Developing Tools to Mitigate the Impact of Design Errors and Omissions

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Table of Contents

1. Problem Statement 3
2. Preliminary Literature Review 5
3. Objectives 6
4. Benefits 6
5. Applicable Questions 7
6. Statement of Work 8
   - 6.1 Overview of Research Tasks 8
   - 6.2 Description of Tasks 11
     - Task 1 – Conduct an extensive literature review 11
     - Task 2 – Select WYDOT projects to determine the causes and impacts of design E&O 12
     - Task 3 – Identify the causes and case frequency of design E&O 13
     - Task 4 – Determine the impact of design E&O and rework on the project's performance 13
     - Task 5 – Develop factsheets and infographics summarizing common design E&O and their causes and impacts 13
     - Task 6 – Develop tools to mitigate the impact of design E&O and rework on schedule delays 14
     - Task 7 – Select projects for case studies 14
     - Task 8 – Conduct case studies 15
     - Task 9 – Develop policy and procedure document for design E&O, training resources, and project closeout 15
7. Work Plan and Implementation 15
   - 7.1 Technical Advisory Committee 15
   - 7.2 Deliverables 16
   - 7.3 Progress Reports 16
   - 7.4 Final Report 16
   - 7.5 Project Closeout 16
8. Schedule and Budget 16
9. Technology Transfer 18
10. Data Management Plan 18
11. Personnel 18
12. References 20

1. Problem Statement

Many state departments of transportation (DOTs) struggle to complete transportation projects on schedule and within budget. Several influential factors cause schedule delays and cost overruns, such as design errors and omissions (E&O), project scope change, unforeseeable site conditions, weather conditions, and resource-related delays. Because of some of these factors, rework in the construction industry is unavoidable and considered to be one the major contributors to cost overrun and schedule delay (Love et al. 2010). Moreover, a study by Hanna and Swanson indicated that design changes resulting from E&O are inevitable in construction projects. Therefore, many state DOTs (e.g., Florida, New Jersey, Texas, Louisiana, and Minnesota) have developed policies and procedures to address design E&O. For example, Texas DOT (TxDOT) has published a policy on design E&O that acknowledges that even the best contracts will likely have design E&O (TxDOT 2014). Therefore, it is crucial for any DOT to catch E&O as early as possible and during the Plans, Specification and Estimate (PS&E) phase. Otherwise, design E&O may result in significant additional costs and schedule delays (TxDOT 2014). Additionally, design E&O may also result in a strained relationship between the project's stakeholders (e.g., the design team, field personnel, and contractors). It is worth noting that most of the DOTs' policies and procedures address the legal aspects of design E&O and little has been done the address the impacts and causes of design E&O.

Design E&O can stem from causes such as poor communication between the design and construction teams, lack of coordination between the project stakeholders, lack of expertise, change in the project scope or requirements, absence or inadequate of design quality control measures, project's technical complexity, and unforeseen job site conditions. The impact of design E&O can be mitigated through the use of systematic design review processes to identify errors and omissions as early as possible, digital design and simulation tools, and checklists with common design E&O. These tools and processes can be developed and improved by analyzing historical of design E&O and their impacts.

Similar to other construction projects, transportation projects in Wyoming are also prone to design E&O. This is evident by a study done in 2021-2022 to investigate schedule delays in Wyoming (Abdelaty and Jamal 2022). As part of the project, the Principal Investigator (PI) conducted a questionnaire survey distributed to the WYDOT district and construction engineers to determine the top causes of schedule delays in Wyoming. The survey results show the following reasons are the top causes of schedule delays in Wyoming:

1. Labor and material shortage
2. Poor communication and coordination
3. Contractor not starting work as stipulated
4. Rework due to errors (design/faulty materials) during construction

In agreement with several previous studies, the survey results shows that one of the top reasons for rework is errors in design or faulty material. It is also believed by field personnel that the pressure to complete projects under tight schedules has led to letting some projects with incomplete designs or shortened design process flowchart. This has led to rework, change orders, and costly errors in the field that could be minimized or eliminated by developing tools and methods to control the quality of the design. It is worth noting that survey results are based on feedback from the construction and district engineers only. Thus, there is a need to quantify the significance of design E&O and their impact on WYDOT projects. This will provide WYDOT with more evidence regarding the magnitude of design E&O-related issues. Based on the analysis of design E&O in WYDOT projects, tools and guidelines can then be developed to minimize the impact of design E&O and thus reduce the amount of rework and improve overall project performance. Thus, this proposal addresses the need for analyzing historical projects to determine the impact and causes of design E&O and rework on project performance. Moreover, this proposal will address the need to develop tools and guidelines to mitigate the impacts of design E&O.

