discussed their DOT practices related to consistency and coordination during design reviews. Key areas of focus include how feedback from various teams is coordinated, how consistency is maintained across different disciplines, and how effective communication of project updates is ensured. Additionally, the survey examined the implementation of standardized guidelines or policies for collaboration. The goal was to identify best practices and areas for improvement, ultimately facilitating better coordination and reducing project errors.

Design Checklists and Lessons Learned: This section focuses on the use and effectiveness of standard design review checklists for quality assurance. Participants will share information about the availability of these checklists, methods for distributing them, and approaches for capturing lessons learned from previous projects. Additionally, it will involve reviewing the existence of a standard project close-out process. Understanding these elements allows DOTs to leverage past experiences, promoting continuous improvement and the sharing of knowledge both within and among agencies.

The primary goal of this survey is to identify current practices, areas of challenge, and opportunities for improving design coordination, reducing design errors, and ensuring QA in highway project development. The insights gained from this survey will provide WYDOT with valuable information to develop actionable tools and policies, ultimately leading to enhanced design quality across state DOTs. This collective data can foster more effective collaboration and result in higher-quality outcomes in transportation infrastructure projects.

7.2 State DOTs Survey Results

As shown in Table 18, 22 representatives from 19 different State DOTs participated in the survey, providing diverse insights. Most respondents were from the Project Development and Design division and QA and Review, Digital Delivery, and Bridge Maintenance. The participants brought experiences ranging from 5 to 37 years. Many of them had over 25 years of experience, showcasing a group of seasoned professionals who are deeply engaged in the design and review processes within their respective DOTs. Their collective expertise promises valuable perspectives on the challenges and innovations in the field.

Table 18: State DOT Survey Participants

State DOT	Department	Years of Experience	Responses
Alabama Dept. of Transportation (ALDOT)	Project Development/Design	33	1
Kentucky Transportation Cabinet (KYTC)	Project Development/Design	15, 8	2
Florida Dept. of Transportation (FDOT)	Project Development/Design	30	1
Utah Dept. of Transportation (UDOT)	Project Development/Design	23	1
Michigan Dept. of Transportation (MDOT)	Quality Assurance/Review	27, 27	3
	Project Development/Design	18	
Louisiana Dept. of Transportation (LADOTD)	Project Development/Design	24	1
Rhode Island Dept. of Transportation (RIDOT)	Project Development/Design	30	1
Idaho Transportation Department (ITD)	Project Development/Design	32	1
Ohio Dept. of Transportation (ODOT)	Project Development/Design	5	1
Pennsylvania Dept. of Transportation (PennDOT)	Digital Delivery	24	1
South Carolina Dept. of Transportation (SCDOT)	Project Development/Design	30	1
Oklahoma Dept. of Transportation (ODOT)	Project Development/Design	15, 11	2
Arkansas Dept. of Transportation (ARDOT)	Project Development/Design	34	1
North Carolina Dept. of Transportation (NCDOT)	Bridge Maintenance	12	1
Virginia Dept. of Transportation (VDOT)	Project Development/Design	23	1
Alaska Dept. of Transportation (AKDOT&PF)	Project Development/Design	17	1
Vermont Dept. of Transportation (VTrans)	Project Development/Design	25	1
New Hampshire Dept. of Transportation (NHDOT)	Project Development/Design	37	1
North Dakota Dept. of Transportation (NDDOT)	Project Development/Design	30	1

State DOTs predominantly utilize ProjectWise and AssetWise for their document management needs. Specifically, sixteen DOTs reported using ProjectWise, while two indicated they employ AssetWise. In addition to these platforms, several others were mentioned, including Project Suite Enterprise Edition (PSEE), SharePoint, Hicams, NC Connect, SAP, FileNet, and Microsoft Office 365, highlighting various tools employed across various agencies.

Recognizing the significance of collaboration and coordination, state DOTs were surveyed about their teams' strategies to ensure effective collaboration throughout the process. The results showed that out of the 23 participating DOTs, most participants (95 percent) utilized emails and direct communication. Additionally, 87 percent reported using both informal meetings and platforms like Bluebeam, Acrobat, and other cloud-based tools, as shown in Figure 44. Some state DOTs have developed their own platforms for collaboration and coordination. The Florida DOT has created an application called the Electronic Review Comments (ERC) system, which is used for phase reviews of plans and other documentation. Some DOTs use QA/QC forms during the design phase. They also conduct both formal and informal partnering meetings during construction to discuss how to resolve issues at the lowest possible level. This approach encourages open and honest communication among all parties involved in the project.

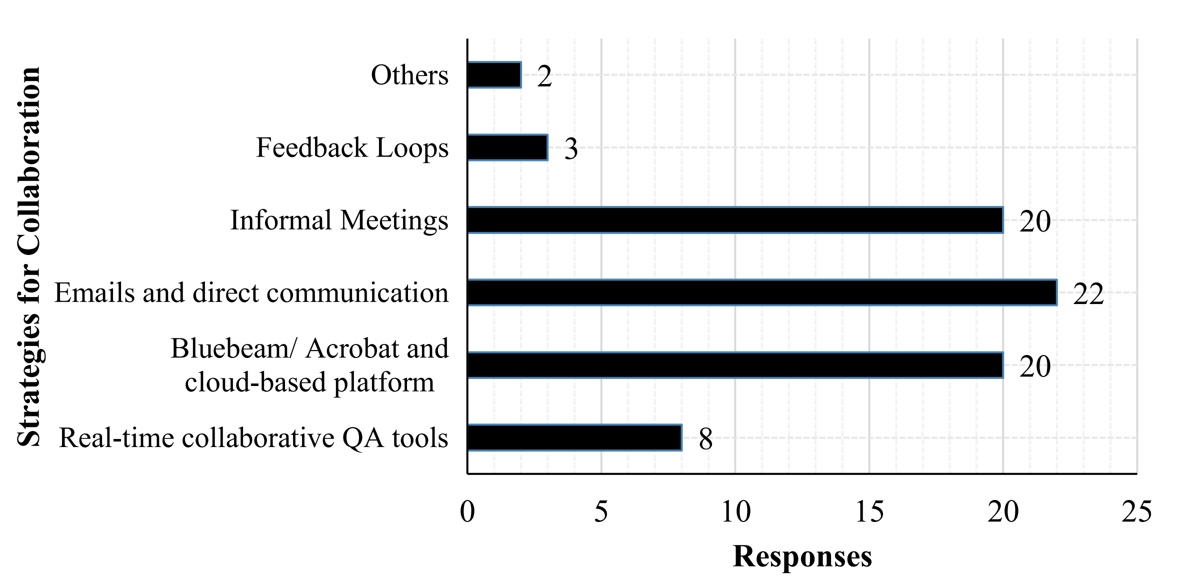

Figure 44: Strategies Used by State DOTs for Collaboration and Coordination

The survey responses mentioned that ALDOT ensures that all members are informed about project updates and changes through a comprehensive communication strategy that includes an in-house system developed by the Department, which integrates financial processes. KYTC uses a constructability review, which is completed and forwarded to the Project Manager, who shares it with the entire Project Team. The Central Office Location Engineer monitors the review process to ensure all design comments are addressed or explained. FDOT mentioned that communication occurs via email, direct discussions, and meetings, with a feedback loop facilitated through the Electronic Review Comments (ERC) system, where reviewers can view responses to comments. The system is not a "real-time" collaborative system, as plans and documents must be uploaded and commented on. The ERC system comprises various roles, including Reviewer, Lead Reviewer, and Project Manager. Among these, the Lead Reviewer plays a crucial role by reviewing comments made in their section and coordinating with other involved disciplines. To support these roles, the Department has established an ERC Manual, which provides detailed guidance on each role's responsibilities and functions within the system. Significant changes between project phases can be highlighted in meetings or through "Notes to the Reviewer." The QA process does not absolve the consultant of responsibility for errors, and milestone meetings are scheduled to keep the team informed of updates. VDOT mentions regular meetings, including Preliminary Field Inspections and project days, that foster discussion regarding scope and schedule. Additionally, the NDDOT relies on a Program Manager for updates, and a Project Status Report is maintained to track progress, ensuring timely communication and collaboration throughout the project development process.

7.3 State DOTs Design Review Practices

State DOTs utilize design review checklists to ensure consistency and adherence to established standards in their engineering designs. Of the 19 state DOTs that responded regarding the use of design checklists, 13 indicated that they utilize some form of design checklist for QC during the design phase. We had access to some of their design checklists for reference based on which the new updated design checklist was developed for WYDOT. The checklists are tailored to meet the specific standards of each state's DOT. Detailed description of some of the practices from state DOTs used as reference while developing the updated design checklist for WYDOT is as follows:

7.3.1 Virginia DOT

LD-436 is the standard Design QC Checklist from the VDOT that aids in the systematic evaluation of highway design submissions. It guarantees that every discipline participating in a project adheres to relevant design standards and that plans are thorough and coordinated throughout all project stages. The document includes five dedicated columns, each representing a different project stage that needs to be completed. These stages are: Preliminary Field Inspection (PFI), Public Hearing (PH), Field Inspection (FI), Right of Way (RW), and Final Submission (FS).The checklist is structured into multiple discipline-specific sheets. Each section includes a checklist of items relevant to that scope of work and allows reviewers to verify completion, flag issues, and provide comments. Breakdown on each of the sheets are:

- **Project Information**: It captures high-level project metadata, such as the (Unique Project Code) UPC number, project type, location, and district. It serves as the general information cover page for the checklist.
- **Electronic File Management**: This section verifies the organization and formatting of electronic deliverables by checking proper CADD file naming conventions, adhering to PDF formatting standards, maintaining an appropriate folder/directory structure, and ensuring file integrity for digital submissions.
- **Survey**: This section emphasizes the importance of survey control and topographic data inputs. It ensures the creation of accurate Digital Terrain Models (DTMs), proper documentation of control points, consistency in coordinate systems, and sufficient survey coverage for design purposes.

- **Roadway**: This section reviews horizontal and vertical alignment, typical roadway sections, access, grading, and pavement design. The items reviewed include cross-sections and roadway templates, superelevation and curb returns, right-of-way considerations, and compliance with design manuals..
- **Hydraulics**: This sheet assesses drainage and stormwater design adequacy, which includes details for culvert and storm sewer design, stormwater BMPs, erosion and sediment control plans, and hydraulic computation documentation.
- **Traffic**: VODT design checklist includes a designated sheet for traffic verification, which covers traffic-related features such as signing and pavement marking plans, signal layout and lighting, temporary traffic maintenance during construction, and reviews for ADA compliance and safety.
- **Design-Build**: This section of the review sheet is dedicated to handling the specific requirements for DB project delivery. It focuses on the critical checks needed during the 15–20 percent Request for Proposals (RFP) stage. The preliminary performance-based design elements outlined here are pivotal in guiding the project's objectives and maintaining standards. Additionally, effective utility coordination is emphasized to prevent conflicts and ensure seamless integration within the overall design framework. Finally, VDOT QC checks also consider cost and constructability to strike a balance that preserves quality while adhering to budgetary constraints.
- **Comments**: A structured form titled "Project Review Comment and Resolution Sheet" that documents reviewer feedback and comments coded based on resolution status, accepted, designer will evaluate, delete comment, department to evaluate,, and informational or next phase requirement.

This checklist (LD-436) is a unified tool for QC and coordination. It aims to minimize errors, ensure thoroughness, and preserve consistency across all VDOT design initiatives. VDOT also has a design quality evaluation form that provides constructive feedback from the state construction engineer to the design team on what has worked well on the projects and offers suggestions for what can be improved for future projects.

7.3.2 FHWA QC Review Checklist

The Project Development and Design Manual (PDDM) establishes the framework for QA/QC in preparing Plans, Specifications, and Estimates (PS&E). QC is primarily the responsibility of technical specialists, who must adhere to established standards and ensure their work complies with agency requirements before submission. Detailed guidance on QC processes should be documented, and specific QC plans may be needed for unique project elements.

QA, on the other hand, evaluates the effectiveness of QC processes to ensure the final product meets established quality standards. The QA Team conducts independent checks of the PS&E to verify compliance with policies and regulations, assess bid readiness, and identify quality trends. By analyzing data from various sources, including construction feedback and stakeholder input, the QA Team recommends improvements to enhance future project quality.

The macro-enabled QC Review Checklist is an organized tool designed to facilitate thorough QC at two vital stages of project development: Plan-In-Hand (PIH) and Final PS&E . It comprises more than 470 review items organized by essential disciplines such as design development, PS&E preparation, and CADD compliance. The checklist utilizes VBA macros that automatically adjust resizing and track progress according to the chosen project phase. Each review item features fields for completion status and comments from designers and reviewers, ensuring accountability and thorough documentation throughout the design process. Categories like "Develop" concentrate on readiness during the early stages of design, whereas "PS&E" focuses on final plan components such as staging, erosion control, estimates, and compliance with environmental standards. The checklist identifies unresolved issues between phases and aids teams in making sure that no essential elements are overlooked before moving forward. Ultimately, it acts as a centralized, dynamic QC log that promotes accuracy, coordination, and formal project documentation.

7.3.3 Georgia DOT QA/QC Program

GDOT uses structured checklists at six key design development stages to ensure quality and accountability. Each checklist corresponds to a QA milestone review and helps reviewers verify that critical design components have been properly developed, checked, and documented.

The first stage in GDOT's QA/QC process is the Concept Report Review, which establishes a solid foundation for the project. This review assesses the early project framework, focusing on the scope, alignment options, and environmental considerations. Key inclusions in this stage involve evaluating all design alternatives, including a "No Build" option, conducting an environmental and crash data review, and determining preliminary right-of-way (ROW) and staging requirements. The internal consistency of typical sections, layouts, and cost estimates is also examined, as early errors in this phase can significantly impact future stages.

Next is the Geometric Design Review, which ensures that all design geometry complies with safety and design standards. This review includes horizontal and vertical alignment checks, verification of superelevation, skew angles, and curve radii, as well as cross-section and typical section accuracy. Additionally, ROW coordination in the plan view is assessed. This stage is critical for confirming that the road design is safe, functional, and meets the necessary geometric requirements.

The third stage, the Preliminary Field Plan Review, focuses on the readiness of design plans for field inspection. It evaluates the completeness of geometry, drainage layouts, and staging elements while ensuring bridge design consistency, ROW sufficiency, and ADA compliance. Coordination with utilities and environmental constraints is also reviewed. This stage is essential for confirming that the plans are field-ready and helps identify major issues before inspections occur.

The Right-of-Way Plan Review validates the final ROW plans to ensure they meet all construction and environmental needs. This review checks proper ROW and easement boundaries, driveway access, and limited access labeling, along with utility and railroad coordination. It also verifies that environmental commitments are appropriately reflected in the design. By ensuring the ROW is sufficient and clearly documented, this step helps prevent costly legal and construction delays.

Following that is the Final Field Plan Review, which confirms that all technical components are complete and compliant with project requirements. This review includes updated staging plans and erosion control measures, integration of environmental commitments, resolution of utility conflicts, and a final review of bridge layouts and constructability. This detailed technical validation is critical before the project is finalized to ensure all field-related design aspects are sound.

Finally, the Final Plan Submission Review verifies that all feedback from earlier stages has been incorporated and that the project is ready for advertisement. This stage includes a final review of plans, specifications, estimates, Traffic Management Plans (TMP), and Notices of Intent (NOI). It also entails completing the Designer's Checklist and confirming special provisions and final documentation. This ensures that the plans are thoroughly polished and ready for bidding and construction without unresolved issues.

Standard elements across all checklists include the requirement to include initials, dates, and reviewer notes, which must be archived in the QA/QC Record folder. These checklists are mandatory for advancing to the next design phase and highlight critical items impacting safety or regulatory compliance.

7.3.4 SCDOT Bluebeam QA

SCDOT has developed a comprehensive suite of QA/QC checklists to support design accuracy and consistency across all engineering disciplines. These include specialized checklists for Geotechnical, Hydraulic, Roadway, and Structural components at both preliminary and 95 percent plan stages. Each checklist is tailored to the latest standards and ensures systematic reviews during key design phases. In addition to these structured documents, SCDOT also provides reference materials such as the Design References guide and a Bluebeam QA Guide named "SCDOT Bluebeam QA: A Real-Time Collaborative and Transparent Review Process: to support electronic markup and review processes. Notably, SCDOT has adopted a real-time collaboration platform using Bluebeam, which enables efficient, cloud-based communication and live feedback among design teams, reviewers, and stakeholders, further enhancing QA and reducing review cycle times, the flow for which is as shown in the Figure 45.

The workflow begins when the Design Team notifies the Program Manager that a submittal is ready for review. The Program Manager then coordinates the review schedule with the Review Team and creates a Bluebeam Revu Session, sending notifications to the reviewers. During the session, the Review Team provides comments that the Design Team can review in real-time and begin addressing. Reviewers update the status of the comments based on the Design Team's responses. At the end of the review period, a comment summary is exported and sent back to the Design Team. If necessary, the Design Team updates the submittal, and the Program Manager re-uploads it to the same session for comparison. Once all comments are resolved and no further input is needed, a final marked-up submittal is exported for the project records. The

Bluebeam Revu Session will remain open to accommodate any additional submittals related to future milestones.

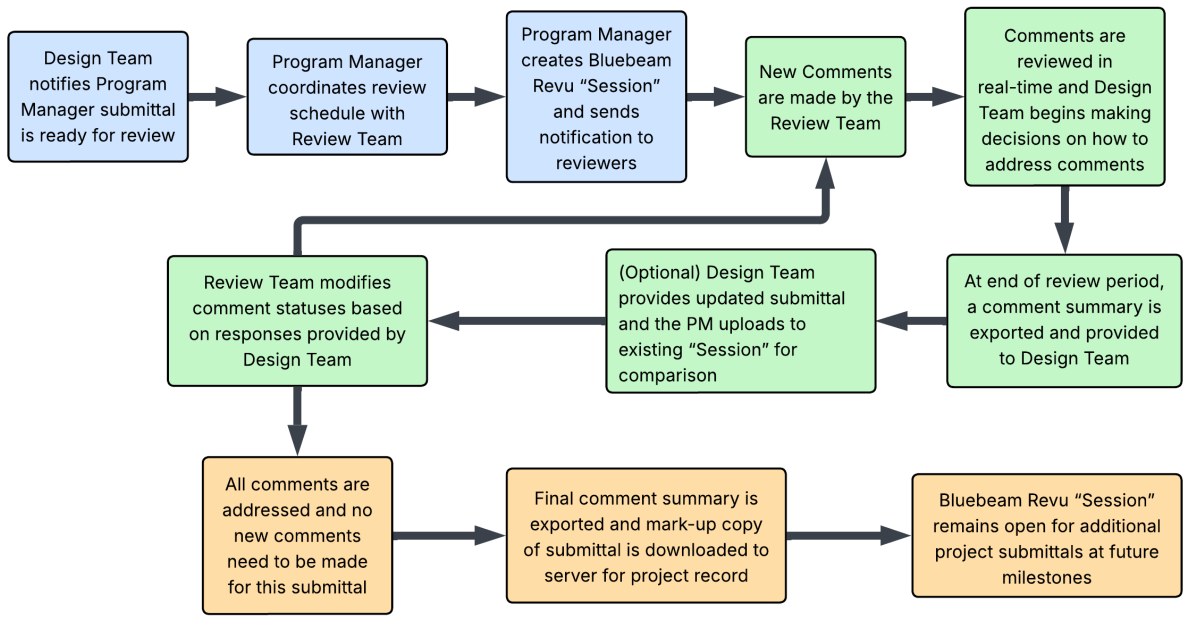

Figure 45: SCDOT Real-Time collaborative Review flow for in-house projects

The process aims to enhance the quality of design deliverables by providing valuable information that supports ongoing QC and assurance practices designers utilize.