2. Preliminary Literature Review

Many DOTs cannot finish their transportation projects within schedule and time for several reasons, including design errors and change orders. For example, Indiana DOT had more than half of their projects experience cost overruns, and about 12 percent were subject to schedule delays because of change orders. These change orders were mainly related to design E&O (Bordat et al. 2004). This suggests a need to develop and implement Design Quality Control (DQC) tools. A recent study by Herrera et al. (2020) reviewed the main causes for cost overruns for road infrastructure projects - the study found that failures in design are the most influential and frequent factor in transportation projects. Han et al. (2011) also indicated that design errors are the leading factor for rework and schedule delays and cost overruns. Therefore, Han et al. (2011) developed a model to capture the design errors and evaluate their impact on the construction project. The study shows that design errors create schedule pressure on project stakeholders and can affect construction activities that are not directly related to the design error. Similarly, Ye et al. (2015) determined the leading causes for rework. The study indicated that design E&O, poor coordination, lack of constructability, and incomplete understanding of design intent are among the top factors causing rework. Therefore, one of the recommendations Ye et al. (2015) provides is to improve the constructability of design work by using effective communication between the project stakeholders. Forcada et al. (2013) also investigated the rework in highway projects using case studies. The case studies revealed that design E&O were the main factor causing rework and cost overruns.

The design quality is also an issue associated with project delivery methods. Even when the design is delegated to the contractor through a project delivery method such Design-Build (D-B), the owner is still responsible for assuring the design quality. A study by Gransberg and Molenaar (2004) investigated 26 transportation D-B requests for proposals to analyze the owner's design and construction quality management approaches. The study indicated that owners were executing D-B projects with the mentality of design-bid-build and failed to ask for quality management plans before awarding projects. Owners also assumed that the professional qualifications of the

designer-of-record would bring design quality, except for a few owners who required design quality management plans.

Design E&O is not an issue exclusive to the highway construction industry. Many studies also investigated design E&O in non-highway construction projects to identify the cause and impacts of design E&O and tools to address design E&O. For example, Hwang et al. (2009) used the construction industry institute database to investigate the impact and causes of rework on cost performance. The study found that owner changes and design E&O are the most influential factors on project cost performance. Moreover, design E&O can result from several factors, such as poor project definition, inadequate preplanning, ineffective design, poor change management, poor communication, and absence of constructability reviews (CII 2002). The preliminary literature review reveals that design E&O is one of the influential causes of schedule delay and cost overrun in several construction industry sectors. Several relevant studies can support the research methodology in analyzing the impact of design E&O and developing tools to mitigate their negative impacts. The research team will build upon past research studies to achieve the goals of this project.

3. Objectives

This project has three main objectives as follows:

1. Evaluate the impact of design E&O and rework on schedule delays and project costs.
2. Develop implementable DQC tools to minimize the negative impacts of design E&O and rework
3. Develop or improve policy and procedures document to handle design E&O.

4. Benefits

Based on the preliminary literature review, design E&O are one of the top reasons for schedule delay, cost overrun and rework. WYDOT also faces the same problem as seen by the results of a recent survey conducted by Abdelaty and Jamal (2022). The survey shows that WYDOT construction and district engineer perceive design E&O as

one of the top five reasons for schedule delay. This indicates the need to investigate design E&O causes, and develop strategies to mitigate the negative impact of design E&O.

There are several benefits of conducting this research. First, WYDOT will have quantitative and qualitative data regarding the impact of design E&O and rework on transportation projects' schedules and cost performance. The research team will analyze a representative sample of WYDOT projects considering different types of work, project delivery methods, size, technical complexity and design responsibility. The analysis will be done qualitatively using focus groups, surveys and expert interviews to collect qualitative data regarding the impact of design E&O on WYDOT projects. The analysis will also be extended to quantitively analyze the impact of design E&O on WYDOT projects using cost and schedule metrics. Therefore, the study will provide WYDOT with qualitative and quantitative information regarding the impact of design E&O instead of relying on data fragments.

Second, the research team will develop DQC tools and guidelines based on the analysis of the impact of design E&O. These tools and guidelines will help WYDOT staff ensure the quality and constructability of the project's design based on past historical E&O. Therefore, the study will enable WYDOT to detect as many design E&O as early as possible and thus to minimize their negative impact on the project. It is worth noting that these tools and guidelines will help maintain high-quality standards for in-house design. Furthermore, these tools and guidelines will assist in checking the quality of the design prepared by external consultants. Finally, this study will produce a policy document, factsheets and practical training resources for WYDOT staff to help implement the proposed tools and guidelines to facilitate the implementation of the project deliverables.

5. Applicable Questions

There are two main challenges associated with the project. The first challenge is collecting project's data regarding design E&O. We expect that some of the project's data is not digitized and could be stored in paper forms. Therefore, the research team

will communicate with project teams, collect data related to design E&O, and digitize it for further analysis to support the research tasks. We also expect that change orders and contract addendums are stored in WYDOT's Construction Management System (CMS) in PDF format. The research team will retrieve all relevant data from the CMS and analyze it to achieve the project goals. The PI has access to the CMS and will work with the project champion and WYDOT staff to collect all relevant data.

The second challenge is selecting and conducting case studies to validate the research deliverables. This challenge will be resolved after analyzing the causes and impacts of design E&O. The analysis will reveal which project attributes are associated with the highest negative impacts of design E&O (e.g., technical complexity, project delivery method, design responsibility, and schedule requirements). The research team will work with the project champion and WYDOT staff to select appropriate projects based on design E&O causes and impact analysis. The team will coordinate the research project timeline with the schedule of WYDOT projects to conduct case studies and validate the proposed deliverables. Therefore, PI has scheduled relevant research tasks to overlap with the construction season in Wyoming, assuming that this project will start in August 2023.

6. Statement of Work

6.1 Overview of Research Tasks

Nine tasks conducted in two phases are planned to achieve the main objectives of this study. Phase I includes a literature review, data collection, and qualitative and quantitative analysis of design E&O impacts on WYDOT projects. The work tasks included in phase I are listed as follows:

1. Conduct a comprehensive literature review on the causes and impacts of design E&O tools, best practices used to address design E&O by state DOTs, and the latest innovations in the building and highway construction industry to address design E&O. Moreover, the team will review WYDOT design review processes.

2. Select a representative sample of projects with different criteria (e.g., project delivery method, project size, type of project, in-house design, and external design consultants)
3. Determine causes of design E&O on the selected sample of WYDOT projects.
4. Evaluate the impact of design E&O on the project performance (e.g., cost and schedule)
5. Develop fact sheets to summarize the impacts and causes of design E&O on WYDOT projects.

Phase II of the project includes developing tools and guidelines addressing design E&O, conducting case studies, and creating fact sheets and training resources. The work tasks included in Phase II are listed as follows:

1. Develop tools and guidelines to mitigate the impact of design E&O on WYDOT projects.
2. Select several projects to be used as case studies.
3. Conduct case studies to revise and validate the proposed tools and guidelines.
4. Develop or improve training resources and policy and procedure document to facilitate the implementation of the proposed tools and guidelines.
5. Document the project findings and results and submit the final report.

Figure 1 illustrates the list of planned tasks and deliverables. A further explanation of each task is presented in the description of tasks section.