7.3.5 NCDOT Collaboration Approach

The NCDOT adopts a continuous and collaborative approach to QA/QC throughout the entire project lifecycle. Their QA/QC framework is founded on: Accountability, Communication, and Teamwork, the ACT model which emphasizes clear expectations, shared responsibility, and coordination across teams. Accountability is upheld through an objective performance evaluation system, while open communication fosters transparency among team members. Teamwork encourages collaboration among NCDOT personnel, Professional Services Firms (PSFs), and Professional Engineering Firms (PEFs) to meet consistent quality standards.

To facilitate this process, NCDOT employs a digital collaboration platform that utilizes ProjectWise and SharePoint. ProjectWise manages CADD-related files, providing secure access, document control, and long-term storage, while SharePoint functions as the document management system for non-CADD files. Additionally, NCDOT implements a staged QC checklist to ensure that roadway design submissions align with required standards and project specifications. There is a four-stage review process, with each checklist customized for the specific scope and expectations of that phase. Each section of the checklist includes detailed task-specific review items, such as verification of plan sheet naming, consistency in pavement design, alignment connectivity, access control notes, bridge envelope definitions, and guardrail layout. The checklist also incorporates specialized checks for coordination with various disciplines, like hydraulics, traffic, and geotechnical input, and considers real-world factors such as property access, detours, and signage. Reviewers are required to mark each item as "Yes," "No," or "N/A" and to provide comments when needed, ensuring both accountability and documentation of design quality at every stage.

In summary, NCDOT's tiered QC review process fosters a structured, consistent, and cross-disciplinary assessment of design packages prior to their final design and PS&E development.

7.4 Developing WYDOT Design Checklist

In any design project, it is essential to include elements that outline the necessary components to be incorporated into the design plans. These specifications serve as a foundation for the entire process. Additionally, establishing clear review stages is crucial; this involves identifying the specific checks that need to be performed at each phase of the project by the parties involved or departments. Ensuring that the required elements and review stages are well-defined, the project can proceed smoothly with thorough oversight and accountability at every step. The process of developing the updated WYDOT Design Checklist involved several key steps. All available design specifications and guidelines from the WYDOT website were initially collected, ensuring only the latest versions were referenced to form a comprehensive checklist. Some other DOTs referenced were taken from the following checklists:

1. FHWA - 30 percent & 70 percent PS&E Design Review Checklist and QC-Design checklist
2. MDOT - QC Checklist (Phase A)
3. Oregon DOT - Design Checklists (Version 6)
4. Wisconsin DOT - Design Study Project Review Checklist
5. Caltrans - Design Checklist
6. TxDOT - Project Development Checklist
7. KYTC - Project Development Checklist

The updated design checklist for WYDOT was created to enhance the QC process by using these DOTs as references, along with those specified in section 7.3. The updated checklist divides the process into departmental checks and stages, aligning with the documented design process flowchart as documented in the Road Design Manual by WYDOT, which could serve as a comprehensive guide for engineers, ensuring that new team members can easily identify the key elements that need to be verified throughout the design process.

Focusing on existing design checklists and QC measures allowed for identifying critical elements that required systematic review during the design process. Additional checks were customized from these references to align with WYDOT standards. Responses from surveys conducted with various state DOTs were used to further enhance the checklist. Many of these agencies utilized structured document management platforms, with ProjectWise being the most used for design reviews. By integrating these insights and industry practices as detailed in section 7.3, the WYDOT checklist was refined to meet compliance requirements and enhance its overall effectiveness.

This structured approach ensures that each state's DOT can effectively review and maintain high standards in its design processes.

The Plan Review Checklist is a comprehensive tool designed to guide the systematic and efficient review of project plans. It ensures that key project elements are thoroughly examined at different stages of the design process. The checklist serves multiple purposes:

- ***Standardization:*** Provides a consistent framework for reviewing project plans across different phases and teams.
- ***Collaboration:*** Facilitates better communication and coordination among project stakeholders.
- ***Quality Assurance:*** Helps identify gaps or inconsistencies early, ensuring compliance with design standards and project requirements.

The Road Design Manual's design process chapter/section is to be followed for general flow and navigation. The review checklist, following the design process flow, consists of six key project stages as per the WYDOT's Road Design Manual and guidelines. A short explanation of what each plan submission includes from the Road Design Guidelines is listed below:

- ***Preliminary Plans:*** include existing ROW, utilities, and railroad, preliminary information for horizontal alignment, ground profile, grade line, typical sections, section lines, earthwork design with mass haul, proposed interchange or intersection layouts, and locations for possible retaining walls.

- ***Grading Plans:*** These include the same information as preliminary plans but are more refined, with the following additional information: land ties, soil profile, ownerships, surfacing recommendations, cultural sights, wetland delineation, and hydraulics report. It will have a preliminary grade line, proposed ROW, borrow sources, approaches, pipe culvert sizes, geology information, proposed detours, structure selection, and storm drains. May include preliminary information that did not make it into the preliminary plans.

- ***ROW and Engineering Inspection Plans:*** These plans include the same information as the grading plans but are more refined. They also include the following additional information: traffic control plan, striping details, bridge title and general notes sheets, a more defined structure layout, and an index of proposed special provisions.

- ***ROW and Utility Plans:*** All preliminary design features are already specified in the right-of-way and engineering inspection plans, but they will include draft electrical plans, surfacing source layout, pit and plant site, materials agreements, and finalized structure layout.

- ***Final Design Plans:*** These include special provisions, final summaries and quantities, detail drawings, 404 permits, categorical exclusions, bridge plans, and railroad structure approval/authorization.

- ***PS&E Plans:*** These plans must compile all previous information in complete form. All information mentioned in the previous plan must be included before advertising the project.

7.5 Checklist Content

The checklist consists of nine sheets, each focusing on essential areas of the design and construction process. It follows a structured guideline derived from WYDOT's design checklists and is organized for easy access and usability. The contents of the checklist is further described in the following subsections.

7.5.1 Contents

This section is an introductory summary that captures key information related to the project and the review process. It overviews the review phase, identifies the department responsible for the review, and lists the individual(s) responsible for the design. The contents sheet from the design checklist is provided in Appendix D1 .

7.5.2 Links Sheet

Links sheet (Appendix D2) is a resource hub that provides direct access to necessary references and publicly available documents on the WYDOT website.

7.5.3 Field Review and Design Check

The updated spreadsheet incorporates checks based on Section 6-02 from the WYDOT Road Design Manual and the Field Design Checklist, which align with the QA criteria outlined in the QA/QC checklist. One key improvement from the previous version is the inclusion of distinct design phases, as detailed in the Design Process Flowchart from the WYDOT Design Manual. This enhancement introduces a dedicated section for conducting checks at each review phase, ensuring compliance with the specific requirements and criteria for each plan phase. These adjustments are made under the standards and guidelines established by the FHWA and WYDOT, reinforcing our commitment to thorough and effective QA in the design process. The field review and design check is provided in Appendix D3.

7.5.4 Survey Checks

This section, adapted from the WYDOT Survey Manual, ensures that accurate surveying practices are followed and that established procedures are complied with. The standards for the survey documents have been derived from the Survey Manual provided by the Photogrammetry and Survey Sections. The checks are categorized based on the fundamental structure of the survey documents and the standard naming conventions outlined in the Manual. Since the survey phase is typically completed before the design phase begins, it is primarily reviewed only once during the project development reviews conducted by designers and the squad leader, making additional checks less necessary in later stages. The field review and design check is provided in Appendix D4.

7.5.5 ROW Checks

This segment (as shown in Appendix D5) covers the necessary verifications for right-of-way acquisition, management, and documentation, ensuring compliance with project and legal requirements. The ROW Manual (2018) provides a comprehensive outline of the key criteria and major checks involved during the final review phases of ROW and utility plans. These checks are crucial for ensuring compliance with established standards and for verifying ROW lines within the plans. Major areas of focus in the checklist include the acquisition of right-of-way, environmental and legal compliance, title and deed examination, civil rights compliance, appraisal and valuation, the condemnation process, relocation assistance, and documentation and record management. By adhering to these criteria, the process maintains accuracy, transparency, and legal compliance throughout, ultimately supporting the integrity of ROW management.

7.5.6 Computer-Aided Design and Drafting (CADD) Drafting Standards

The CADD Standards Checklist (detailed in Appendix D6) includes establishing a clear framework to ensure adherence to WYDOT's CADD standards, promoting consistency in computer-aided drafting and design practices. Key areas of focus encompass file naming and structure, requiring verification of naming conventions; seed files and units, ensuring appropriate selections and measurements; design content and geometry, confirming accurate representations; raster and attachments, reviewing proper data use; cross-section and quantities, checking accuracy in designs and calculations; and final submission, verifying readiness for project development. Additionally, the checklist emphasizes the importance of quality and accuracy checks, requiring miscellaneous reviews to uphold design integrity. It also highlights the need to tailor CADD practices to meet the specific requirements of various departments or organizations, such as FDOT or VDOT, ultimately fostering productivity and consistency across all projects.

7.5.7 Materials Independent Assurance

This outline details the steps to independently verify the quality of materials used, ensuring they meet project specifications. WYDOT Independent Assurance (IA) Manual contains guidelines for verifying equipment, sampling, and testing procedures in construction projects. The checks include construction test and certification requirements, manufactured products certification, field laboratory testing equipment, field testing procedures, and materials acceptance as detailed in Appendix D7.

7.5.8 Bridge Design Checklist

This section outlines essential checks for bridge design to ensure compliance with the standard Bridge Application Manual and relevant engineering standards. The checklist includes criteria for examining the following areas: geology layout, bridge layout, culvert layout, railroad site layout, substructure layout, riprap and gabions, bent/pier design checks, final design evaluations, and quantity calculation checks, as shown in Appendix D8.

7.5.9 Comments Section

This area includes space for documenting observations, feedback, or notes relevant to various aspects of the project.

This spreadsheet document simplifies navigation and efficiently addresses critical aspects of the project by consolidating key elements from the design checklists into a streamlined format. The spreadsheet is attached in Appendix B1 to B9.

7.6 Checklist Pilot

To evaluate the effectiveness and usability of the developed checklist, a survey was distributed to 17 design and construction engineers, and which received 12 responses. The survey aimed to determine whether the engineers had used the old design checklist, how they utilized the new checklist, and their opinions on the usability and effectiveness of the updated version.

Twenty-five percent of the survey participants had used the design checklist before, while 75 percent hadn't used it at all. The engineers noted that the updated checklist would be beneficial for new hires, as it would provide a way for them to track essential project items and serve as a valuable training tool for important considerations in upcoming projects. When asked how effective the engineers think the updated checklist is based on their use, everyone mentioned it'd be effective somehow, with almost 60 percent agreeing it would be very effective for QC, as shown in Figure 46.

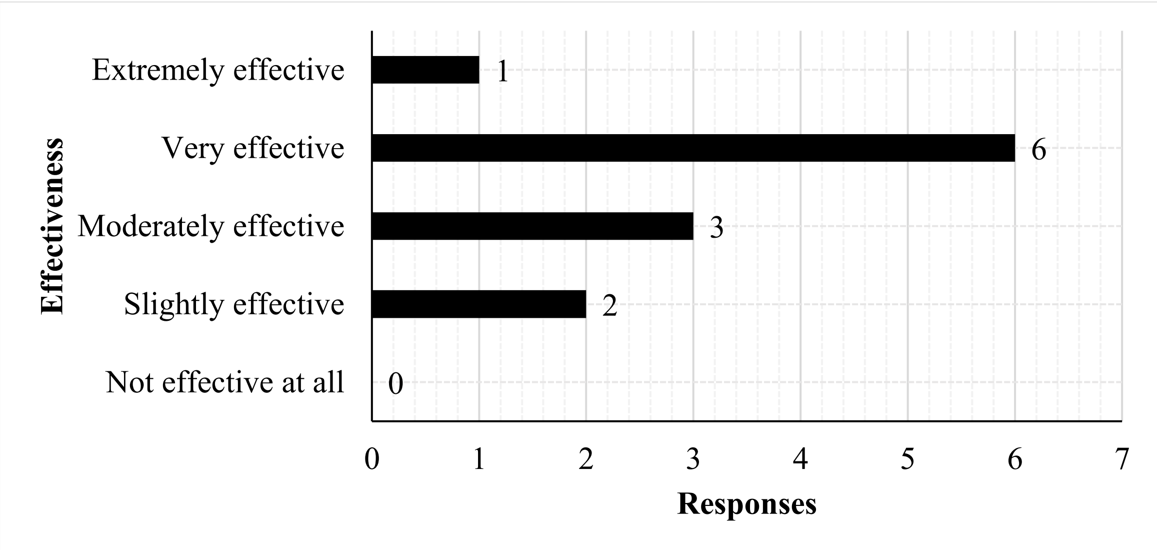

Figure 46: Effectiveness of the updated Checklist

Figure 47 displays the number of reviews for each sheet. The field review and design checks received the most feedback, with eight reviews from different individuals. The CADD, materials, and bridge design checklists each garnered 2 reviews, while all other sheets received just 1 review each.

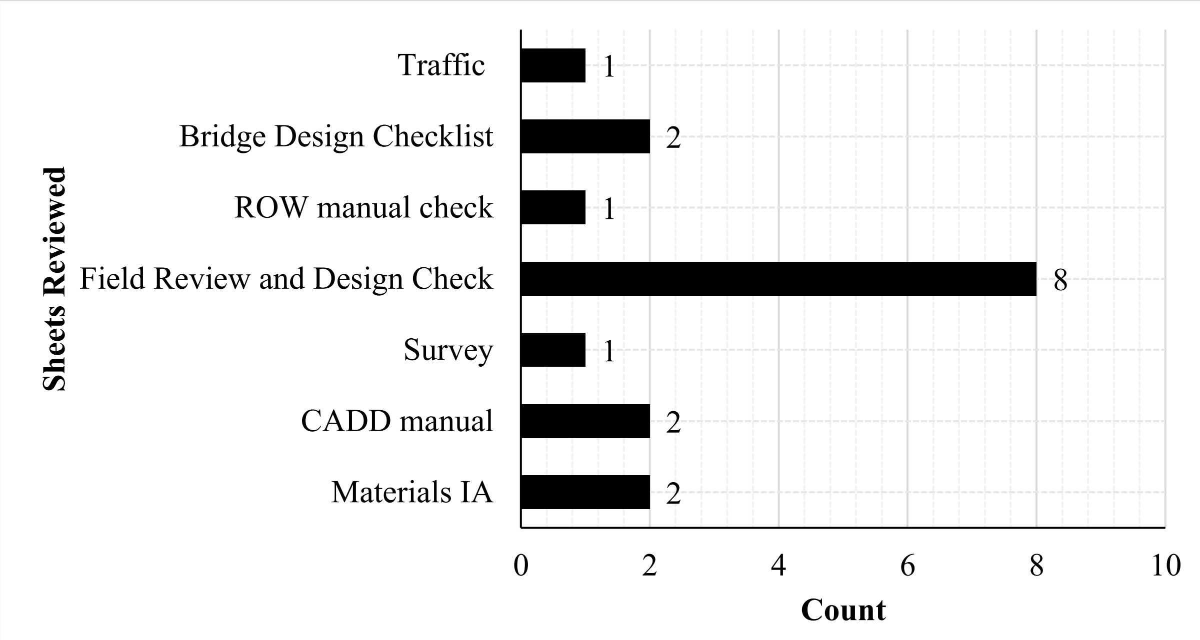

Figure 47: Number of reviews for each sheet

The survey investigated reviews for each one of the sheets, the findings of which are described below:

7.6.1 Materials IA

There were two reviews of the materials IA sheet. One reviewer mentioned that the checklist would be moderately useful, but not as much for the field. The other reviewer provided more detailed comments, which mentioned that the material IA manual provides an overview of the checks outlined in the Independent Assurance manual and mentioned that the checks focus more on the construction aspects of the review process. Most of the forms mentioned in the checks are submitted after the contract has been awarded and are not particularly relevant to the materials lab design check process, rendering them less useful for evaluating plans.

The participant noted that navigating the checklist was neither particularly difficult nor easy. They found that some key review elements were harder to locate, such as total estimates, material rates, and tracking changes in plans and their modifications. This presents an opportunity for improvement in version 2 of the checklist. Although the respondent acknowledged that the checklist is highly organized, they expressed concerns about the effectiveness of the materials sheet, as it primarily addresses construction items rather than design elements. Additionally, the specifications listed are variable depending on the plan settings. To enhance the calculation of material requirements, it would be beneficial to incorporate formulas and coding.

The checklist could also be improved with input from the materials program to identify which items should be checked during plan reviews, ensuring that it remains relevant and useful in the future. Furthermore, the respondent raised a concern about the use of macros in the sheet, as many users may not be familiar with programming. This could lead to potential issues if updates are necessary later, especially if developers are unavailable to implement changes in a timely manner.

After discussions with the engineers and principal investigators, it was determined that using macros would be more efficient for long-term use compared to websites that require frequent updates from developers. The research team has restricted editing access to the spreadsheet macros to prevent accidental changes; however, they will share the macros with the administrators for updates. Additionally, the Materials IA sheet has been revised to address existing bugs and can be further improved based on feedback from the department's engineers.

7.6.2 CADD sheet

There were two reviews for the CADD standards sheet. Both reviewers mentioned that the checklist was easy to follow and very detailed. They noted that it was well-organized and did not seem to have anything missing, and appreciated how the cells update as you fill in the information, showing how many items have been checked and how many remain. The comments section was also highlighted as useful, allowing users to navigate and import comments from all sheets and print them directly. Additionally, they liked the ability to customize the checklist based on departmental needs, reducing the hassle of going through unnecessary checks.

The reviewers had no concerns but suggested that adding an option to toggle the expansion of stage options would be beneficial. One reviewer mentioned that they used the checklist for an actual project, while the other simulated a review scenario. They both found it extremely useful and agreed that the checklist would help streamline their review processes.

One concern was the use of certain terms, as terminology might vary by department. This could be addressed by incorporating recommendations from engineers in those departments to improve the checklist. One reviewer indicated that they would likely use the checklist in the future, while the other was conflicted about their opinion. Another reviewer mentioned that they were unaware that a checklist like this existed before our study and believed it to be extremely detailed, potentially replacing some specific checks currently in use by the department.

They suggested improving the checklist by incorporating more general checks to make it user-friendly for everyone. The current level of detail may be too complex for those who do not need to perform all the listed checks. Overall, they appreciated the checklist's structure and found it easy to focus on relevant areas, noting that the references provided were extremely useful. The suggested changes have been integrated as much as possible, and the checklist can be further refined with additional use and experience on what updates could make the checks and the checklist more efficient.

7.6.3 Survey Sheet

One review of the survey sheet highlighted its ease of navigation and usability. The reviewer noted that the checklist was extremely detailed, with very little missing, and that the checks were easy to locate. They used the checklist to review an actual project and found the updated version to be extremely useful for design reviews, believing it would help streamline the process. The reviewer commented that the checklist is well-organized, although they might not use it in the future, as they have 28 years of experience and have memorized the checks. They believe the checklist would be especially beneficial for new employees and those with less experience. Additionally, they appreciated how the cells updated automatically as information was entered in the tabs and would highly recommend using the checklist for design reviews.

7.6.4 Bridge Design Checklist

Two reviews were received for the bridge design checks. One reviewer noted that the checklist was neither easy nor difficult to use and navigate, while the other found it extremely easy to use and navigate. Both reviewers agreed that the checks were moderate to very detailed and that there were no missing items on the checklist. They also mentioned that the checklist would be slightly to very useful for design reviews. While there was a consensus that the checklist could help streamline the design review process, some drawbacks and issues were highlighted.

The bridge team noted that the checks and stages outlined in the checklist may not be completely accurate and could benefit from improvements. Although no specific issues were mentioned, in accordance with the bridge team and each department, the checklist can be modified accordingly. One member expressed a desire to use the checklist in the future, while another emphasized the importance of incorporating their recommendations for enhancement. They also mentioned that the checklist is more comprehensive than necessary for the average employee. The Bridge program already has its own checklist, and the updated review checklist might be more beneficial for squad leaders, who would be the primary users. Overall, they expressed support for creating a checklist and believe that the existing list is a solid foundation that will be extremely useful after refinement. The suggested changes have been integrated, making the checklist more efficient with further use.

7.6.5 Field Review and Design Checks

The field review and design checks received feedback from a total of eight reviewers. Half of the responses indicated that the checklist was easy to navigate and use, while the other half found it neither easy nor difficult to use. All reviewers agreed that the checks were moderately to extremely detailed, and 75 percent believed that nothing was missing from the checklist. Some reviewers suggested adding alignment sheets for highway construction, as they would be useful for most projects. Additionally, one reviewer recommended including more details on guardrails and creating a comment thread to track updates made in response to comments from previous reviews.

Eighty-five percent of the responses praised the checks for being extremely organized, noting that the breakdown of each summary into separate components was helpful. Reviewers appreciated how the different levels of plans were handled and separated. They also mentioned that basic items checked were clearly listed. The detailed checking process heightened awareness of the necessary checks for each design phase and ensured comprehensiveness by including relevant information as needed.

Participants raised concerns about the updated checklist's structure and functionality. A common suggestion was to organize the checklist by plan issuance phases, as many items, such as summaries, do not apply until the Final Plans stage. Marking these items as "N/A" repeatedly in earlier phases was seen as inefficient. It was also recommended that these items default to "N/A" until the appropriate phase is reached.

Respondents reported a variety of uses for the checklist: two used it on actual projects, four went through the checks for general review, and one simulated a scenario, while one checked in detail all the checks they would usually have more influence over. 83 percent of the respondents mentioned that the checklist is moderate to extremely useful and would recommend it for use in reviews.

Participants offered a variety of feedback and suggestions regarding the revised checklist. One idea was to incorporate WYDOT's list of bid items into the checklist system, enabling users to choose project-specific items upfront, which would then trigger the appropriate checklist sections, particularly for summary items. This possibility could be explored in future studies. Some respondents mentioned they had limited interaction with the checklist so far but expected to provide more insights as they continue to use it. Others expressed overall support, indicating that while they appreciated the concept, they anticipated the need for further improvements as it is implemented more broadly. One participant highlighted the necessity of utilizing the checklist for all upcoming projects to ensure consistency.

In conclusion, the survey results showed that the revised checklist is an effective and promising resource for enhancing design review processes. Although it had limited prior use, most respondents found it user-friendly, well-structured, and helpful for pinpointing essential project elements. The checklist was especially valued for its role in training new employees and ensuring consistency in design QC. Feedback indicated that while many components were well received, certain sections—like the materials IA and bridge design sheets—would benefit from updates to better fit current design workflows and department-specific guidelines. Suggestions included the addition of project phase-specific checks, customizable options, and input from various departments, highlighting the need for a more flexible checklist system.

Overall, participants expressed strong support for the wider implementation of the checklist, with many recommending its use in all forthcoming projects. The feedback demonstrates a general agreement that the checklist improves accountability and streamline review processes; however, ongoing refinement and collaboration with users will be crucial for maximizing its long-term effectiveness and adoption.

In response to the valuable suggestions gathered from the pilot review, the research team has implemented several enhancements to the checklist. Specifically, more checks were added on the alignment sheets, enriching the details concerning guardrails to better serve the projects.

Additionally, the research team is actively requesting feedback from various departments to improve specific sections.

8.8 Chapter Summary

In summary, Chapter Seven underscores the essential function of a well-defined design review checklist as a QC tool within the WYDOT framework. The chapter reveals several key findings from interviews and surveys conducted with design and construction personnel across various state DOTs, emphasizing the importance of having an effective checklist. While the existing WYDOT checklist has served its purpose, it is primarily outdated, generalized, and lacks the specificity needed for various design phases. It fails to provide clear directives regarding regulatory compliance and does not adequately guide users in navigating its complexities, resulting in underutilization among engineers.

The chapter calls attention to the need for a revamped checklist that incorporates comprehensive criteria tailored to specific structures and design elements. By integrating input from successful practices observed in other state DOTs, the updated checklist aims to enhance usability through organized sections, direct links to current specifications, and clear user guidelines on responsibilities and expectations. This focused approach is intended not only to facilitate better adherence to design standards but also to promote accountability among team members during the design phase. Ultimately, the improvements proposed in this chapter are designed to transform the checklist into a practical resource that aids engineers, particularly those new to the field, in effectively navigating essential requirements and ensuring high-quality design outputs.

CHAPTER 8: PLANS AND PROCEDURES

This chapter examines practices adopted by various DOTs for managing design E&Os. It evaluates the current WYDOT policy and recommends an enhanced policy framework based on successful practices from other state DOTs. Effective management of design E&Os is essential for ensuring quality project outcomes, cost efficiency, and accountability among professionals involved.

8.1 Practices of Other Agencies

Arizona Department of Transportation (ADOT): ADOT has established comprehensive guidelines that clearly delineate responsibilities among project stakeholders, including the RE, Project Manager (PM), consultants, and DE. The procedures include structured methods for identifying, mitigating, and resolving errors and omissions. An E&O Claims Review Board oversees the resolution process, providing additional accountability and thorough review (ADOT 2019).

Florida Department of Transportation (FDOT): FDOT utilizes a detailed, structured, multi-stage approach to manage E&Os involving both design consultants and Construction Engineering and Inspection (CEI) consultants. The FDOT procedure tracks E&O identification, initial assessments, solution implementation, further assessments, and settlement negotiations. Documentation and recovery processes are rigorously maintained, encompassing detailed record-keeping of settlements, payments, and services in-kind (FDOT 2025).

Georgia Department of Transportation (GDOT): GDOT emphasizes rapid corrective actions and detailed documentation through each stage of the E&O management process. The process starts with initial discovery and assessment, followed by early notification to stakeholders. It then proceeds with immediate action when necessary, plan revisions, construction resolution, detailed cost recovery estimates, and final reviews by the Construction Problem Resolution Committee (CPRC). The procedure culminates in a settlement agreement, supported by comprehensive documentation (GDOT 2022).

Maricopa County Department of Transportation (MCDOT): MCDOT's approach involves a meticulous 13-step procedure addressing discovery, mitigation, and resolution of E&Os. Each step of the process is clearly defined, ensuring comprehensive management and clear accountability at every phase. This structured approach enhances transparency and effectiveness in addressing E&Os (MCDOT 2021).

Massachusetts Bay Transportation Authority (MBTA): MBTA employs a robust risk management framework emphasizing proactive identification and management of potential E&Os. The Project Office plays a crucial role in maintaining an extensive log of E&Os, facilitating clear and continuous communication with the Design Team and E&O Committee. The policy includes systematic documentation, rigorous initial reviews, structured evaluations, and explicit lessons-learned documentation to inform and improve future project performance (MBTA 2022).

Minnesota Department of Transportation (MnDOT): MnDOT uses structured and clearly defined assessments to evaluate damages based on the timing of E&O discovery (pre-letting or post-letting). MnDOT procedures involve detailed initial analyses, timely corrective actions by consultants, rigorous evaluations by the Design Errors Review Committee, and systematic documentation of remedial actions, ensuring thoroughness and accountability in addressing E&Os (MnDOT 2023).

Texas Department of Transportation (TxDOT): TxDOT's structured process is particularly rigorous, encompassing thorough identification, detailed documentation, structured communication, and precise categorization of change orders through reason codes. The process involves meticulous cost recovery procedures, clear identification of responsible parties, and robust management of claims and settlements. TxDOT employs specific reason codes for documenting change orders resulting from E&Os, including:

- 1A – Incorrect PS&E (TxDOT design)
- 1B – Incorrect PS&E (Consultant design)
- 1C – Other
- 1D – Design error or omission resulting in delay, rework, or inefficiencies (TxDOT design)
- 1E – Design error or omission resulting in delay, rework, or inefficiencies (Consultant design) (TxDOT 2025).

Collectively, these practices from other state DOTs and agencies strongly emphasize structured processes, thorough documentation, clear stakeholder responsibilities, and proactive management strategies. These insights form a valuable foundation for developing robust and effective E&O management procedures within WYDOT.

8.2 Current E&O Policy and Procedures

Currently, WYDOT primarily manages consultant-related E&Os through specific contractual language embedded in professional services agreements. These agreements explicitly require consultants to deliver services that meet professional standards of accuracy and quality, promptly addressing and rectifying identified errors without entitlement to additional compensation. Consultants are contractually obligated to indemnify WYDOT against any claims, damages, or legal actions resulting from their negligence or failure to adhere to professional standards, thereby protecting WYDOT from financial and legal liabilities.

A notable limitation of the existing approach is the lack of a formalized internal policy to manage and document in-house E&Os. This gap could potentially lead to inconsistencies in how internal design errors are addressed, documented, and rectified, making it difficult to identify systemic issues or apply lessons learned to improve internal processes.

Further contractual requirements include maintaining professional liability insurance, with stipulated minimum coverage limits of $1,000,000 per incident and in aggregate, accompanied by an extended two-year reporting period after contract completion. This ensures that financial coverage is available for addressing claims or corrective actions arising post-completion of a project. Additionally, consultants must formally validate and endorse all their deliverables, affirming their licensure and compliance with Wyoming's professional regulations, thereby ensuring accountability and adherence to legal and professional standards.

8.3 Recommended In-House E&O Policy Statement

Policy Statement

All WYDOT design staff must provide services consistent with the professional Standard of Care explicitly defined in their contracts. This Standard of Care refers to the diligence, expertise, and judgment exercised by reputable professionals within comparable organizations undertaking similar work.

Purpose

The primary purpose of this policy is to enhance the quality and accuracy of contract drawings and specifications. This is achieved through the systematic collection and analysis of data regarding all design errors and omissions that result in change orders. Utilizing this data, WYDOT aims to identify recurring issues, develop targeted lessons learned, and implement process improvements to mitigate future occurrences.

This policy document comprehensively outlines the responsibilities, guidelines, and procedures for assessing, processing, and documenting E&Os encountered during different project phases, including design advertising, letting and award, or construction. It also establishes clear recommendations for resolution processes involving consultant design companies, and it identifies critical areas for potential quality control improvements.

Definitions

- **Engineer of Record (EOR):** A professional engineer responsible for sealing project drawings or calculations. This seal indicates that the EOR has developed, coordinated, or supervised the preparation of drawings and calculations, ultimately bearing professional responsibility for the design.
- **Errors and Omissions (E&Os):** These constitute acts of negligence committed by the EOR during the provision of engineering design or creative work. Additionally, it includes negligent actions by Construction Engineering and Inspection personnel during inspection services, as well as contractual breaches.
- **Standard of Care:** The level of diligence, expertise, and skill ordinarily exercised by reputable professionals under comparable circumstances.
- **Quality Control:** Operational techniques and activities performed to fulfill defined quality requirements.

Procedures for Addressing In-house Design E&Os

Despite robust quality control and assurance processes, design errors and omissions may still occur at various stages, including during the development of Plans, Specifications, and Estimates (PS&E), and throughout construction phases. Errors identified during PS&E development must be addressed immediately upon discovery. However, errors discovered during construction could potentially result in significant additional costs and impacts on project schedules.

Assessment: Upon identifying an error or omission, a thorough assessment must be conducted to determine the root causes. This assessment should evaluate compliance with current processes and standards, such as WYDOT standards and procedural flowcharts. Findings from these assessments should highlight opportunities for procedural enhancements and additional training needs.

Early Notification: Immediate notification to the design professional and construction engineer is required if an error or omission is discovered after PS&E completion or during construction. Urgent corrective actions may be initiated immediately when necessary to prevent public or workforce safety hazards, property damage, environmental harm, or significant operational impacts. Such immediate corrective actions require authorization from the District Engineer or their representative. Necessary corrections must be documented and executed through established departmental guidance on change orders.

Documentation: Prompt and thorough documentation is essential to effectively manage and resolve design errors and omissions. Documentation responsibilities lie primarily with the resident or district engineer and must include:

- A detailed timeline of all relevant activities.
- Comprehensive descriptions of the error or omission and its impacts.
- Contributions of involved personnel in resolving the issues.
- Supporting documentation for associated costs.
- Minutes of meetings held to address the issue.
- All formal communications and correspondence.
- Additional relevant information or documents related to the issue.

8.4 Recommended Consultant E&O Policy Statement

Even under well-structured contractual conditions, consultant-provided services may contain errors and omissions. Errors identified during the PS&E phase should be corrected at the consultant's expense, typically without incurring additional cost to WYDOT. However, E&Os discovered during construction may significantly impact project costs.

Assessment: WYDOT evaluates consultant errors and omissions on a case-by-case basis, considering the timing and nature of the error's discovery. Assessments focus on determining whether errors were due to gross negligence or carelessness, significantly impacting construction costs or schedules. Recoverable costs generally encompass additional expenses directly attributable to the identified error or omission, including additional staffing, consultant efforts, and peer reviews.

Early Notification: Like in-house procedures, immediate corrective actions must be taken if necessary to mitigate safety risks, environmental harm, or operational disruptions. Decisions for immediate corrections require authorization by the District Engineer. All corrective actions must follow established departmental guidelines.

Documentation: Comprehensive documentation by the resident or district engineer is mandatory, including:

- A detailed timeline of relevant activities.
- Clear documentation describing the error or omission and resultant impacts.
- Documentation of involvement and actions by WYDOT staff and consultants.
- Detailed supporting materials for all related costs.
- Minutes of relevant meetings.
- Formal correspondence and communications.
- Any additional relevant information, findings, or documents.
- Consultant Design E&O Resolution

Settlement/Recovery: A detailed memorandum recommending cost recovery is prepared by the resident or district engineer and submitted to the Highway Development Engineer after consultations with departmental personnel.

Notification Letter: A formal notification letter detailing WYDOT's decisions, estimated costs, and financial responsibilities is sent to the consultant. A written response from the consultant is required.

Negotiations: Negotiations for settlement can occur at any stage during the resolution process. The EOR, resident or district engineer forwards negotiated settlement offers to the Chief Engineer for review and approval.

Claims: Standard claim and change order procedures apply for contractor-submitted claims related to identified E&Os. Settlement amounts include contractor-incurred additional costs due to the consultant's errors or omissions.

Lessons Learned and Process Improvements

The Design Office will systematically collect and analyze E&O data that results in change orders, facilitating the development of lessons learned. Annual or periodic reviews of existing policies, procedures, standards, specifications, and training programs are recommended to proactively eliminate recurring issues. Specific attention will be given to enhancing quality assurance and control measures.

8.4 Chapter Summary

The chapter focused on the development and enhancement of a policy and procedure document aimed at addressing design E&Os within the WYDOT. The research team undertook the task of reviewing existing practices from other state DOTs. This analysis revealed a critical gap in the current policy structure: while there are provisions to address E&Os related to consultants through contractual language, a formal policy governing in-house E&Os does not exist. Consequently, the chapter strongly recommends that WYDOT establish a comprehensive formal policy that clearly delineates how both consultant and internal E&Os will be managed.

In detailing the current Consultant E&O Policy, it was highlighted that consultants are responsible for ensuring their professional services are accurate and meet a standard of care typical of their profession. WYDOT is tasked with notifying consultants promptly when corrective action is necessary. Furthermore, consultants must indemnify WYDOT against any claims arising from their failures or negligence. The policy also mandates that consultants obtain professional liability insurance, with specified minimum coverage amounts, and requires them to endorse and validate the work they produce under their agreements.

A recommended E&O policy statement aims to elevate the quality of contract drawings and specifications by setting a standard that aligns with best practices from comparable organizations. The purpose of this proposed policy is to systematically collect data on all E&Os that lead to change orders, enabling the department to develop lessons learned and prevent similar issues in future projects.

Chapter 9: Conclusion and Discussion

The report focuses on the pressing issue of design E&Os in highway construction, acknowledging their significant impact on project outcomes. It emphasizes the need to investigate the multifaceted factors contributing to these errors, measure their financial consequences, and understand the perspectives of key stakeholders, specifically design and construction engineers. By examining their roles, the study aimed to pinpoint critical areas that can be targeted to reduce the frequency and impact of design E&Os.

The literature review highlights prior findings acknowledging the financial ramifications of design E&Os in the construction sector, particularly in relation to DOTs. Despite this recognition, existing research often lacks a detailed analysis of the root causes and common types of errors, which are essential for developing effective mitigation strategies. This thesis aims to bridge that gap by focusing on WYDOT and its unique context.