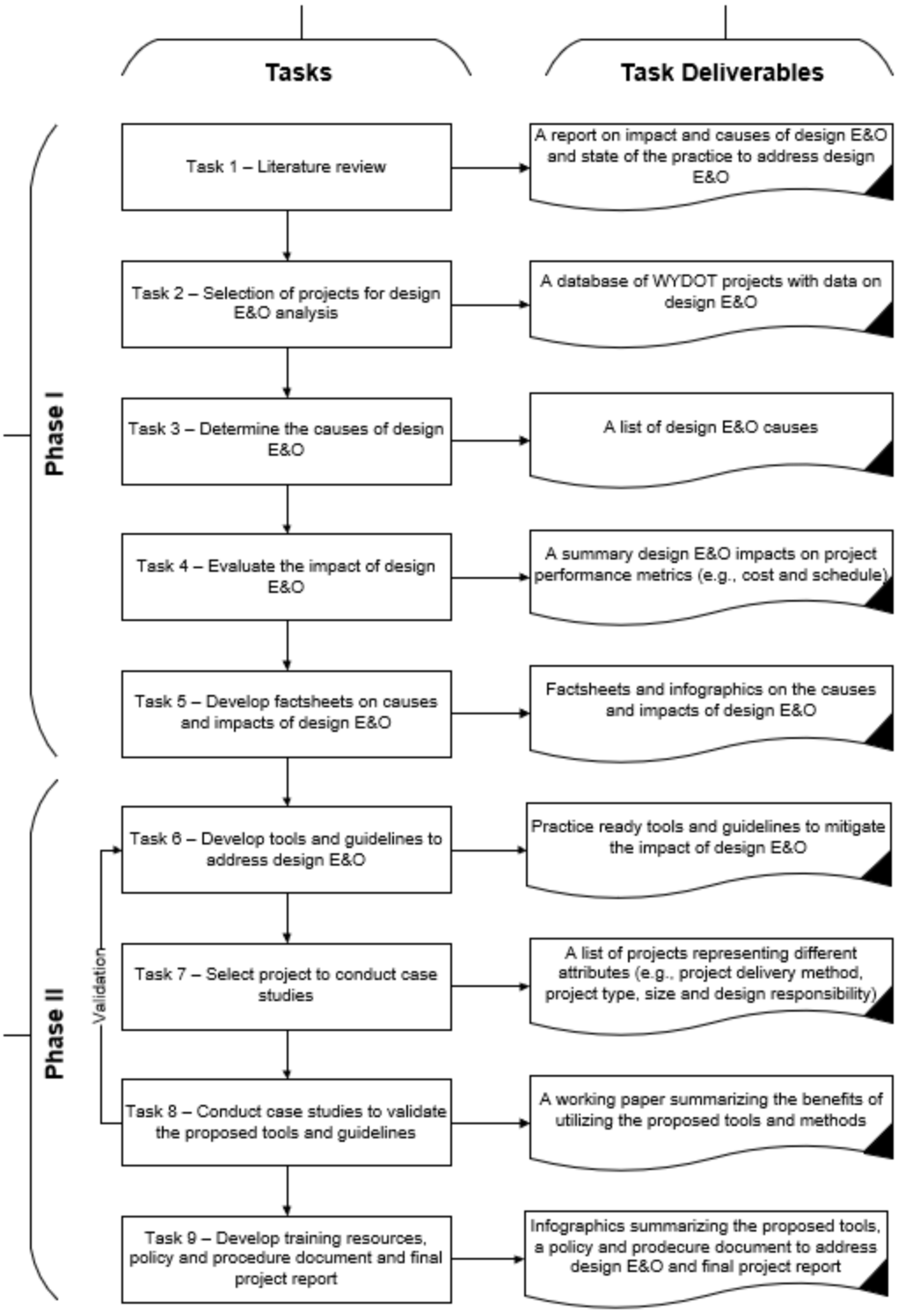

Figure 1. Research tasks and deliverables

6.2 Description of Tasks

Figure 2 shows the flow of the research tasks to determine the causes and impacts of design E&O, and develop tools to mitigate the impact of design E&O.

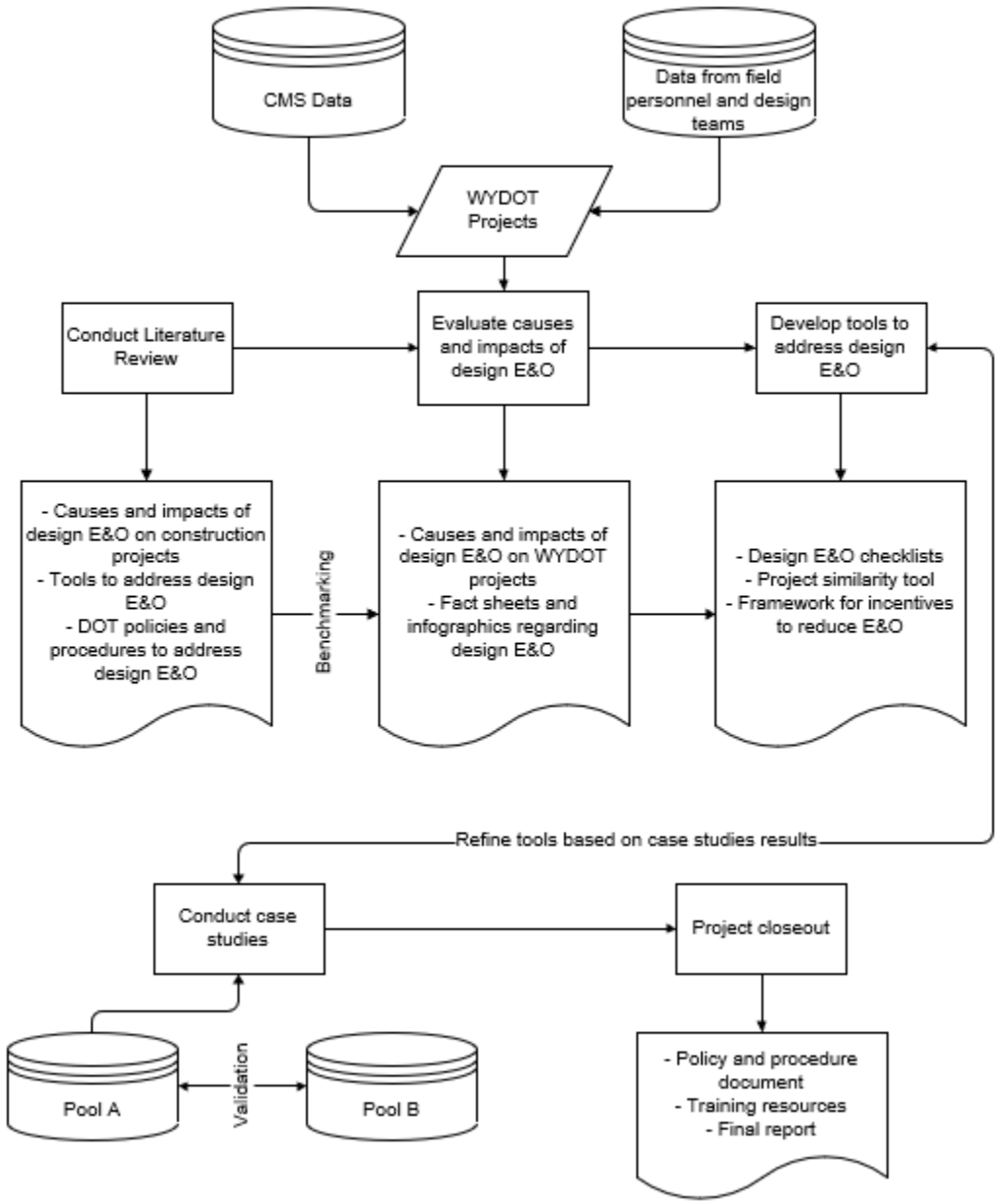

Figure 2. Research methodology

Task 1 – Conduct an extensive literature review

The research team will conduct an extensive literature review focusing on studies related to schedule delays and cost overruns because of rework and design E&O. The literature review will mainly focus on 1) causes of design E&O in the highway industry, 2) the impact of design E&O on project performance, 3) best practices to handle design E&O, 4) tools to mitigate the impact of design E&O, 5) policy and procedure documents published by state DOTs to address design E&O. We will extensively review the policy and procedure documents for handling design E&O published by other state DOTs. The review will document the processes of detecting, documenting, and handling design E&O. A quick scan of state DOTs shows that Texas, Florida, Minnesota, Maryland, Illinois, and North Dakota have policy documents to handle design E&O. The research team will also review WYDOT processes regarding design reviews, constructability reviews, contract change orders, and requirements to transfer from design to construction phases.

In addition, the team will review the topics mentioned above in the highway construction industry and the private contracting industry. This will help the research team identify the latest advancement in addressing design E&O in all construction sectors. The finding from this task will be used as a basis to develop DQC tools for WYDOT.

Task 2 – Select WYDOT projects to determine the causes and impacts of design E&O

The research team will work with the project champion to form a Technical Advisory Committee (TAC) representing field and design teams. The TAC will help the research team select a representative sample of WYDOT projects to determine the causes and impacts of design E&O. A diverse list of projects will be selected that represent multiple project attributes such as 1) project type, 2) asset type, 3) project size, 4) project delivery method, 5) technical complexity and 6) design responsibility. These project attributes will be revised and updated after meeting with the TAC. A diverse case method will be used to determine potential projects for analysis. Afterward, the team will collect data regarding design E&O for each project. The team will collect data from WYDOT CMS as well as data generated by other WYDOT teams (e.g., design teams, field personnel, project development, and design check squad). The collected data will be assessed in terms of completeness and analysis viability before starting Task 3.

Task 3 – Identify the causes and case frequency of design E&O

The team will analyze the data collected in Task 2 to determine the leading causes of design E&O by using project data, interviews and surveys with field personnel, design teams, and contractors. The research team will contact AGC Wyoming to include contractors in the surveys and/or interviews. First, the collected project data will be used to determine a list of potential causes for design E&O. This list will then be used to conduct structured interviews and survey with project teams to determine an extensive list of design E&O causes. The causes will then be statistically analyzed to determine the significance of each cause.