To systematically categorize design E&Os, several key types have been identified based on previous literature and thematic analysis: plan errors, estimate errors, misinterpretations or misrepresentations, existing utility issues, and omissions. Analyzing a substantial dataset of 960 documented change orders from an eight-year span at WYDOT allowed for a comprehensive assessment of error frequency and financial impact. The findings reveal that while design E&Os may not drastically alter the overall annual budget of the DOT, projects burdened with these errors can encounter significant cost overruns—up to 16 percent of the original estimated contract amount. On average, design E&Os result in budget fluctuations of around 1 percent, with plan errors emerging as the most financially consequential. Interestingly, this view aligns with perspectives from construction engineers but diverges from that of design engineers, who perceive omissions as having the most substantial impact.

Investigating the root causes of design E&Os, interviews with construction and design engineers at WYDOT reveal prevalent challenges, particularly those related to communication and the timelines of updates. These discussions led to a key recommendation: the implementation of a comprehensive checklist designed to enhance accountability and ensure thorough reviews at every stage of the design process. Informed by best practices and quality control measures from other state DOTs, this checklist was piloted at WYDOT and received positive feedback from 80 percent of participants, many of whom found it beneficial. Reviewers expressed that the updated checklist marks a significant improvement in quality control, becoming a valuable asset for both novice and experienced engineers.

Ultimately, the study emphasizes that WYDOT has significant opportunities to enhance the acceptance and implementation of various quality control tools. By refining processes particularly through the establishment and improvement of a design checklist the organization can significantly strengthen quality control mechanisms employed during the design phase. This proactive approach aims not only to mitigate design E&Os but also to foster better communication and collaboration between design and construction teams, paving the way for more efficient and cost-effective highway construction projects in the future.

The discrepancy between the plans created during the design phase and the actual execution in the field often leads to significant challenges in highway construction. Design E&Os can arise from inadequate consideration of field conditions or miscommunication between teams. The stakes are high, as these errors can result in cost overruns, project delays, and unsafe conditions on the highways. The study identifies communication problems as a primary factor contributing to design E&Os. Misunderstandings regarding project goals, specifications, and field conditions can exacerbate these errors. Therefore, establishing clear lines of communication between design and construction teams is essential for effectively addressing these issues.

To mitigate design E&Os, the research findings suggests implementing real-time collaboration platforms alongside an updated design checklist. These technologies enable team members to share information rapidly, clarify uncertainties, and make adjustments on the fly. By facilitating immediate communication and feedback, such platforms can help identify and rectify potential errors before they escalate into more significant problems during construction.

The differing perspectives of construction and design teams play a crucial role in how errors are perceived and managed. Construction professionals often focus on practical implementation challenges, while design engineers may prioritize theoretical ideals. Recognizing and respecting these differing viewpoints can enhance collaboration and lead to more effective problem-solving.

Additionally, the observations suggest that QC practices from other state DOTs could be beneficial for WYDOT. Adopting proven tools, such as an updated design review checklist, can streamline the QC process and improve overall project outcomes. Fostering a culture of continuous improvement by learning from others can lead to more efficient practices.

Moreover, there is a call for future research to explore the development of collaborative tools tailored specifically for DOTs. Such tools could facilitate better communication, coordination, and data sharing among stakeholders, ultimately improving project outcomes and reducing errors.

In summary, the findings indicate that addressing the communication gap between design and construction teams, utilizing technology for real-time collaboration, and learning from the experiences of other DOTs can significantly enhance the quality and efficiency of highway construction projects.

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Appendices

Appendix A: Plans and Procedures from Other State DOTs

This appendix provides further details on the policies and procedures for handling design errors and omissions across various state Departments of Transportation (DOTs).

Maricopa County DOT (MCDOT, 2021) has issued a procedure for handling design errors and omissions (E&O). The purpose of this document is to identify liability, facilitate resolution, and provide suggestions for settlement to the Director of MCDOT or for resolution with the consultant design firm. According to this procedure, MCDOT will recover expenses related to consultant negligence that result in errors and omissions. This procedure also determines financial liability for design errors and omissions that lead to change orders and claims.

According to the responsibilities:

- MCDOT Project Management, Engineering, Procurement, and Construction personnel shall work with their Consultants to examine any claims of error or omission.
- If the design professional's due diligence or standard of care results in a design error, MCDOT will attempt to recover the expenses from the Consultant. MCDOT's internal and external purpose is to create engineering documentation that is current, accurate, comprehensive, and of the best quality while satisfying engineering standards.
- In order to tackle the issue at the lowest level, the MCDOT PM will work with the Consultant or in-house design team. MCDOT shall provide any manuals, specifications, drawings, guidelines, and procedures requested by the Consultant under contract.

The procedures are as follows:

1- A probable design conflict/project issue is reported to the Project Manager (PM) in writing by the Resident Engineer (RE).
2- As needed, the RE and PM will cooperate on the design dispute, problem, or probable error and omission concern.
3- The problem will be assessed by the RE and PM. This action should be taken within five working days of the issue's discovery.
4- The Consultant will assist the PM find solutions. Within 10 working days, the PM, Consultant, and RE will resolve the design issue. Written information and documentation are required.
5- If the PM and RE determine that the Consultant is financially responsible, the PM shall notify the Consultant within 3 working days.
6- The Consultant shall notify the PM within 5 working days if the problem will be fixed or escalated for resolution and that the Consultant will: a. Take measures to remedy the issue and discuss financial responsibility with the PM.

Depending on the situation, financial accountability might be partial or total. b. Not accepting responsibility for the issue.

7- If the Consultant requests an escalation, the PM and RE shall escalate to the MCDOT Chief Construction Engineer and Project Management Branch Manager.
8- The Chief Construction Engineer and Project Management Branch Manager shall direct the Consultant to take prompt corrective action if needed, regardless of the procedure.
9- If resolution fails, the Chief Construction Engineer and Project Management Branch Manager shall submit a formal claim notification. The Chief Construction Engineer and Project Management Branch Manager shall require the Errors and Omissions Claims Review Board (Review Board). This step will be performed within 5 working days from step 7.
10- The Review Board will have an informal review within 10 working days and invite the PM, RE, Consultant, and others. The Review Board must receive all claim documents in writing five working days before the hearing.
11- In a separate hearing, the Review Board will hear the MCDOT claim and the Consultant's answer and make a recommendation. Within 10 working days of the claim hearing, the MCDOT Director or designer will receive this suggestion. Director is not bound by Recommendation.
12- The Consultant, PM, and RE will be informed of the Director's decision.

New Jersey DOT has developed a Design errors and omissions process to enhance the design quality and recover the additional costs caused by the consultants' negligence during design and construction services (NJDOT, 2019). The objective of this process is to facilitate the communication with the consultant when a potential E&O is discovered and prevent any delays that would yield to additional costs, to allow the early consultant participation in solving the raised problem in order to mitigate any possible damages, and to create a procedure that is equitable and encourages collaboration between the NJDOT and the Consultant.

The process involves seven main tasks which are stated below as follows (NJDOT, 2019):

1- *Discovery:* Contractor provides NJDOT with "notice" of prospective claim or NJDOT staff identifies Design "issue" or CI "issue" that might be an E&O.

2- *Notification:* As soon as the NJDOT becomes aware of a Designer CI problem, it is obligated under the contract to provide adequate written notification of a potential E&O to the Consultant.

3- *Inquiry and Verification:* The Consultant's response is considered by the NJDOT to determine whether or not there were E&O and whether or not the associated expenses are recoverable. If NJDOT pursues Change Order cost recovery, the Consultant may use either the Contractual Claims Resolution Process (if a "claim") or the Capital Program Management (CPM) E&O Resolution Process (to defend its design or cost consequences).

4- *Negotiation:* After verifying an E&O, NJDOT will begin discussions with the consultant to recoup expenses.

5- *Recovery/Collection:* In the event of a settlement, it is possible that the NJDOT and the Consultant may need to sign a binding Agreement with Releases. Payments to the Consultant will be invoiced and collected by NJDOT in accordance with NJDOT Policy and Procedure No. 230, Cash Receipts-Invoicing.

6- *Tracking/Reporting:* The Project Reporting System (PRS) will be used by NJDOT to monitor and report on the development of an E&O. The Project Manager will keep track of any prospective E&Os and their current status.

7- *Training/Evaluation:* The New Jersey Department of Transportation's Program Management Office (PMO) will help in training employees and keeping track on "lessons learned."

(Several flowcharts providing more details could be found through these links:
- Designer Workflow with Contractor's Notice or Complete Claim: https://www.state.nj.us/transportation/capital/pd/documents/EO_W_NoticeClaim.pdf
- Designer Workflow without Contractor's Notice or Complete Claim: https://www.state.nj.us/transportation/capital/pd/documents/EO_WO_NoticeClaim.pdf
- Consultant Construction Inspection Workflow: https://www.state.nj.us/transportation/capital/pd/documents/EO_CI_WNoticeClaim.pdf
- E&O Settlement Against Consultant Workflow (see Figure 25): https://www.state.nj.us/transportation/capital/pd/documents/EO_Settlement.pdf

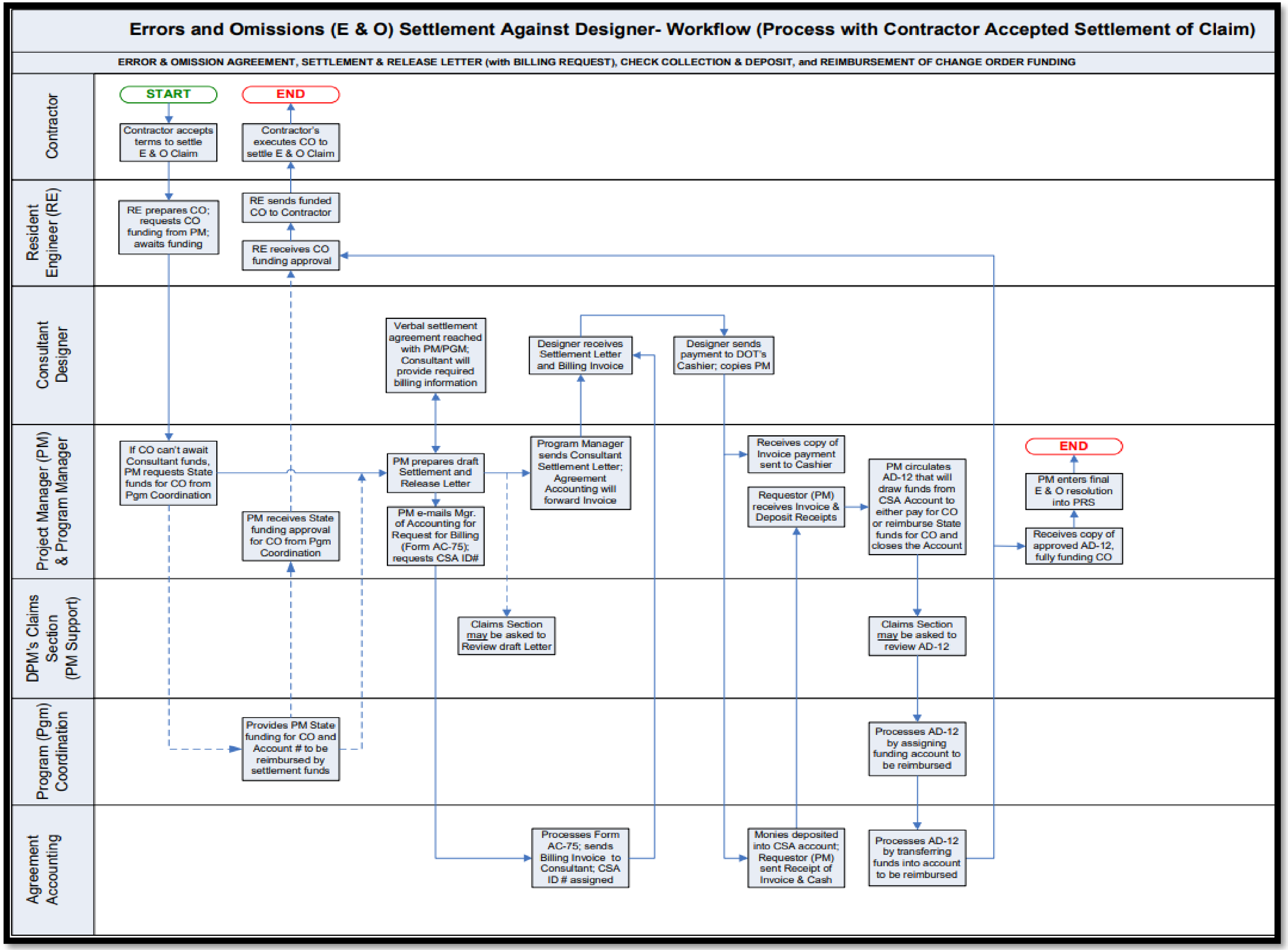


Figure 44: E&O Settlement Against Consultant Workflow (NJDOT, 2019)

Minnesota Department of Transportation (MnDOT) developed a policy "**Consultant Errors and Omissions"** that provides the MnDOT with guidelines and procedures for dealing with the discovered error, omissions, or contractual breaches.

Link: https://www.dot.state.mn.us/policy/financial/fm004.html

Minnesota Department of Transportation (MnDOT) to hold consultants (including design-builders) who perform architecture, engineering and design-related services accountable for the quality and accuracy of deliverables provided to the department. When MnDOT finds the consultant responsible for error or omission, MnDOT will consider the nature, extent and circumstances of the E&Os, the resulting damages and possibility of recovering the damages either from the consultant or take other appropriate action after notifying them of the problem. The consultant is allowed to mitigate the damage from the E&Os. Upon reaching a conclusion, the plan is executed:

1. Consultant Plans Errors Review Committee is established, who is responsible for conducting reviews of identified potential design E&Os, for making recommendations to the Commissioner as to whether to seek a remedy which could be monetary or non-monetary, consisting of: State Design Engineer, State Construction Engineer, Chief Counsel, Audit Director, Director of Consultant Services, Assistant Chief Counsel, construction and Contract Management and some other members as designated by the Commissioner or Deputy Commissioner from time to time.
2. Measures of Damages depending on whether the E&Os were determined before or after the letting of a contract.
    - E&Os discovered pre letting consists of cost to correct the plans and to prepare and publish any addenda for corrections.
    - E&Os discovered post-Letting and Pre-Awarded includes cost to correct the plans or cost incurred by the DOT to re-let the project, lawsuits etc.
    - E&Os discovered post-letting; post-award reflects the additional costs of construction due to a design E&Os.
3. Action Steps
    - Discovery of Potential Error or Omission; Initial Analysis; Reporting.
    - The Design Engineer notifies the Resident Engineer of the possible Design E&Os and report the initial assessment of the E&Os to the Chair of the Consultant Plan Errors Review Committee.
4. Correction of Error by Consultant: MnDOT requires the consultant to correct the errors without additional charge to the DOT. Communication between the Design Engineer and the consultant regarding potential E&Os must be carefully documented and made available to the Consultant Plan Errors Review Board. The design engineer mustn't enter into any agreement or understanding with the consultant that might limit further action against the consultant by MnDOT.

5. Review by Consultant Plan Errors Review Committee: If the Committee believes that an error or omission has occurred, the committee will make an initial assessment of the nature and magnitude of damage to MnDOT.
6. Recommendation by Committee: The committee may suggest monetary or non-monetary actions to the consultant.
7. Remediation: may lead to litigation.

Texas Department of Transportation (TxDOT). Consultant Errors & Omissions Correction and Collection - Policy and Procedures. Link: https://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/design/eo_procedures.pdf

This policy was developed to enforce its contracts with engineering, architectural, and surveying consultants to ensure the delivery of quality professional services, the prudent expenditure of public funds, and the preservation of cooperative business relationships. The developed policy involved 13 sections for dealing with E&O, change orders, cost recovery and settlements, briefly:

1- *Consultant contract administration:* stating that the consultant is deemed responsible for the design E&O in accordance with the stated consultant provisions in the engineering, architectural and surveying contracts. Also, errors and omissions that are discovered before construction are to be corrected at the consultant's expenses, otherwise if they are discovered during or after construction the resulting additional costs are considered as a damage for the TxDOT and TxDOT is entitled to collect them.

2- Error and Omission Identification and Communication: this section specifies the action that should be taken on discovering E&O throughout the project phases, as stated:
"Errors and omissions identified during PS&E development are corrected at the consultant's expenses with typically no or negligible additional cost to TxDOT"
"Errors and omissions identified during construction, however, can potentially result in significant additional cost to TxDOT"
As for the communications: the consultant contract will be kept active through the construction stage, "If the consultant contract is no longer active, TxDOT should still contact an appropriate person at the consultant firm rather than contacting the engineer responsible for the design directly".

3- *Error and Omission Correction*: Consultants are responsible for promptly correcting errors and omissions without compensation. During the design phase (PS&E Development): the consultant is responsible for delivering high quality correct plans, if any changes occurred by TxDOT that are not a result of consultant omissions, it shall be paid. If the errors and omissions are due to the consultant's incorrect design or unacceptable plan sheet preparation, the TxDOT design PM will require the consultant to correct them at his own expense and this correction should be documented. During Project construction: TxDOT must notify the consultant and allow them to help resolve an apparent error and omission. TxDOT should document consultant notifications.

4- *Change orders*: TxDOT must notify the consultant and provide them with a chance to help in resolving an apparent error and omission that may lead to a change order. The section further specifies the reasons for change orders due to E&O and how the additional costs would be recovered in each case.
5- *When to Request Payment*: The request for payment can occur by change order or after project completion. When completing change order expenses, TxDOT should engage the consultant about timing and payment. By Change Order: "At the time the additional cost is being finalized, subsequent to a change order, resolution may not be possible if the consultant does not agree with the identification of fault, its identified share of responsibility, or the determination of amount to be requested." Upon Project Completion: "Upon completion of the construction project, the appropriate TxDOT staff should review change orders involving additional cost to be recovered. TxDOT staff should notify the consultant in writing of the project's construction completion, outline the errors and omissions, along with the additional costs as documented with the change orders."
6- *Contractor Claims Following Construction*: After construction, a contractor might claim an error or omission. The consultant may pay some or all of the contractor claim. When TxDOT receives a contractor claim, the consultant must be contacted and given the chance to provide TxDOT with any relevant information. The contractor and consultant will not negotiate during the claim's procedure. After settling any contractor claims, TxDOT should use the same considerations as during construction to determine the consultant's amount of responsibility for any excess expenses. If additional costs are to be recovered, TxDOT personnel shall advise the consultant in writing of the final claims, errors, and omissions. Any previous coordination and preliminary agreements regarding errors and omissions should be included in the notification. The letter should inform the consultant that TxDOT will proceed with the official request for payment if the consultant does not seek a meeting within 30 days.
7- *Post-Construction Design Error*: After construction and operation, an error in design may be identified. After construction and engineering contract termination, the consultant is liable for the design. TxDOT personnel should contact CSO quickly if a design problem is discovered after construction to avoid the statute of limitations. In these cases, CSO should be contacted for advice.
8- *Cost Recovery Procedures:* it specifies how the costs will be recovered from the consultant because of errors and omissions. First the consultant is notified through the initial notification letter, then he should pay the required amount in accordance with step 11 or step 13 (in case of settlement agreement. In case of the consultant disagreement "The Chief Engineer will review the disagreement as submitted through the PEPS Division Director. Upon request for the Administration's consideration, the district will contact the PEPS Division and submit a complete copy of the initial notification letter together with the consultant's written explanation of disagreement."

9- *Consideration by TxDOT Administration:* "Consideration by TxDOT Administration provides an opportunity for the disagreement to be reviewed outside the district".

10- *Statute of Limitations*: "The statute of limitations is four years. The Attorney General's Office has four years from the time the consultant contract terminates to file suit against the consultant for recovery of costs. In a situation where timing may be a factor, CSO should be contacted for specific guidance".

11- *Remittance of Payment* is to be handled in accordance with the Revenue Accounting Manual, Ch. 2, Sect. 11, "Remittance of Payment".

12- *Credit of Recovered Funds*: "Credit of recovered funds is to be handled in accordance with the Revenue Accounting Manual, Ch. 2, Sect. 11, "Proper Credit of Recovered Funds".

13- *Settlement Agreement*: "If not requested by the consultant, it is not necessary to execute a settlement agreement. If a consultant requests a settlement agreement, there is a standard Release and Settlement agreement that can be prepared for execution upon receipt of the payment."

14- *TxDOT Responsibility*: "It is TxDOT's responsibility to identify errors and omissions and fairly evaluate the responsibility for additional cost when applicable. There are steps where judgment is required and the exercise of good judgment is expected. TxDOT is responsible for spending large sums for engineering and construction services. This responsibility includes the recovery of appropriate costs where they are clearly due. It is the responsibility of TxDOT staff to ensure that TxDOT's business practices are professional, fair, equitable, and reasonable."

California DOT (Caltrans) has developed a plan checklist for quality control in design enlisting several items to check in for each of the criteria as:

1. **Design**- "Design calculations, check calculations, and supporting documentation are bound and properly identified; all differences have been properly resolved, and registration seals and signatures are affixed."
2. **Plans**: "Plans conform to Caltrans drafting standards and requirements (e.g., standard plans are listed; standard abbreviations and symbols are used; spelling is correct; tradenames and proprietary items are not shown; staged construction and traffic control are shown as applicable), are consistent in details and cross-references among sheets, are readable when reduced, and are properly signed and sealed."
3. **Special Provisions**: "Requirements for conformity, consistency, legibility, proper sealing and signatures similar to those listed above; plus inclusion of complete, correct information for all items covered in the Special Provisions."
4. **Estimate**: "Quantity calculations and independent checks are bound, properly identified, and within allowable tolerances; estimates are appropriately rounded; quantities on forms are consistent with those in calculations; standard units of measure are used; reasonable unit prices and a working day schedule are included; and format and presentation requirements similar to those in above items are met."

5. **Late Plan Changes**: "Design calculations, independent checks, and supporting documentation have been prepared and submitted; road plans and bridge plans are consistent in details; Special Provisions have been modified as necessary; and quantities and estimates have been revised as necessary."
6. **General**: "Typical cross-sections, layouts, profile grades, super elevations, contour grades, and structure plans are consistent with approved project geometrics and current road plans; on structure projects with PS&Es produced by two or more consultants, elements of plans and details are coordinated and consistent; railroad requirements are coordinated; Justification for non-standard items of work is provided."

Caltrans' response to resolution of design errors and omissions lists the following steps:

1. Caltrans compiles a quarterly list of significant design changes and Contract Change Orders (CCOs) for consultant- designed project, consultants receive this list and potential Design Breaches are reported to higher management based on the guidelines.
2. The Region Division Chief/ Deputy District Director collaborates with their peers to undergo the PDBs as per the rules and sends it to the Chairperson of the Management Review Panel (MRP) for further review if deemed necessary.
3. MRP comprises of 2 members: Chairperson (Headquarters Construction Coordinator) and Design Coordinator/ State Bridge Engineer for the District who evaluate the potential design liability using the provided guidelines and submit the recommendations to Chief Engineer.
4. Chief Engineer decides on no action or further action against consultants, if further action is approved, a representative or team is appointed, and an informal discussion is initiated with the consultant to resolve the issues keeping the legal division and Chief Engineer informed. Alternatively, Non-binding dispute review boards are appointed if agreed upon and the suggestions are sent for review to the Chief Engineer. Also, the Consultant participates in discussions about additional costs and reviews and comments on cost increasing project changes that may lead to liability. If mutual resolution isn't reached, the representative consults legal division for potential, additional advice.
5. If legal action is approved, State law mandates retaining a consultant in the same discipline as the defendant, facts of the case are presented to the consultant for review and analysis and Consultant is supposed to independently conclude consultant design professional's negligence.
   Link:
   http://www.pe.com/localnews/transportation/stories/PE_News_Local_D_caltrans08.2abf274.html

Montana DOT (MDT) expects the Consultant to provide a professional service to the Department to meet the standard agreement, the consultant is deemed responsible for any additional costs, quality of the work products. Some of its resolution procedures to uniformly address errors and omissions from plans developed by consultants are:

1. Allow MDT field construction personnel to quickly obtain a solution to construction problems encountered due to errors and/or omissions from plans developed by consultants.
2. Allow MDT field construction personnel to quickly obtain a solution to construction problems encountered due to errors and/or omissions from plans developed by consultants.
3. Establish a uniform method to recuperate costs incurred by MDT due to errors and/or omissions on plans developed by consultants.

Plans and Procedure of MDT-

1. Identification of potential error/ omissions.
2. MDT Construction project Manager notifies Consultant Design Engineer, contract consultant as necessary.
3. Consultant Design Engineer (CDE) evaluates if E&O procedures should be implemented and notifies EPM and Consultant Project Engineer (CPE).
   - If not, EPM implements the corrective action.
   - If yes, EPM and CPE begin tracking time and determine a solution, change order and solution is implemented EPM then submits the change order within 60 days for Consultant Performance Evaluation, who compile the MDT time and costs and schedules a E&Os meeting to decide Consultant's liability.
   - If the committee decides not to take further action, E&O is closed else E&O decides to pursue payment from consultant who if agrees to the findings will close the E&O and pay, else further meeting is held to review Consultant's liability.
   - If the committee decides not to take further action, CDE notifies E&O is closed else E&O decides to continue payment from Consultant and CDE sends Consultant "Dispute Resolution Letter."
   - If the consultant agrees to it, process ends else the same process goes on for two more times until final dispute resolution letter where dispute resolution committee considers Consultant's appeal and decides on final action, which could be one of the following:
     a. DRC reaffirms the findings from the 3rd E&O Committee meeting.
     b. DRC agrees with the Consultant to share equally the cost to jointly present the issue to a creditable, neutral third-party panel to obtain a non-binding recommendation.
     c. The DRC pursues other Alternative Dispute Resolution methods. (e.g.: binding arbitration).

     Further information in MDT Consultant Services Manual,2019 (Appendix B).

Ohio Department of Transport (ODT) in Specifications for Consulting Services identifies errors and omissions as "Services provided by the consultant under this agreement shall be performed in a manner consistent with that degree of care and skill ordinarily exercised by members of the same profession currently practicing under similar circumstances". The consultant is deemed responsible during the subsequent phase of work for:

- Responding promptly to the Department's request for clarification/correction.

- Preparing any plans or data to correct the negligent act, error, or omission without additional compensation.

ODT's procedure for dealing with Errors and Omissions are:

1. Discovery phase: Notify the consultant of the problem by phone or writing.
    - ask for clarification of discrepancy, agree to a deadline for response, fully document the call in writing, direct the consultant to maintain separate cost accounting specific to their effort to resolve the problem and begin to separate and track ODOT labor costs that directly attribute to the problem.
    - Never characterize a discrepancy as an error and don't negotiate, reach agreement, or sign any document relative to the consultant's responsibility for the problem.
2. Fully investigate the discrepancy to determine its extents, impacts and source. Notify other ODOT personnel as appropriate including the Consultant Contracts Manager, the District Planning and Engineering Administrator, District Construction Administrator, and Central Office Personnel as appropriate.
3. Take appropriate steps to resolve the issue and minimize the damages to the Department including:
    - direct the consultant to provide a solution and review it.
    - involve appropriate District and Central Office personnel and develop and review other solutions if appropriate, continuing to involve the consultant.
    - if the consultant's recommendation isn't accepted, ask for his comments in writing and include the consultant in all aspects of decision making, documenting all the information and communications.
4. Take appropriate steps to resolve the issue and minimize damage to the department.
5. Complete an investigation of the circumstances of the error or omission including:
    - Determination that the project was completed in accordance with the specifications and plans and the problem was not the result of contractor error.
    - Evaluation of the consultant's scope of services and review comments related to the issue.
    - Cost analysis of damages including rework, lost work, soft costs, extra work for betterment and due to error, alternate designs, and potential costs mitigated by ODOT actions.
    - Full documentation of investigation in writing including conclusions reached concerning responsibility for the error or omission.
    - Providing the documentation to administrator, office of consultant Services.
6. Upon receipt of the District Report, the Administrator, Office of Consultant Services will refer the matter to the Director's Consultant Resolution Board. (Section 2.38 (Ohio Department of Transportation Administration of Contracts for Professional Services, 2022).

North Dakota Department of Transportation (NDDOT) considers errors and omissions as deficiencies from the standard of care on the part of a design/ construction engineering consultant in the performance of professional services under contract with NDDOT. Errors and

Omissions are considered alleged only when they are acknowledged as errors by the review board or the consultant.

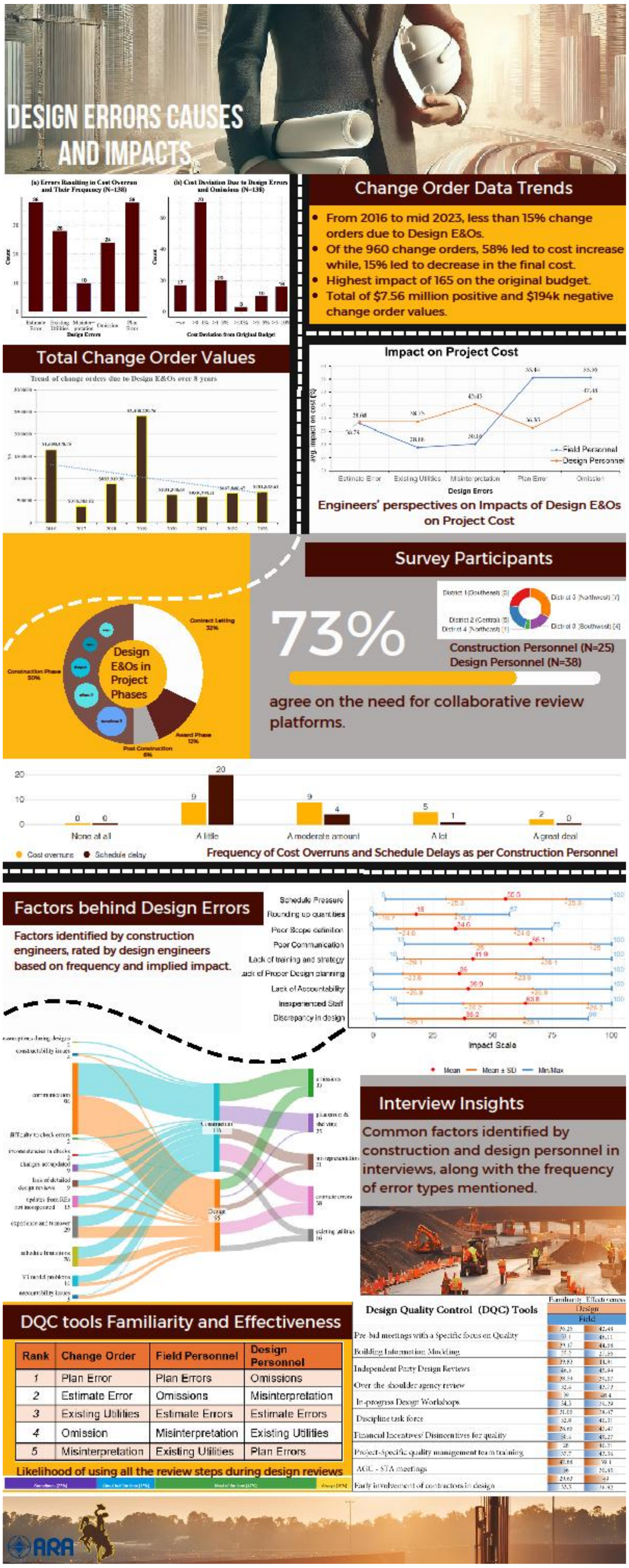
NDDOT's plans and procedure include:

1. Discovery, in which the alleged error or omission is identified.
   a. prior to bid advertisement
   b. after advertisement but prior to bid opening
   c. after bid opening but prior to construction contract award or,
   d. after the construction contract is awarded.
2. Resolution of error, which details procedures for resolving the matter. This stage assigns responsibility, calculates change-order cost, and seeks consultant's responsibility to errors and omissions. The matter is resolved if the consultant accepts liability, if unresolved, matter escalates administratively and ends with a hearing from the Errors and Omissions Review Board (EORB). Non-compliance against the EORB leads to claim and legal action against the consultant for cost recovery pending decision from the Director.

   EORB comprises of four members plus a committee chair, with following membership requirements: (NDDOT, 2007):

   a. All the board will be professional engineers.
   b. The director of the Office of Project Development shall chair the committee.
   c. Two members from NDDOT not involved in the project directly appointed by Deputy Director of Engineering (DDE).
   d. Two members from the American Council of Engineering Companies (ACEC) appointed by Chair and co-chair after being notified by the Director of the Office of project Development.

Appendix B: Infographics



Appendix C: Surveys and Interview Questions

Questionnaire Survey Set 1: Construction Engineers' Survey

Design Errors and Omissions handling and Data Management Survey
Survey Flow

Standard: Welcome Message (7 Questions) Block: Data Management & CMS (5 Questions) Standard: Design Error and Omission during the Construction Phase (15 Questions) Standard: Construction, Bidding, and Design Reviews (4 Questions) Standard: Tools to mitigate Design Errors and Omissions (3 Questions) Standard: Thank you!!! (1 Question)

Block: Welcome Message
Q1. Personal Information:

1. Full Name:
2. Job Title:
3. Years of experience in the highway industry:
4. District:
   - District 1(Southeast)
   - District 2 (Central)
   - District 3 (Southwest)
   - District 4 (Northeast)
   - District 5 (Northwest)
5. Contact Information:
   - Email address
   - Contact number

Q2. Can we contact you for a virtual/in-person follow-up interview?

- Yes
- No

Block: Data Management & CMS

Data Management and Construction Management System (CMS) Practices. WYDOT extensively uses iCX Construction Management System and Falcon for data management and records. This section deals with the use and effectiveness of these platforms.

Q3. How often do you recall contractors using Construction Management System for data entry?

- Never
- Sometimes
- About half the time
- Most of the time
- Always

Q4. Do you agree or disagree that CMS for data records is sufficient?

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Q5. Does WYDOT use other platforms for data management besides CMS?

- No
- Yes

Q6. What other platforms does WYDOT use to store/archive data?

____

Block: Design Error and Omission during the Construction Phase

Design errors and omissions can be encountered in any phase of construction and lead to cost overruns or schedule delays. This section delves into identifying the specific locations or instances where these errors occur and their impacts.

Q7. In which project phase are the design errors and omissions often noticeable? (Select all that apply.)

- Contract Letting phase
- Award Phase
- Construction Phase
- Post Construction - maintenance & operations.

Q8. How often do you encounter design errors and omissions during the construction phase?

- Always
- Often
- Sometimes
- Rarely
- Never

Q9. WYDOT has a list of general requirements for their design plans on their website specifying criteria for the plans in each phase (e.g., preliminary, grading, final design plans and PS&E plans etc.). How often do you think that the design plans meet the requirements for each phase?

- Never
- Sometimes
- About half the time
- Most of the time
- Always

The following questions focus on the relationship between cost overruns and design errors and omissions.

Q10. How often do you face cost overruns due to design error and omissions?

- None at all
- A little
- A moderate amount
- A lot
- A great deal

Q11. Rate the impact of the following factors on cost overrun based on your experience on a scale of 0 to 100, with 0 being the least significant and 100 being the most significant. You can hover over each factor to see the definition or click here to view the definitions.

0 10 20 30 40 50 60 70 80 90 100

Estimate Error	
Misinterpretation/ misrepresentation of field data	
Plan Error	
Omission	
Unknown third party/ utilities	

Q12. What other reasons resulted in cost overruns not listed in the previous question? Mention any that you might've encountered during construction. Leave blank if not applicable.

____

Q13. How often do you get involved in resolving design errors and omissions resulting in cost overruns?

- Never
- Sometimes
- About half the time
- Most of the time
- Always

Q14. What is the average impact of design E&O on project budget?

- Negligible Significance (0%)
- Sightly Significant (1-3%)
- Moderately Significant (3-5%)
- Very Significant (5-10%)
- Extremely Significant (>10%)

The next questions focus on schedule delays as a result of design errors and omissions.

Q15. How often do you face schedule delays due to design errors and omissions?

- None at all
- A little
- A moderate amount
- A lot
- A great deal

Q16. Rate the impact of the following factors on schedule delay based on your experience on a scale of 0 to 100, with 0 being the least significant and 100 being the most significant. You can hover over each factor to see the definition or click here to view the definitions.

	0 10 20 30 40 50 60 70 80 90 100
Estimate Error	
Misinterpretation/ misrepresentation of field data	
Plan Error	
Omission	
Unknown third party/ utilities	

Q17. What other reasons resulted in schedule delays not listed in the previous question? Mention any that you might've encountered during construction. Leave blank if not applicable.

____

Q18. How often do you get involved in resolving design errors and omissions resulting in schedule delays?

- Never
- Sometimes
- About half the time
- Most of the time
- Always

Start of Block: Construction, Bidding, and Design Reviews

Q19. **The next questions focus on construction, bidding, and design reviews.**

Q20. How effective are the AGC-WYDOT meetings in addressing overall issues related to design errors and omission and quality of construction documents released by WYDOT?

- Not effective at all
- Slightly effective
- Moderately effective
- Very effective
- Extremely effective
- Not applicable

Q21. How often do you get involved in reviewing construction documents before letting construction documents for bidding?