Additionally, we will analyze historical data to determine a list of common design E&O that occur more frequently across several projects. This analysis will include routine design reviews conducted during the PS&E phase and communication regarding design E&O between WYDOT staff and consultants/WYDOT design teams. Moreover, the analysis will include change orders issued due to design E&O. The research team will also analyze the design review process and standards for in-house projects. Finally, this task's results will evaluate the effectiveness of the design reviews by determining how many E&O were detected during the PS&E phase versus how many E&O went undetected until the construction phase.

Task 4 – Determine the impact of design E&O and rework on the project's performance

We will then use quantitative and qualitative research methods to evaluate the impact of the design E&O on the project performance. We will analyze contract documents, performance reports, schedules, and daily work reports/logs to quantify the schedule delay because of a design E&O. Additionally, the team will analyze design E&O-related change orders or costs incurred to quantify the impact of design E&O on cost performance. Qualitatively, we will also survey or interview project teams, including contractors and designers, to evaluate the impact of design E&O on project performance.

Task 5 – Develop factsheets and infographics summarizing common design E&O and their causes and impacts

The research team will then summarize the results of Tasks 3 and 4 using factsheets and infographics. These factsheets will disseminate information on common design E&O, and causes and impacts of design E&O. The research team will consider project attributes such as project delivery method, design responsibility, project type and size when developing factsheets and infographics.

Task 6 – Develop tools to mitigate the impact of design E&O and rework on schedule delays

Based on phase I results, the research team will develop tools and guidelines to enhance WYDOT DQC. These tools are expected to improve the project performance by mitigating schedule delays and cost overruns because of design E&O. For example, we will develop a checklist of common design E&O and their frequency based on historical data provided by WYDOT. The checklist will help WYDOT design teams to identify potential problems before starting the construction phase. Also, the research team will develop a project similarity tool. This tool can retrieve similar historical projects based on several parameters (e.g., design responsibility, project type, location, design features, and delivery methods). Project teams can then look at a refined checklist of design E&O and rework issues for past similar projects, which can mitigate the impact of future design E&O and reduce the number of rework incidents. Additionally, the research team will formulate guidelines to ensure design quality and incentivize high-quality design. For example, the research team will conduct a benefit-cost analysis to determine the appropriate incentives WYDOT can pay consultants or in-house designers to avoid or mitigate the impacts of design E&O. The team will also work with the TAC to determine the viability of tools mentioned above and potentially determine new approaches to mitigate design E&O.

Task 7 – Select projects for case studies

The research team will work with the TAC to select multiple projects in which the proposed tools and guidelines can be applied to measure their effectiveness. The selection of the case studies will be diverse and similar at the same time. The team will create two pools of projects (i.e., pool A and pool B, as shown in Figure 2). Each pool contains a set of diverse projects in terms of the project attributes. Each project in pool

A will be matched with a similar project in pool B. The research team will then apply the tools and procedures proposed in this study to pool A. This will allow the research team to measure the benefit of the proposed tools and guidelines by comparing the performance of projects in the first pool against the projects in the second pool.

Task 8 – Conduct case studies

The research team will then conduct the case studies by meeting with project teams and implementing the proposed tools and guidelines before starting the construction phase. We will then measure how many design E&O were caught as a result of the implementation of the proposed tools and guidelines. Afterward, we will compare the performance metrics of selected projects against similar projects to measure the perceived benefits of this study. Finally, depending on the results of the case studies, the research team will revise and refine the proposed tools and methods to mitigate the impact of design E&O on the project's performance.

Task 9 – Develop policy and procedure document for design E&O, training resources, and project closeout

Based on other DOTs' practices, and the feedback from the TAC, we will develop or improve a policy and procedure document to provide detailed steps on how to handle design E&O. We will also provide training resources on how to implement the proposed tools and procedures to mitigate the impact of design E&O on WYDOT projects. Finally, we will prepare a final report summarizing the research project results and findings.

7. Work Plan and Implementation

7.1 Technical Advisory Committee

The research team will work with the project champion to form a TAC to review and discuss the project's tasks, schedule, implementation, and deliverables. The team will schedule a kickoff meeting (in-person or virtual) with the TAC within 30 days of the start of the project. Additionally, the team will schedule periodic meetings with the TAC to oversee the project's progress and review the deliverables of the project.

7.2 Deliverables

The main deliverables of phase I is an analysis of causes and impacts of design E&O for WYDOT projects. The team will also deliver tools and guidelines to address E&O and mitigate their impact on WYDOT project performance in phase II. All project deliverables will be reported to the TAC in addition to the project's final report for review and feedback. The team will then address the TAC's review and submit all deliverables at the end of the project.