- Always (20)
- Most of the time (21)
- About half the time (22)
- Sometimes (23)
- Never (24)

Q22. How effective is the design review process to limit design errors and omissions?

- Extremely effective
- Very effective
- Moderately effective
- Slightly effective
- Not effective at all

Block: Tools to mitigate Design Errors and Omissions

The next questions focus on existing tools to mitigate design errors and omissions and their familiarity. While various tools are commonly employed in the industry, it is important to note that not all of these tools are utilized by WYDOT. Below, we have outlined some of the prevalent tools used in the industry for this purpose.

Q23. How familiar are you with the existing tools to avoid Design errors and omissions? Please rate your familiarity with these tools. You can hover over the text for or click here for more information on the tools listed below.

	Not familiar at all	Slightly familiar	Moderately familiar	Very familiar	Extremely familiar

0 10 20 30 40 50 60 70 80 90 100

Pre-Bid meetings with Specific focus on Quality	
Building Information Modeling (BIM)	
Independent Party Design Reviews	
Over the shoulder agency review	
In-progress Design Workshops	
Discipline task force	
Financial Incentives/ Disincentives for quality	
Project-Specific quality management team trainings	
AGC-WYDOT meetings	
Early involvement of contractors in design	

Q24. Please rate the effectiveness of the tools listed above to limit design Errors and Omisssions.

0 10 20 30 40 50 60 70 80 90 100

Pre-Bid meetings with Specific focus on Quality	
Building Information Modeling (BIM)	
Independent Party Design Reviews	
Over the shoulder agency review	
In-progress Design Workshops	
Discipline task force	
Financial Incentives/ Disincentives for quality	
Project-Specific quality management team trainings	
AGC-WYDOT meetings	
Early involvement of contractors in design	

Block: Thank you!!

Q25. Thank you for contributing to our survey. Please use this space to provide additional comments or feedback that was not covered in the survey.

____

Interview Questionnaire Set 1: Construction Engineers' Interviews

1. What are the most common design or pre-construction errors encountered during construction? Can you share specific project examples and discuss your involvement in mitigating such errors?
    a. Problems due to shelving of plans and lack of updates:
    b. Reduction in design reviews:
    c. Employee turnover and lack of experienced designers:
    d. Multiple parties conducting design checks (Consistency of plans meeting required standards Compliance with checklist steps by designers)
2. How do you evaluate schedule impacts? Have there been incidences of schedule delays because of design errors and omissions? Does the DOT have platforms to record them?
3. Can you share any success stories or best practices in mitigating design errors and omissions from previous projects?
4. Have there been any instances where lessons learned from past design errors and omissions have influenced future project planning and execution?
5. Regarding data archiving for design errors and omissions, how do you personally manage this compared to WYDOT processes?
6. Thoughts on software for data records varied among survey respondents. Do you believe standardizing record keeping would help mitigate design errors and omissions? Would WYDOT personnel benefit more from a single data record platform, or is diversity in services preferable?
7. Drawing from your experience, what strategies would you propose to reduce design errors and omissions?
    a. Plans for digitizing the design process:
        i. WYDOT's future plans for digitization.
        ii. Involvement in digitization efforts.
        iii. Actions taken towards digitization.
        iv. Importance of training engineers for digitization.
    b. Common issues discussed in AGC-WYDOT meetings:
        i. Contractor involvement in project design.
        ii. Effectiveness and improvement opportunities.
    c. Third-party (independent) reviews:
        i. Perceived benefits.
    d. Design Quality Control tools:
        i. Requested tools for effectiveness testing.
        ii. Suggestions for additional helpful tools.
    e. Evaluation of schedule impacts:
        i. Incidences of schedule delays due to design errors.
        ii. Recording platforms for schedule impacts.
8. What other topics would you have liked us to discuss?

Questionnaire Survey Set 2: Design Engineers' Survey

Survey Flow

Standard: Welcome Message (1 Question)
Block: Challenges faced (6 Questions)
Standard: Construction, Bidding, and Design Reviews (3 Questions)
Standard: Quality Control Mechanism (4 Questions)
Standard: Design Error Causal Variables (4 Questions)
Standard: Tools to mitigate Design Errors and Omissions (5 Questions)
Standard: Thank you message (1 Question)
Standard: Contact information (5 Questions)

Block: Challenges faced

Q1. Challenges Faced This section covers WYDOT's data management and collaboration practices, as well as the design errors encountered and their impact on cost and schedule.

Q2. Do you agree that Construction Management System (CMS) and Falcon used by the department for data records and plan issuance is sufficient?

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Q3. Do you agree that WYDOT needs a tool to track the changes in the plans that would help benefit the review process?

- Strongly disagree (6)
- Somewhat disagree (7)
- Neither agree nor disagree (8)
- Somewhat agree (9)
- Strongly agree (10)

Q4. What are the most common issues caused by design errors and omissions? (Select all that apply.)You can hover over the text for or click here for more information on the errors listed below. Mention anything that you might've experienced or heard of.

- Estimate Error
- Misinterpretation/ misrepresentation of field data
- Plan Error
- Omission
- Unknown third party/ utilities
- Other (Mention anything that you might've experienced or heard of. Leave blank if not applicable) (7) ____

Q5. Rate the impact of the following factors on cost overrun based on your experience on a scale of 0 to 100, with 0 being the least significant and 100 being the most significant. You can hover over each factor to see the definition or click here to view the definitions.

	0 10 20 30 40 50 60 70 80 90 100
Estimate Error	
Misinterpretation/ misrepresentation of field data	
Plan Error	
Omission	
Unknown third party/ utilities	
Other	

Q6. What are the most common high-risk areas during the design phase that might lead to cost overrun, schedule delays, or delays in the design process in your experience? Leave blank if not applicable.

____

Block: Construction, Bidding, and Design Reviews

Q7. How effective are the AGC-WYDOT meetings in addressing overall issues related to design errors and omission and quality of construction documents released by WYDOT?

- Not effective at all (6)
- Slightly effective
- Moderately effective
- Very effective
- Extremely effective
- Not applicable (7)

Q8. How effective is the design review process to limit design errors and omissions?

- Extremely effective
- Very effective
- Moderately effective
- Slightly effective
- Not effective at all

Block: Quality Control Mechanism

A standard checklist for reviewing designs, encompassing various components such as bridges, roads, etc., has been recommended for consideration. The following section intends to examine the existing checklists, their effectiveness, and potential enhancements for optimization.

Q9. WYDOT has a design review checklist organized by project categories. How often are all the steps followed during the review process?

- Never
- Sometimes
- About half the time
- Most of the time
- Always

Q10. How effective are review checklists to limit the occurrence of design errors and omissions?

- Not effective at all
- Slightly effective
- Moderately effective
- Very effective
- Extremely effective
- Not applicable

Q11. How can the checklist be structured to improve the review process and provide benefits to all parties involved in the design process? Leave blank if not applicable. ____

Block: Design Error Causal Variables

Several research studies have identified common causal factors behind design errors. These factors eventually lead to cost overruns and project delays. This section will delve into the common factors contributing to design errors and assess their significance in impacting outcomes.

Q12. What do you think are the common reasons behind design errors and omissions? (Select all that apply.) Hover over each factor to see its definition, or click here for more information.

- Inexperienced staff/ Employee turnover
- Lack of training, strategy, and leadership in the organization
- Poor scope definition
- Lack of proper planning during design
- Poor Communication
- Schedule pressure
- Discrepancy in design checks and audits
- Lack of accountability
- Rounding up quantities

Q13. Rate the impact of the following causal variables on design errors and omissions on a scale of 0 to 100, with 0 being the least significant and 100 being the most significant. Hover over each factor for its definition, or click here for more information.

0 10 20 30 40 50 60 70 80 90 100

Inexperienced staff/ Employee turnover	
Lack of training, strategy, and leadership in the organization	
Poor scope definition	
Lack of proper planning during design	
Poor Communication	
Schedule pressure	
Discrepancy in design checks and audits	
Lack of accountability	
Rounding up quantities	

Q14. What other causes result in design errors and omissions? Mention any that you might've encountered. Leave blank if not applicable.

____

Block: Tools to mitigate Design Errors and Omissions

The next questions focus on existing tools to mitigate design errors and omissions and their familiarity. While various tools are commonly employed in the industry, it is important to note that not all of these tools are utilized by WYDOT. Below, we have outlined some of the prevalent tools used in the industry for this purpose.

Q15. How familiar are you with the existing tools to avoid Design errors and omissions? Please rate your familiarity with these tools. You can hover over the text for or click here for more information on the tools listed below.

	Not familiar at all	Slightly familiar	Moderately familiar	Very familiar	Extremely familiar

	0 10 20 30 40 50 60 70 80 90 100
Pre-Bid meetings with Specific focus on Quality	

Building Information Modeling (BIM)	
Independent Party Design Reviews	
Over the shoulder agency review	
In-progress Design Workshops	
Discipline task force	
Financial Incentives/ Disincentives for quality	
Project-Specific quality management team trainings	
AGC-WYDOT meetings	
Early involvement of contractors in design	
Others	

Q16. Please rate the effectiveness of the tools listed above to limit design E&Os

	0 10 20 30 40 50 60 70 80 90 100
Pre-Bid meetings with Specific focus on Quality	
Building Information Modeling (BIM)	
Independent Party Design Reviews	
Over the shoulder agency review	
In-progress Design Workshops	
Discipline task force	
Financial Incentives/ Disincentives for quality	
Project-Specific quality management team trainings	
AGC-WYDOT meetings	
Early involvement of contractors in design	
Others	

Q17. Listed are some of the recommendations from the field engineers. How effective do you think these would be in limiting the occurrence of design errors and omissions? Hover over the text or click here for more information.

	0 10 20 30 40 50 60 70 80 90 100
Design review checklist	
Better Communication	
Real-time review tracking	
Infield meetings	
Peer review process for designs and plans	
In-person/ online plan reviews	
Post-construction reviews	
Spreadsheets and checklists to help new engineers.	
Others	

Q18.Do you use any specific risk analysis processes or methods during the design phase of the project? If yes, could you please explain the steps used.

____

Block: Thank you message

Q19. Thank you for contributing to our survey. Please use this space to provide additional comments or feedback that was not covered in the survey. The section after this will ask you about your contact information for follow-up interviews.

____

Block: Contact information (optional)

Full Name:

Job Title:

Years of experience as a highway/bridge designer:

Contact Information:

- Email address
- Contact number

Can we contact you for a virtual/in-person follow-up interview?

- Yes
- No

Interview Questionnaire Set 2: Design Engineers' Interviews

Interview Purpose

The purpose of this interview is to gather your insights and feedback on several key aspects of our design and construction processes. Specifically, we're interested in your views on the design review process, constructability review process, procurement changes, change orders related to design changes, and the post-construction closeout phase. Your input will help us understand current challenges and identify opportunities for improvement.

Design Review Process

1. What is your experience (positive and negative) of your current design review process?

Constructability Review Process

1. What is your experience (positive and negative) of your constructability (biddability and buildability reviews with construction staff) review process?

Procurement Changes (bid document amendments)

1. What is your experience (positive and negative) of your amendment process?
    a. How are procurement, or bidding, document changes typically identified – internally or by bidders?
    b. How is the designer of record typically notified and involved in preparing the changes (amendments)?

Construction Change Order (Review process and design change/review tracking)

1. How would you describe the current process for reviewing design changes between field engineers and designers?
2. What tools or methods do you think could improve real-time tracking of design changes?

Post-construction and closeout

1. Is there a formal process for documenting lessons learned after a project is completed? If not, why do you think this is the case?
2. How do you currently share lessons learned from completed projects with your team?
3. How could the implementation of a post-construction conference be integrated into the current workflow?

Other Issues and Improvement Suggestions

1. Is there anything else you would like to add regarding the challenges and potential solutions for design errors and omissions in transportation projects?

Questionnaire Survey Set 3: State DOTs Survey

DOT survey on DQC and Collaboration Tools

Survey Flow

Standard: Welcome Message (1 Question)
Standard: Contact information (4 Questions)
Block: Challenges faced (9 Questions)
Standard: Tools to mitigate Design Errors and Omissions (3 Questions)
Standard: Design Review Checklists (3 Questions)
Standard: Thank you message (1 Question)

Block: Contact information

To better understand the diverse experiences and insights of professionals within state Departments of Transportation (DOTs), the following section will ask for some information about your background and current role. This will help us to contextualize your responses and ensure that our findings accurately reflect the perspectives of those working across different divisions and functions. Please provide details about the division you serve in, your specific role, and the state DOT you are affiliated with. Your input is invaluable to enhancing our understanding of your organization's coordination and collaboration practices.

Q1. What State Transportation Agency do you work for?

Q2. Which department/ division most closely describes your role in the DOT?

- Project Development/ Design
- Field/resident/Construction Engineer
- Material/Rates
- Quality Assurance/Review
- Survey
- Utility Program
- Other ____

Q3. How many years of experience do you have working in the Transportation Agency? ____

Block: Challenges faced

Design review and Collaboration: According to the NCHRP report on Digital Project Management and Delivery, many state transportation Agencies have started pilot programs to digitize the management of STAs' data. Based on ongoing trends and available information, some platforms and methods have stood out as being useful for quality assurance and review during the design process. This section will deal with the current process of document management and collaboration tools used by the DOTs and their effectiveness.

Q4. What is the department's electronic document management system for handling and keeping records of all plans and correspondence?

- ProjectWise
- AssetWise
- Others ____

Q5. The design process involves multiple parties, each crucial in shaping the final outcome. For a design to be successfully developed and implemented right through to the bidding stage, seamless collaboration between all these parties is essential (including the field, the designers, reviewers, the check squad, etc.). Given the importance of this coordination, what strategies and tools has your team been using to ensure effective collaboration throughout the process?

- Real-time Collaborative Quality Assurance tools.
- Bluebeam/ acrobat or other cloud-based sharing platform
- Emails and direct communication
- Informal Meetings
- Feedback Loops
- Other (Mention anything that you might've experienced or heard of. Leave blank if not applicable) (7) ____

Q6. Does the collaborative tool allow real-time tracking and response?

- Yes
- No

Q7. How effective do you think the collaborative tools have been in maintaining design quality and limiting design errors and omissions during design development on a scale of 1 to 100?

	Not effective at all	Slightly effective	Effective	Very effective	Excellent	Click to write Label 6
	0	20	40	60	80	100
Real-time Collaborative Quality Assurance tools.						
Bluebeam/ acrobat or other cloud-based sharing platform						
Emails and direct communication						
Informal Meetings						
Feedback Loops						
Other (Mention anything that you might've experienced or heard of. Leave blank if not applicable)						

Q8. How do you ensure the team members are informed about the project updates and changes?

____

Q9. Given the involvement of multiple sections in the design review process, how does your office ensure that consistency is maintained across disciplines during these reviews?

- Formal plans/policy
- Trainings and standard practices
- Others ____

Q10. Is there a standardized approach or set of guidelines that your team follows to coordinate and align the feedback from different sections?

- Yes
- No

Q11. Can you provide the link to the policy and procedures if possible?

____

Block: Tools to mitigate Design Errors and Omissions

The next questions focus on existing tools to mitigate design errors and omissions and their familiarity. While various tools are commonly employed in the industry, it is important to note that not all of these tools are used by all state agencies. Below, we have outlined some of the tools that are prevalent in the industry for this purpose.

Q12. How familiar are you with the existing tools to avoid Design errors and omissions? Please rate your familiarity with these tools. You can hover over the text or click here for more information on the tools below.

	Not familiar at all	Slightly familiar	Moderately familiar	Very familiar	Extremely familiar
	0 10	20 30	40 50	60 70	80 90 100

Pre-Bid meetings with Specific focus on Quality	
Building Information Modeling (BIM)	
Independent Party Design Reviews	
Over the shoulder agency review	
In-progress Design Workshops	
Discipline task force	
Financial Incentives/ Disincentives for quality	
Project-Specific quality management team trainings	
AGC-DOT Collaboration Programs	
Early involvement of contractors in design	
Others	

Q13. Please rate the effectiveness of the tools listed above to limit design Errors and Omisssions.

	0 10 20 30 40 50 60 70 80 90 100
Pre-Bid meetings with Specific focus on Quality	
Building Information Modeling (BIM)	
Independent Party Design Reviews	
Over the shoulder agency review	
In-progress Design Workshops	
Discipline task force	
Financial Incentives/ Disincentives for quality	
Project-Specific quality management team trainings	
AGC-DOT Collaboration Programs	
Early involvement of contractors in design	
Others	

Block: Design Review Checklists

Q14. Does your department have a standard design review checklist for quality control and design assurance?

- Yes
- No

Q15. If the department's design checklist is available and can be shared, could you please provide us with a copy?

Q16. How are lessons learned from projects documented or implied in future projects? Does the department have a standard for the project close-out process?

- Yes
- No

Block: Thank you message

Q17. Thank you for contributing to our survey. Please use this space to provide additional comments or feedback not covered in the survey, which you'd like to discuss further on.

Questionnaire Survey Set 4: Survey on Usability and Effectiveness of the Spreadsheet

Survey Flow

Block: Usability Testing

This section will ask general questions about your initial impressions of the updated design checklist. You may return and modify your answers as needed.

Q1. How effective do you think the updated design checklist is?

- Not at all effective (11)
- Slightly effective
- Moderately effective
- Very effective
- Extremely effective

Q2. Have you utilized the design checklist that WYDOT has available?

- Yes
- No

Q3. Would the updated design checklist be a useful reference for new engineers?

____

Q4. Were the instructions and layout of the spreadsheet clear and intuitive?

- Strongly disagree
- Somewhat disagree
- Neutral
- Somewhat agree
- Strongly agree

Q5. Which sheets of the checklist will you be reviewing today?

- Materials IA
- CADD manual
- Survey
- Field Review and Design Check
- ROW manual
- Bridge Design Checklist

Block: Block 1

Q6. Welcome to the review of the ${lm://Field/1} checklist sheet. All subsequent reviews in this section will focus specifically on the ${lm://Field/1} checklist sheet. If you are reviewing multiple sheets, you'll be directed back to this section after you've completed all the questions.

Q7. Overall, how difficult was it to use the design checklist?

- Extremely easy (8)
- Somewhat easy (9)
- Neither easy nor difficult (10)
- Somewhat difficult (11)
- Extremely difficult

Q8. Overall, how difficult was it to navigate the checks on the checklist?

- Extremely easy (8)
- Somewhat easy (9)
- Neither easy nor difficult (10)
- Somewhat difficult (11)
- Extremely difficult

Q9. How detailed are the checks included in the sheet you are currently evaluating?

- Not detailed at all
- Slightly detailed
- Moderately detailed
- Very detailed
- Extremely detailed
- Other (6) ____

Q10. Was there anything missing from checklist that you were expecting to see?

- Yes
- No

Q11. What specific checks were missing, and how do you think they should be incorporated?