7.3 Progress Reports

The team will submit quarterly progress reports to the research center for review and feedback. Each progress report will summarize the progress and finding of the project work tasks.

7.4 Final Report

The team will submit a draft final report 60 days prior to the end of the project. The TAC will then review the final report for technical accuracy and clarity. A final review of the report's grammar and formatting will be conducted before submitting the report to the WYDOT research center.

7.5 Project Closeout

A copy of the final report and project deliverables will be presented to the TAC and WYDOT research center by the end of the project's schedule.

8. Schedule and Budget

The team will conduct the proposed work tasks in 24 months. Dr. Abdelaty and Mr. D'Angelo will lead and supervise the project tasks. One graduate student will be assigned to work on the project tasks. Table 1 shows the breakdown of the project budget. The project's total cost is $167,251, which will cover salaries for the research team, editing costs, and travel to interview project teams and disseminate the research results. Figure 3 shows the project schedule.

Table 1. Project budget

Budget Years 2023-2025					
Category		Year 1	Year 2	Total	Notes
Personnel - Salary					
PI (Abdelaty, UW)		$10,245	$10,245	**$20,491**	Two month salary to lead and supervise research tasks
Student		$23,784	$23,784	**$47,568**	Graduate student salary for 2 years
Fringe					
PI (Abdelaty)	44.30%	$4,539	$4,539	**$9,078**	
Graduate student	1.80%	$428	$428	**$856**	
Subaward					
Co-PI (D'Angelo, ARA)		$18,000	$18,000	**$36,000**	Co-PI salary (144 hours) including fringe
Travel		$2,000	$2,000	**$4,000**	
Publications/Editing services		$120	$120	**$240**	
Student tuition and fees		$10,572	$10,572	**$21,143**	
Total direct		**$69,688**	**$69,688**	**$139,376**	
Indirect rate	20.00%	$13,938	$13,938	$27,875	
Total cost		**$83,626**	**$83,626**	**$167,251**	

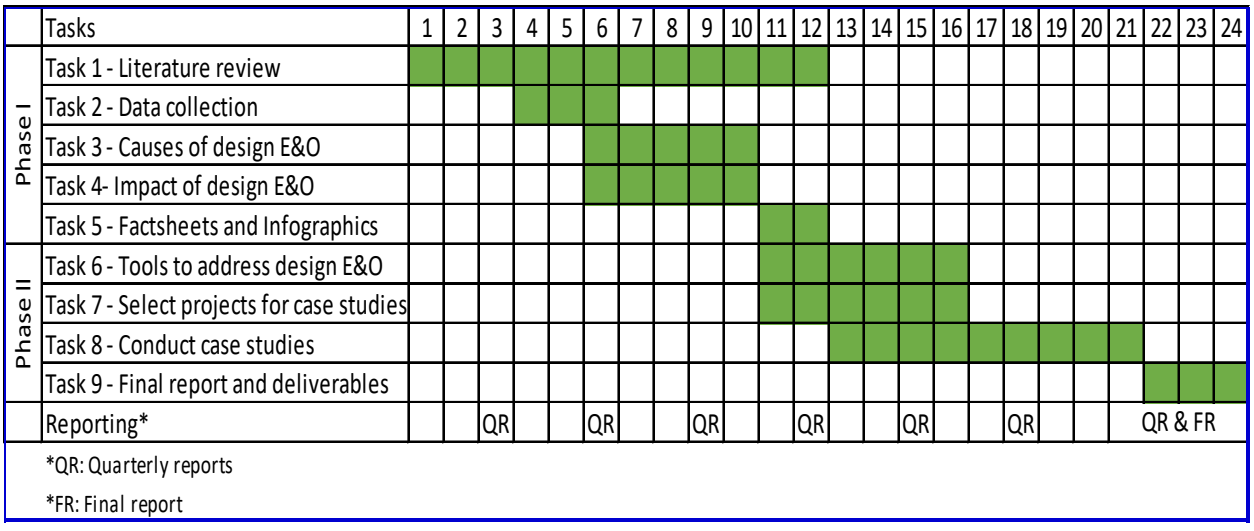

Figure 3. Project schedule

9. Technology Transfer

The research team will disseminate the results of this research project through technical papers and presentations in academic venues. The results will also be shared with WYDOT construction and district engineers throughout the implementation of the case studies. Finally, the research team will work with the Associated General Contractors of Wyoming to disseminate relevant results to Wyoming contractors during their periodic meetings.