____

Q12. Were there any specific checks that were difficult to locate?

- Yes
- No

Q13. What were the checks that were difficult to locate, please describe.

____

Q14. How organized or disorganized was the layout on checklist?

- Extremely organized
- Moderately organized
- Slightly organized
- Neither organized nor disorganized
- Slightly disorganized

Q15. What was your favorite feature about the updated checklist?

____

Q16. What was your least favorite feature about the updated checklist?

____

Q17. Evaluating the Usefulness of the Updated Design Review Checklist This section seeks your reviews on the checklist's effectiveness and practicality in guiding design reviews.

Q18. How did you use the checklist during your review?

- I used it to check an actual project
- I went through it for general review only
- I simulated a review scenario
- Other (please specify) ____

Q19. How useful is the updated checklist for design reviews?

- Not at all useful
- Slightly useful
- Moderately useful
- Very useful
- Extremely useful

Q20. Would this checklist help streamline your review process?

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Q21. Any additional comments or suggestions to enhance the spreadsheet's usability and effectiveness?

Q22. How likely are you to use the updated checklist in your design reviews in future?

- Definitely will
- Probably will
- Might or might not
- Probably won't
- Definitely won't

Q23. We're sorry that you're unlikely to use the checklist in the future. Please tell us what we could change to better structure the checklist?

____

Q24. What, if anything, would prevent you from using this checklist regularly?

____

Q25. Based on your experience, how likely are you to recommend this checklist for design quality reviews? (0 = Not at all likely, 10 = Extremely likely)

○ (0)
1 2 3 4 5 6 7 8 9 10

Q26. Please leave any additional comments about how we can improve the checks or what are your thoughts on the updated checklist in the space provided below.

____

Appendix D1

Contents: Project Information

Quality Control Checklist

Review Date: ____________

Project Name: ______________________________

Project Number: ______________________________

WYDOT Section: ____

District & County: ____

State Project Number: ____

NAD: ____

Handling: ***Please Select***

Squad: ________________________

Stage	PDR	GP	RW	UP	FD	PS & E
Checked by:						
Designed by:						

Appendix D2

Links

ROAD

WYDOT Road Design Manual

Photogrammetry and Surveys

Design process Flowchart

Design Guide for Interstate Highways

SurveyManual

WYDOT Plan Standards

BRIDGE

Standard Bridge Details

Bridge Replacement "Off System" (B.R.O.S.) Design Guide

Current Bridge Projects

Bridge Application Manual

Appendix D3

Field Review and Design Check

References
a. Engineer's Recommendations
b. Lab Recommendations
c. Traffic Recommendations
d. Seeding Recommendations
e.Structure Selection/Rehabilitation Reports
f. Geology Recommendations
g. Email Correspondence
h. District Final Plan Review Correspondence
Title Page
Does the Title page follow requirements/examples in the Road Design Manual, Chapter 4, Section 4-01?
Are all project numbers shown correctly with current prefix?
Does Roadway, Section, & beginning RM matches ERP?
County(s) listed and correct?
Standard Plans recommended by Traffic included?
Index of sheets, with required Standard Plans, included?
Maps
All locations shown on map(s)?
Road Designations shown, i.e. I-80?
Beginning and Ending RM and Stations shown?
Townships and Ranges shown and correct?
Direction arrows, i.e. To Cheyenne, shown and correct?
North Arrow present?
Roadway Length(s), Structure Length(s) and Total Length(s) shown?
County(s) shown?

PE Stamp Sheet
Include PE stamps if plans include bridge sheets, guardrail sheets, or other engineering design details not covered by standard plans
Typical Sections
Does the Typical Sections follow the requirements/examples in the Road Design Manual, Chapter 4, Section 4-02?
Does the thicknesses match Lab Recommendations?
Does the Traveled way and shoulder widths match project design information?
Taper widths match Engineer’s Recommendations or current Design Standards?
Correct bid item names used?
Proposed thicknesses show ±, except for concrete?
Hot Plant Mix Leveling and Profile Milling show Avg. Thickness note instead of depth?
Does the Station/RM ranges match summaries?
Are the road designations shown, if multiple roads are on the project?
Is "Match Existing Slope" note present on overlays or normal crown rate shown if correction being done?
General for Summaries
Is spelling correct?
Are all items on the project present in the summaries?
Columns of numbers summed correctly?
Columns are wide & tall enough that text is not being cut off?
Correct Bid Items names are being used on all summaries.
Are notes and recommendations listed in engineer’s recommendations covered?
Confirm preliminary proposed right of way is shown with widths measured from centerline.
TEQ
Are all items in summaries present in TEQ, except for incidental items?
Do the Bid Item Numbers and Names match the bid item list?

Units in TEQ match the units on the other summaries?
Are there separate columns for each project number and Roadway/Structure code?
Do the quantities in the For Estimate match the quantities in summaries?
Are the items requested in the Engineer's, Lab, Traffic and Seeding Recs. shown?
Items from Bridge plans shown?
Materials and Rates
Materials and rates listed in Lab and Seeding Recs. present and correct?
Is the Available Material Sources listed correctly with agreement numbers?
Dead haul distances shown from available materials sources?
Water sources listed with agreement numbers (if available)?
Plant Sites listed with agreement numbers and dead haul?
Surfacing notes present, generally from Lab Recs.?
Oiling notes listed for Tack, Seal, etc.?
Correct Bid Item names used?
Are the correct rates listed for water, based on pay unit for item?
If required on project, is there unclassified exc., borrow special exc., riprap, etc. included?
SUMMARIES
Miscellaneous Summary
Does the Force Account Work match what is requested in Engineer's Recs.?
If needed, are there notes for what Force Account includes, i.e. listing work activities covered?
Mobilization included?
Contractor Testing is included (when required)?
Storm Water Control items included (unless Storm Water Prevention is part of the contract with separate bid items)?
*Are Equipment Hours included and match the Engineer's Recs.?
*Are notes included describing what the equipment hours will be used for?
Test Strip included (when required)?
Field Laboratory included?

Railroad Insurance & RR Flagging included (if RR properties are affected)?
Are Tribal Employment Rights Ordinance bid item included (if within or adjacent to the Wind River Indian Reservation)?
***Equipment Hours may be in separate summary.**
Length of Project Summary
Are beginning and ending stations (or reference markers) shown correctly?
Bridge end stations (or reference markers) shown correctly?
Computed lengths in feet and in miles shown correctly?
Station (or reference marker) equations shown correctly?
Removal & Resetting Summaries
Does Removal of Fence, Gates, and Cattleguards match bid items & quantities in Engineer's Recs.?
Do items designated for Resetting match bid items & quantities in Engineer's Recs.?
Does method of measurement for Removal and/or Resetting comply with Spec. Book (i.e. is removal incidental?)?
Are there notes for disposal of removed items when item does not become property of contractor?
Removal of Surfacing & Milling Summaries
Are cutting bituminous pavement or cutting concrete quantities required and included in summaries?
Does the Milling Plant Mix summaries include milling thicknesses, milling widths, milling lengths, and recommended unit of measurement?
Are water calculations for milling included?
Has the use for millings been verify (recycle, stockpile, or disposal)?
Has the stockpile location(s) and haul distance(s) been included?
Are the Removal of Surfacing bid item, unit of measurements, and quantities included?
Grading Summary

Are the Unclassified Excavation, Borrow Special Excavation, and cymi hauls quantified and summarized correctly and in accordance with Engineer's Recs. or project earthwork designs?
Are excavation items (and embankment items) categorized and totaled correctly in summary?
Are water quantities included for embankment compaction and dust control?
Is a shrink factor included or required?
Are Moisture & Density control or soft sport repair quantities included or required?
If material is to be wasted, are waste site locations and haul distances included?
Is average haul included?
Does summary include all additional notes recommended in the Engineer's Recs. and by the Geology Program?
Culvert Summary
If a culvert summary is required, are all pipe culvert bid items and quantities recommended in the Engineer's Recs. accounted for?
Are culvert replacement or extension recommendations outlined in the Structure Selection Report (if issued) accounted for?
Are concrete collar bid item and quantities for all pipe extensions included?
Are cut-off walls, headwalls, rip-rap required and included in summary?
Are fill heights and CR numbers for pipe replacements included?
Does method of measurement for Removal of pipe and flared ends comply with Spec. Book (i.e. is removal incidental?)?
Surfacing Summary
Does summary includes correct surfacing bid items and units of measurement?
Does summary includes correct station limits, distances, top widths values?
Does summary includes changes in roadway widths, equations, bridge ends, etc.?
If a surfacing source is included, does summary include direction of haul, computed ½ haul distances, average haul distances and haul quantities?
Does surfacing items columns include both ton/ft & ton (or cy) computed for each surfacing bid item?
Are Surfacing Additives and water bid items, and quantities, are included below the surfacing summaries or in a separate "Surfacing Additive" summary?

Are quantities and formulas computed correctly, and use the items and unit weights shown in the Materials & Rates?
Is mailbox turnout or acel/decel lane widening accounted for?
Approach Summary
Are all approaches within project limits, or listed in the Engineer's Recs., included in summary?
Are approach locations, widths, and radii shown correctly?
Are approach culvert and flared end replacements or extensions required and listed in summary?
Are hot plant mix approaches, and base course surfacing quantities calculated in accordance with the surfacing thickness recommendations, materials & rates, and approach typical sections?
If a surfacing source is specified, are haul distances and haul included and calculated correctly?
Are approaches classified as "major" or "minor"?
Are paving limits and type (field, residential, commercial, etc.) of each approach listed?
Topsoil and Seeding Summary
Are topsoil removal and placing, seeding, fertilizer, mulch bid items and quantities included in accordance with Engineer's Recs. and Environmental Services seeding recommendations?
Do quantities include pits, plant site, and staging area reclamation (when required)?
Temporary Fencing, Fencing, Cattleguard, Gates Summary(ies)
Are fence types, locations, and quantities that are listed in the Engineer's Recs. included?
End panels and brace panel quantities provided?
Are recommended gates and cattleguard relocations and replacements included?
If guardrail is to be upgraded or replaced, have guardrail details been included for each location?

Are guardrail removal and replacement bid items and quantities correct and included in the summary?
Does summary match the accompanying guardrail details?
Does method of measurement for Removal and/or Resetting comply with Spec. Book?
Is removed guardrail to remain property of WYDOT?
Other Summaries
Have uncommon bid items, quantities, and summaries been accounted for?
Is a Crack-Sealing summary required?
Is a Curb and Gutter, Double Gutter, Sidewalk summary required?
Is a Microsurfacing required?
Structure Details & Summary
Have Final Structure details been submitted?
If structure work is included, is a structure summary is included?
Are the bid items, units of measurement, calculated and for estimate quantities included in the structure plans summarized correctly in the Structure Summary?
Are location, drawing number, Structure designation, and accounting code for each structure included?
Traffic Program Details and Summaries
Are Final Traffic summaries and details (electrical, traffic control, signing, striping) included with the plans?
Design Details
Are necessary design details complete and included in the plans?
If in an urban locations, are ADA upgrades required and included in plans?
Are guardrail details included, if existing guardrail is to be upgraded or replaced?
Are there Special Fencing details required, such as wildlife fence?
Plan and Profile sheets required?
Contract Documents

Are all Special Provisions accounted for?
Have the required Supplemental Provisions been identified?
Has the pit and/or plant site agreements been received?

Appendix D4

Survey Check

Survey Documentation
Ensure the project name, section, and number are clearly documented.
Ensure the location and type of survey are accurately recorded.
Ensure the date of the survey is included.
Ensure atmospheric conditions are documented.
Ensure all personnel involved are listed along with their assigned activities (e.g., instrument operator, rod person, note keeper).
Ensure the equipment used for the survey is specified.
Ensure it is indicated whether permanent, extendible, or temporary control was used.
Ensure the original data values are recorded without any edits or error corrections.
Ensure any pertinent explanations of the survey or other conditions are provided.
P&S policies: (Survey Manual)
Ensure the plans or documents adhere to the guidelines in Chapter 4 for feature codes, linking codes, and attributes.
Ensure the proper placement of survey shots on specific features as outlined in Chapter 5.
Ensure file naming conventions are followed as described in Chapter 6.
Ensure procedures for editing, downloading, and archiving survey data files from the Trimble data collector are followed as per Chapter 7.
Ensure the instructions for editing, processing, and plotting survey data in MicroStation using Geopak are followed according to Chapter 8.
Ensure the guidelines on coordinate file formats are reviewed and applied as specified in Chapter 8.
Preliminary Survey Standards [Survey Manual Section VIII]
Ensure the design of roadway elements is based on the mapping files created by the Photogrammetry & Surveys Section (P&S).

Ensure Feature Codes are updated according to the latest P&S standards.
Ensure a draft report of the survey meeting minutes is written by P&S personnel, distributed to all participants for review and comment, and that the final report is made available in the Falcon document management system after the review period.
LOCO MAP
Ensure the LOCO map includes a title block with the project name, section, and number.
Ensure the title block also includes the name of the map preparer, the county or counties where the project is located, the date the map was completed, LOCO map scale, total number of sheets, and a landowner table listing owners and lessees.
Ensure the map identifies land parcels, the location of the roadway, and any other significant roads in the vicinity of the project.
Ensure the map includes project limits, property lines, section lines, section numbers, township and range labels, and a north arrow.
Ensure a copy of the LOCO map and Permit to Survey forms are submitted to the State Photogrammetry & Surveys Engineer, and that the LOCO map is distributed as specified in the survey meeting.
Ensure NAD 83 (2011) is used exclusively as the primary horizontal datum to determine geodetic coordinates.
Current vicinity map provided
Begin, Suspend, Resume, and End Project stationing accurate
Schedules/Options identified (if used)
Distance to nearest city
Material source, disposal areas, stockpile sites, staging areas, storage areas, water sources, etc. Shown?
Major roads, creeks, rivers, County, National Parks, National Forest, and key features identified and legible.
Scale is provided, as applicable. Graphic scale bar is preferred.

Appendix D5

ROW Checks

ROW Data (Plan Check)
Ensure ROW limits shown on the plans are correct, properly labeled, and match the ROW plans for acquisition.
Ensure proper easements (temporary & permanent) for construction of driveways, drainage structures, outlet or inlet ditches, temporary diversion channels, sediment basins, etc., are identified.
Ensure ROW fences are included where necessary.
Ensure clearing limits are contained within the ROW/construction easement limits.
Ensure ties to section corners are shown in the ROW plans.
Ensure ownership is shown in ROW drawings, not in the construction packet.
Ensure all commitments contained in the ROW agreements are included in the plans and Standard Construction Requirements.
Property lines shown
Tracts numbered
Ensure tract numbers are correctly labeled on the plan sheets, especially on boundary control plat sheets and within the project files (**RWPM, Part III, Right-of-Way Engineering**).
Check that tract boundaries do not overlap and are correctly dimensioned relative to existing and proposed right-of-way lines (**RWPM, Part IV, pg. 95**).
Verify that all digital records and hard copies are synchronized with the correct tract numbers (**RWPM, Part III, pg. 63**).
Right of way labeled at beginning and end of each sheet
Station-Offset & labels given for shifts and at beginning and end of tapers for present ROW
Station-Offset & labels given for shifts and at beginning and end of tapers for new ROW
Ensure consistency between the labeled taper stations and the design data provided in the engineering drawings (**RWPM, Part IV, pg. 95**).
ROW included for sight triangle areas
ROW included for infall/outfall ditches
ROW included for signal equipment areas
Station-Offset text shown (if not on separate sheet)

Additional ROW acquired for bridge sites
Walls with backfill or reinforced backfill requiring easement or additional ROW
Sufficient space provided between construction limits and existing/new ROW for construction activities
Mathematical Verification of Right-of-Way Lines
Mathematical verification of all coordinate and curve data must be completed for consistency with the right-of-way plan (**RWPM Sec. III, pg. 44**).
Draft and verify acreage summaries for all parcels, ensuring the total matches project estimates (**RWPM Sec. V, pg. 103**).
Land ties should have a tolerance of +/- 0.01 ft for bearings and distances from the nearest monument (**RWPM Sec. III, pg. 52**).
Appraisals should include a detailed breakdown of land value vs. improvement value, with checks against market data (**RWPM Sec. V, pg. 103**).
All geometric data must be independently verified for curve accuracy prior to plan approval (**RWPM Sec. III, pg. 50**).
Cross-check survey adjustment reports to ensure all coordinates are adjusted to match the final right-of-way layout.**(RWPM Sec. IV, pg. 89)**
ROW Manual Proceedings
Acquisition of Right of Way
Review project files and appraisals submitted in PAECETRAK. Verify appraisals using **Form R/W 57 (Review & Authorization)**.
(Part II, Section 1, p. 21)
Check the **Summary Statement of Fair Market Value**, which should be provided to the landowner and signed by the Lands Management Administrator.
(Part II, Section 1, p. 21)
Verify **Form R/W 31 (Condemnation Request)** and supporting documentation in PAECETRAK.
(Part II, Section 15, p. 36)
Review the final communication with the landowner, documented in project files, and check administrative settlement approvals.
(Part II, Section 15, p. 35-36)
Confirm all bearings, distances, and monument coordinates match between the legal description and survey data.