10. Data Management Plan

Data collected from WYDOT will be stored in electronic forms on the University of Wyoming and Applied Research Associates computers and servers. In some cases, the team might need to collect non-digital data stored in paper forms. In these cases, the team will digitize the data in paper form for further analysis. Data will be stored for the duration of the projects and a backup of the data will stored by the research team with approval from WYDOT.

11. Personnel

Dr. Abdelaty earned his PhD in Civil Engineering from Iowa State University with a concentration in Construction Engineering. His PhD focuses on infrastructure asset management and practices such as supporting decision-making systems using data-driven algorithms. He started his academic career in 2017 at Southern Illinois University-Edwardsville. He then transitioned to the University of Wyoming in 2020. Dr. Abdelaty served as the PI for a project funded by the Mountains Plains Consortium to evaluate schedule delays in transportation projects. Dr. Abdelaty also worked as the lead graduate research assistant for three research projects funded by the Iowa Department of Transportation and one funded by the Midwest Transportation Center. Through his research and funded research projects, Dr. Abdelaty gained experience in infrastructure asset management, preconstruction services, conceptual estimating, and life-cycle cost analysis. Dr. Abdelaty developed a conceptual estimating tool for the Iowa Department of Transportation to estimate bridge design projects' costs and engineering hours. The tool

uses historical bid data and associated bridge design attributes to determine a conceptual estimate of the number of engineering hours and consultant fees to design the bridge using case-based reasoning, neural networks, and regression analysis. Dr. Abdelaty used Excel to develop the estimating tool which enabled the tool to be practice-ready. Similarly, Dr. Abdelaty used the same methodology to develop another conceptual estimating model for a general contractor in Missouri. The tool allows the contractor to develop quick rough order of magnitude estimates using their historical data. Dr. Abdelaty possesses significant experience in developing tools that are ready for implementation to be used by local transportation agencies and contractors. Dr. Abdelaty has published more than 12 journal and conference papers.

Mr. D'Angelo joined ARA's Transportation Infrastructure Division after a 33-year career with the New York State Department of Transportation. While with NYSDOT, Dan led numerous statewide programs across 11 Regional Offices and the Main Office. He was responsible for an annual capital design program of $1.5 B, led the American Recovery and Reinvestment Act (ARRA) Portfolio of $1.7 B and 543 projects in six program areas. He was responsible for cost estimating practices, and was the statewide coordinator for innovation deployment, including implementation of the Federal Highway Administration Every Day Counts Program. At the national level, Dan chaired the Strategic Highway Research Program 2 Renewal Technical Coordinating Committee.

Dan has delivered projects for bridge replacements, bridge rehabilitations, reconstruction, safety improvements, highway rehabilitation, element specific, and transit. He has experience in all project delivery methods. **As Statewide Director of the Design Quality Assurance Bureau and the Office of Design his responsibilities included project guidance and policy, along with approval of all capital projects.** Dan led the Department's effort in creating a project development manual and project delivery risk management process manual. He has served as risk manager on several programs and projects, including the $3.9 B Tappan Zee Bridge Replacement. He is well versed in risk management processes and practices at the project, asset management, and enterprise levels.

Dan is certified by the Project Management Institute as a Project Management Professional, Portfolio Management Professional, and Risk Management Professional. In addition, Dan has experience in adult education having earned a graduate certificate in Teaching & Learning and taught college courses and is a certified NHI instructor.

Mr. D'Angelo is a member of the National Academy of Construction, TRB Committee AKC20 Project Delivery Methods Committee, and Chairs AKC30(1) Quality Management for Alternative Project Delivery Subcommittee. He is a friend to AKC10 Standing Committee on Construction Management, AKC30 Standing Committee on Quality Assurance Management, AJE35 Research Innovation Implementation Management Committee, and AJE45 Committee on Information and Knowledge Management.

Mr. D'Angelo currently Chairs NCHRP Panel 20-44(42) Implementation of the Design-Build and Construction Manager/General Contractor Contract Administration Guidebooks through Comprehensive Agency Training. He is a member of the National Academy of Construction, the NYS State Board for Engineering, Land Surveying & Geology, Chairs the University at Buffalo Civil, Structural, Environmental Engineering Department Advisory Board, is a member of the Dean's Advisory Council for the School of Engineering and Applied Sciences, and is a member of the Institute for Bridge Engineering Advisory Board.

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