(RWPM Sec. IV, pg. 84).
Environmental and Legal Compliance
Check environmental approval forms and public involvement records in the project documentation.
(Part II, Section 3, p. 25)
Review the **STIP inclusion document** and FHWA approvals for protective or hardship acquisitions.
(Part II, Section 2, p. 23-24)
Check **Form E-113 (Project Authorization)**, signed by the Programming Division and approved by the commission.
(Part II, Section 15, p. 36)
Title and Deed Examination
Review **deed documents** and **title records** in the project file to verify property acquisition and ownership status.
(Part II, Section 3, p. 25)
Confirm that all legal ownership documents are properly stored and updated in **PAECETRAK**.
(Part II, Section 3, p. 25)
Civil Rights Compliance
Review correspondence and acquisition records to ensure equal treatment and opportunities for all property owners. (Title VI Compliance)
(Part II, Section 4, p. 25)
Examine relocation assistance documents and acquisition records to check for compliance with non-discriminatory policies.
(Part II, Section 4, p. 25)
Appraisal and Valuation
Review appraisal reports and check **Form R/W 57 (Review & Authorization)** for adherence to appraisal standards.
(Part V, p. 103)

Verify completion and signature on **Form R/W 57 (Review & Authorization)** by the Review Appraiser.
(Part V, p. 103)
Condemnation Process
Verify the presence of the completed **Form R/W 31** and supporting documents in the project file before legal action begins.
(Part II, Section 15, p. 36)
Review legal correspondence and court filings in the project file.
(Part II, Section 15, p. 37)
Relocation Assistance
Review the relocation plan and verify its compliance with federal and state laws.
(Part VII, p. 241)
Review the **90-day notices** and correspondence with property owners or tenants to ensure compliance.
(Part II, Section 1, p. 21)
Documentation and Record Management
Perform a records audit in both (PAECETRAK & FALCON) systems to confirm that all required documents (e.g., appraisal reports, deeds, relocation plans) are stored correctly.
(Part II, Section 13, p. 32)
Check project files for signed conflict-of-interest certificates and ensure they are stored in **PAECETRAK**.
(Part II, Section 13, p. 32)

Appendix D6

CADD Checks

Final Design File checks
1. File Naming and Structure:
Project file is consistent with naming using the ERP job number followed by the three-character description (e.g., *******_Ter.dgn, *******_Geo.dgn).
Ensure that each file adheres to the standardized naming convention based on the type of data (terrain, geometry, models, alignments, etc.).
Confirm that the correct seed files are used (International Feet vs. Survey Feet) based on project mapping (WYDOT_WYDOT_OpenRoads_Modeler_Manual).
Cross-check the directory structure and ensure files are placed in the correct subdirectories (e.g., Design, Sheets).
2. Seed Files and Units:
Files should be created using the specified seed files: Seed2d_Design.dgn, Seed3d_TerrainOnly.dgn, etc.
Confirm that the seed files for International Feet or Survey Feet are used based on the folder structure (e.g., the presence of the _International Feet folder).
Ensure no incorrect mixing of seed file types (International vs. Survey Feet) across the project(WYDOT_OpenRoads_Modeler_Manual).
3. Design Content and Geometry:
Design files contain the necessary components, including terrain models, geometry, and profiles.
Verify that files like *******_Geo.dgn contain correctly drawn horizontal and vertical geometry with appropriate annotations.
Confirm all terrain models in *******_Ter.dgn use the correct seed files and are properly imported(WYDOT_OpenRoads_Modeler_Manual).
Check alignment and profile files (*******_pln.dgn and *******_pro.dgn) for accuracy and that design features such as alignments and profiles are correctly placed according to project standards(WYDOT_OpenRoads_Modeler_Manual).
Ensure the profile grade point is identified.
4. Raster and Reference File Attachments:

Reference files should be attached properly with georeferencing where applicable, such as background mapping or imagery.
Ensure correct reference file attachment order (e.g., Photogrammetry mapping should be attached first to maintain the correct clipping for plan/profile sheets).
Check for consistent use of reference files and ensure that unnecessary references are not attached(WYDOT_OpenRoads_Modeler_Manual) (WYDOT_OpenRoads_Modeler_Manual).
Confirm that raster images, if used, are attached and displayed properly, without unnecessary borders or misalignment(WYDOT_OpenRoads_Modeler_Manual).
Ensure the project location is shown on the Key Map of the state and a current vicinity map is included.
5. Custom Linestyles and Color Table:
Files should utilize the WYDOT-specific custom linestyles and color tables (e.g., V8_WYDOT.rsc for linestyles, newclr.tbl for colors).
Verify that all custom linestyles are attached and in use as per the configuration files.
Check that the correct color table (newclr.tbl) is applied to maintain consistent color representation across design files(WYDOT_OpenRoads_Modeler_Manual).
6. Printing and Plotting:
Plan sheets, profiles, and other design elements are printed or exported to PDF with correct pen table settings.
Ensure that pen tables, such as map2_V8_clrutil.tbl for utilities or xsec_V8_clrutil.tbl for cross sections, are correctly applied during the plotting process.
Confirm that the correct plotting configuration is used based on the file type and output format (e.g., color or black-and-white print, specific paper size like 11X17_pdf(color)).
Ensure mapping files and reference files are screened correctly according to the pen table settings(WYDOT_OpenRoads_Modeler_Manual) (WYDOT_OpenRoads_Modeler_Manual).
7. Cross Section Layout and Earthwork Quantities:
Cross section layout files (*******_xsd.dgn) display all required cross sections with proper labeling (station numbers, offsets, and elevations).

Verify that cross sections are placed with the correct sheet layout scale (e.g., urban jobs use 50 scale, rural/interstate jobs use 200 scale).
Ensure that station labels, tick marks, and other annotations are correctly applied in the cross section sheets(WYDOT_OpenRoads_Modeler_Manual).
Check that cross section layout dimensions (e.g., baseline X-offset values) are properly configured and that sections are centered on the sheets.
Confirm that earthwork quantity labels are added if required and that spacing and margins follow the sheet setup standards(WYDOT_OpenRoads_Modeler_Manual).
Ensure plan quantity totals match supporting documentation in the Design Book.
Provide a scale for applicable drawings, with a preference for a graphic scale bar.
8. Corridor Design and Locking:
Final design corridors should be locked, and any irrelevant files removed from the design directories.
Ensure that all corridors are locked before final submission to prevent accidental modification(WYDOT_OpenRoads_Modeler_Manual).
Review the design files to ensure that non-relevant or temporary files are cleaned up and removed from the project directory(WYDOT_OpenRoads_Modeler_Manual).
9. Final Submission to WYDOT PD Finals Drive:
Final .dgn files and PDF outputs uploaded to the **Google WYDOT PD Finals Drive** with associated Contents_Modeler.txt or Contents_Criteria.txt files.
Ensure that all relevant design files (e.g., geometry, terrain, profiles) are uploaded to the Google WYDOT PD Finals Drive and the directory is cleaned up (WYDOT_OpenRoads_Modeler_Manual).
Verify that Contents_Modeler.txt files are complete, accurate, and uploaded to the same folder, providing a snapshot of the final project design (WYDOT_OpenRoads_Modeler_Manual).
Cross-check that the final PDFs and .dgn design files are in sync, ensuring that the PDF outputs reflect the correct, final design data (WYDOT_OpenRoads_Modeler_Manual).
Ensure that title blocks include fields for dates and signatures of approving officials.
Sheet descriptions should match the sheet's title block. Index to Sheets & Standard Drawings should be accurate.

10. Project Manager and Operator Codes:
Geopak Job Numbers and Operator Codes should be set up correctly within the Project Manager tool.
Verify that the Geopak Job Number is consistent with the ERP number of the project.
Ensure that the Operator Code is properly set based on designer initials, and that all Project Manager tools are configured as per the project specifications (WYDOT_OpenRoads_Modeler_Manual).
11. Miscellaneous Checks:
Plan, profile, and cross-section sheet labeling should be consistent and free from formatting errors.
Ensure that title blocks, legends, and sheet numbers are correctly formatted across all design sheets.
Double-check that all MicroStation and Geopak tools (e.g., D&C Manager, Profile Labeler) have been used appropriately and that labels and annotations are consistent with the project's specified dimensions(WYDOT_OpenRoads_Modeler_Manual).
Ensure appropriate column headings are labeled and match plan sections.
Add a check for clarity and brevity in notes and footnotes. Ensure they are action-oriented and avoid redundancy with specifications.

Appendix D7

Materials IA checks

Construction Test and Certification Requirements
Form T-128 (Construction Test Requirements)
Review the specified sampling and testing frequencies for construction materials listed in Form T-128, ensuring compliance with project plans and specifications. (Section 107.0, p. 1-2)
Form T-131 (Manufactured Products Received)
Verify the certification documentation provided for manufactured goods or products meets the requirements specified in Form T-131, including material/product name, bid item number, and acceptance criteria.(Section 107.0, p. 2)
Form T-132 (Engineer's Verification of Specification Compliance)
Ensure this form is used to document acceptance of materials and manufactured products when exceptions exist and that it is properly noted in Forms T-128 or T-131. (Section 107.0, p. 2)
Manufactured Products Certification
Form T-168 (Certification of Materials)
Check that Form T-168 has been completed by the manufacturer/supplier and includes the required information: project number, description, quantity, specifications, and signed certification. (Section 108.0, p. 1-2)
Pre-Certified Products
Confirm that pre-certified products, products on the Qualified Product List (QPL), or items meeting contract requirements under $1500, comply with all necessary documentation. (Section 108.0, p. 3)
Field Laboratory Testing Equipment
Standard Soils Kit
Check the presence and condition of all required items in the **Standard Soils Kit**, including moisture tins, compaction molds, and sand cone apparatus.(Section 120.0, p. 1-2)
Standard Surfacing Kit
Ensure all equipment in the **Standard Surfacing Kit** is available and functional, such as sieves, compaction molds, balance, and sand cone apparatus. (Section 121.0, p. 1-2)

Standard Concrete Kit
Verify the availability and condition of the items in the **Standard Concrete Kit**, such as slump cones, air meter apparatus, beam molds, and sieves. (Section 122.0, p. 1-2)
Field Testing Procedures
Moisture-Density Relations of Soils (AASHTO T 99)
Confirm that moisture-density testing is being performed using the specified methods, ensuring the compactive effort and soil moisture content are at optimum levels. (Section 101.0, p. 1-3)
Field Density Tests (Sand Cone & Nuclear Density Methods)
Review field density test results to ensure compliance with required density specifications and check that both sand cone and nuclear density methods are correctly applied. (Section 101.0, p. 1-2)
Materials Acceptance
Manufactured Products Documentation
Ensure that all required documentation (certifications, test reports, etc.) for manufactured products delivered to the project site has been properly uploaded into the CMS system. (Section 108.0, p. 2-3)
Buy America/Build America Compliance
Verify that supporting documents for iron, steel, and other construction materials confirm compliance with the **Buy America Act** and that manufacturing processes occurred in the U.S. (Section 108.0, p. 3)

Appendix D8

Bridge Design Checks

Final Design File checks
General Checks
File format adheres to CADD drafting standards (BAM Ch.2)
Design files are named as per standards.
Standard sheets are included and referenced from (BAM Ch.3)
Confirm all right-of-way lines and acquisition areas are shown clearly.
Ensure existing and relocated utilities are correctly placed in the plans.
Verify clearance between utilities and other structures (e.g., culverts, bridges).
Add notes specifying coordination requirements with utility companies.
Verify proper alignment of utility crossings.
Title Sheet
As shown on Project Development Plans (Stationing)
Location using Wyoming Reference Marker System (Reference Marker)
Construction number is shown under the title and in the upper-right project block (no prefix; exclude minor project numbers)
County, counties, or district where the project is located is shown.
Type of work is shown and accurate.
Graphic scales are shown for plan and profile sheets
Design data is shown.
A label is shown to identify the submittal (i.e. Recommendation Plan Set).
Table of estimated quantities is shown.
Index of Drawings shown.
Professional Engineer's stamp, signature, and date
Section, Township, and Range for new structures (above the title block in the bottom-right corner)
3-letter Structure Number and reference marker (RM) shown above the title block for all structures.
North arrow with correct survey datum is shown.

Begin and end stations for the TIP project are shown.
Begin and end stations of construction outside the TIP project limits are shown.
Mileage for the roadway, bridges, and total project lengths are shown to three decimal places and are based on the mainline stations.
Station equalities with adjacent TIP projects (including coordinate equalities) are shown and verified.
Layout of numbered plan sheets are shown.
Proposed alignment names are shown.
Existing road names, interstate, US, WY, and state route numbers are labeled.
Proposed bridges and culverts 20' and over are shown with begin and end stations to the nearest foot (+/-).
Streams and rivers are shown, if applicable.
Railroads are shown, if applicable.
City limits are shown, if applicable.
State and county limits are shown, if applicable.
Destination points are shown at the beginning and end of the project.
TIP number is shown in the block on the left end of the sheet.
State Project Number (WBS element), description, and F. A number, if applicable, are shown for preliminary engineering.
Tentative R/W and Let dates are shown and match the current schedule.
Design exception note is shown indicating the design element(s) requiring the exception, if applicable.
Clearing method note is shown. (Note: The specific type can be provided if it has been coordinated with the Division).
A note is shown stating whether the project is within municipal limits with the name of the municipality or not within municipal limits.
Vicinity map includes the following:
Begin and end project or project site labels
North arrow
City name and municipal limits
County names and limits
Interstate, US, and state routes
Title block

Offsite detours with legend
Symbols for existing, revised, and/or proposed traffic signals are shown per the Signal Recommendations.
Control of access note is shown.
Areas of the proposed roadway construction for the project (-L- lines, -Y- lines, service roads, detours, etc.) are shaded.
Section 4.01 Preliminary
Structure Selection Report Written
Can the existing structure be adequately rehabilitated?
Common Plan Checks
Detail to Scale
Centerline Survey with Stationing and Bearing
North Arrow
Flow Arrow with Name of Channel
Station Call-outs at Substructures/Features
Existing Structure Call-out
Line Styles/Patterning
Utilities Call-out
Section Symbols
Scale Call-out
Common Elevation Checks
Detail to Scale/Projected from Plan
Grade/Vertical Curvature Call-out
Elevations with Symbols
Existing Ground Line Call-out
Scale Call-out
Vertical Clearances
Stationing

Common Section Checks
Centerline Survey/Construction
Horizontal Dimensions
Slope(s) Call-out
Profile Grade/Superelevation Point
Pavement Call-out with Thickness
Base Material Call-out with Thickness
Line Styles/Patterning
1. Preliminary Geology Layout
Plan adheres to the standards for plan layout for preliminary report. (BAM Section 4.01)
Plan Specific Checks:
Centerline Bridge Roadway and Structure/Bents/Piers
Working Line/Construction Line Call-out
Longitudinal and Channel Bottom Dimensions
Offsets (throw on curve)
Skew and Complement at Centerline Feature
Elevation is made according to standards. (BAM Section 4.01)
Elevation Specific Checks:
Profile Grade Call-out
Bottom of Channel and Design Scour Elevations
Embankment Protection Call-out
Pedestrian Safety Railing
Obtain Alkali Sample
Obtain Necessary Foundation Information to Complete LRFD Design
2. Preliminary Bridge Layout
Plan Specific Checks:
Centerline Railroad Track to Centerline Track Dimension
Berm, Stockberm/Bike Path, and Access Road Dimensions

Horizontal Clearance Between Tracks and Substructure
Test Holes, Riprap/Gabions, and Approach Slabs Call-out
Elevation Specific Checks:
Detail Skewed with Superelevation
Ordinary High Water, Design Q, and Review Q Elevations
Footing/Pile Call-out and Number Required
Deck Drainage System
Section A-A Checks:
Clear Roadway Width, Girder Spacing
Cross Slope(s) in Percent
Overlay and Railing Call-outs
Preliminary Culvert Layout
Location Plan Specific Checks:
Centerline Culvert and Skew Call-out
Riprap/Gabions and Culvert Subexcavation Call-out
Right-of-Way Lines Call-out
Longitudinal Section Specific Checks:
Precast Parapet/Cutoff Wall Call-outs
Fill Slope with Dirt Symbol
Section A-A Checks:
Barrel Opening Dimensions
Optional Construction Joints Call-out
Railroad Site Layout
Site Layout Specific Checks:
Centerline Tracks and Working Line Call-out
Horizontal Clearance Between Track and Substructure
Location of Minimum Vertical Clearance Call-out
Test Holes Call-out
Track Profile Specific Checks:

Vertical Clearance
Top of Rail Call-out
Safety Fence/Splashboard Call-out
Substructure Layout
Mark centerline pile/drilled shaft/footing.
Label centerline feature intersected, abutments, bents, and piers.
Add working line/construction line call-out.
Indicate skew and complement at the centerline feature intersected and substructure (if different).
Show offsets (throw on curve).
Number pile/drilled shaft/footing locations.
Add flow arrow with the channel name.
Include top and bottom pile elevations.
Show top and bottom drilled shaft elevations.
Note bottom of footing elevations.
Include pile splice details.
Show pile point details.
Include notes for gouging root to sound metal.
Specify pile size/locations if not included in substructure data.
Specify drilled shaft size/locations if not included in substructure data.
Verify utility placement near substructure elements like piles and footings.
Ripraps and Gabions
Indicate complement of skew at RF abutment.
Show the angle from RF abutment to the end of riprap (if not 0° or 90°).
Include dimensions along the toe of slope.
Specify the channel bottom width.
Indicate stockberm/bike path width.
Show top of riprap/gabions elevations.
Include toe of slope call-out.

Add RF abutment call-outs.
Ensure line styles/patterning for riprap representation.
Confirm right of way lines near riprap.
Note utilities within or near the riprap area.
Include a typical section for machine-placed riprap and gabions.
Ensure the "Cell to be Edited" for detailing machine-placed riprap and gabions.
Bent/Pier Design Checks
Ensure spacing between columns allows water flow and prevents debris collection.
Column diameters: minimum 24”, increase in 6” increments.
For heights over 15', use optional construction joints.
Extend longitudinal reinforcing steel into the cap for tension development.
Ensure cap width is at least 3" greater than column diameter.
Design to minimize risk of concrete spalling.
Ensure a minimum clearance of 6” from edge of concrete seat to anchor bolt.
Crash walls for columns within 25'-0" of the track centerline.
Plan:
Centerline and dimensional callouts for Bent/Pier/Bridge Roadway, Girder/Pile/Drilled Shaft/Column.
Skew and Complement with appropriate width/length dimensions.
Girder/Pile/Drilled Shaft/Column spacing and angles.
Station Note, Swedge Bolt Hole Size/Spacing, Radius Call-out.
Elevation:
Projected centerline callouts for Bent/Pier/Pile/Drilled Shaft/Column.
Vertical/Horizontal dimensions and Seat Length/Level.
Pile Cut-Off, Reinforcing Size/Spacing/Lap/Call-outs.
Keyway/Construction Joint Call-outs, Pile Batter.
Quantity Calculation Checks
Two sets of quantity calculations are required: one for Site A and one for Site B (if applicable).
Each set should be separated, totaled, and clearly labeled by bid item.

Include all numbers used and steps involved in the calculations.
For items such as lump sum bids (e.g., Expansion Device Modification), components like reinforcing steel and concrete must be estimated individually.
Quantities should be calculated using the numbers shown on the plans, rounded to two decimal places for most figures.
Geometric angles must be accurate to four decimal places.
Unless specified otherwise, quantities are rounded up to the next unit of accuracy.
Example tables of estimated quantities, showing total quantities for each bid item across multiple sites, help to organize the data.
Common bid items (like removal of concrete or expansion joint glands) have established units of measurement, including cubic yards (CY), lineal feet (LF), and lump sum (LS).
Bid items such as Removal of Concrete, Class B Concrete, and Expansion Joint (Gland) have specific measurement units and calculation rules.
Quantities for items like reinforcing steel or concrete components are grouped and subtotaled for clarity.
For bid items such as Removal of Concrete or Excavation, calculations may require specific formulas or consideration of factors like existing ground levels and finished grade.
Items like Geotextile and Reinforced Concrete Approach Slabs follow specific dimensions and excavation guidelines for calculating quantities accurately.
Any errors found in plans during the quantity calculation process should be noted and addressed with the detailer or checker to ensure the accuracy of the final quantities.