Development of Multi-Level Scoping Process Framework for Transportation Infrastructure Projects Using IDEF Modeling Technique

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ABSTRACT

State Transportation Agencies (STAs) frequently encounter challenges leading to cost overruns and schedule delays occurring during the execution process of highway projects. Scope changes are one of the major root causes of these cost increases and schedule delays. Therefore, the aim of this study is to evaluate the current practices of the project scoping process (PSP) in the highway industry and develop a multi-level project scoping model for transportation infrastructure projects. For this purpose, the research team used resources from existing literature in order to assess current industry practices for the development of three alternative scoping processes. Integrated Definition (IDEF) modeling technique was used to develop these scoping processes. After analyzing the three developed frameworks, the team selected the one that best represented key scoping activities and had the highest level of detail for further development. The proposed scoping model consists of four levels with three main functions of selecting the project, analyzing the project, and advancing the preferred alternative. The four stated levels include 20 activities and 84 sub-activities as well. Eventually, subject matter experts (SMEs) who worked in different STAs validated the developed PSP framework. Development of a project scoping process model leads to the adoption of appropriate best practices and strategies, which reduce costly scope changes and prevent unnecessary delays for infrastructure projects.

Keywords: Project Development Process, Scope Definition, Pre-Project Planning, Project Scoping
INTRODUCTION

STAs have substantially enhanced many aspects of project delivery; however, they challenge the cost overruns and schedule delays (1, 2), which happen after a project is funded (3). As transportation funding is limited, cost increases in one project can cause reduction in funding for other projects (4, 5). These outcomes can have negative consequences for STA’s relationships with the public and legislative bodies.

A few STAs recognized that project delivery performance could be enhanced by utilization of more sophisticated scoping and planning processes tailored to the type of project (6, 7). However, the highway industry as a whole is still experiencing substantial problems with scope growth (8). Lack of details corresponding to project scoping often leads to delays and cost increases (9, 10). Although a number of STAs including Pennsylvania Department of Transportation (11), Massachusetts Department of Transportation (12), Nevada Department of Transportation (13), California Department of Transportation (Caltrans) (14) and Ohio Department of Transportation (15) have modified their scoping processes with varying degrees of success, a structured approach that provides guidance on the appropriate level of effort to accomplish these improvements is needed.

To sum up, sufficient resources to perform scoping prior to programming, supporting the link between planning and scoping (16), and preliminary cost information are provided with a generic PSP framework (17). So adoption of a generic project-scoping framework by transportation agencies increases cost (18) and schedule performance of highway projects. However, utilization of existing planning and programming efforts by STAs appear to fall short of this end and necessitate an effective approach for project scoping process (19; 20).

Therefore, the goal of this study is to develop and validate a PSP model in order to assists in achieving on-time and on-budget delivery of highway projects. The following objectives were formulated to achieve the above mentioned goal of this study: (1) identify the current state of the practice in scoping processes used by STAs in infrastructure projects, (2) develop the most applicable PSP frameworks adopted by STAs across the nation, (3) analyze the developed PSP frameworks to select the most practical one, (4) utilize the appropriate framework to develop a new scoping model for effective scoping processes, and (5) validate the developed PSP framework.

LITERATURE REVIEW

The researchers of Construction Industry Institute (CII) have been tried to define project scoping in the engineering and construction industry. First, it was initiated by studying the importance of project scoping in the mid-1980s (21). In the first scoping related implementation guidebook published in 1995, CII defined project scope definition as “the key technical and physical attributes of the project, including general quality requirements and budget or commercial issues that would affect design planning and decision making” (22). Recently, several researchers examined the importance of project scope definition (3; 23; 24; 25; 26). In 2006, Gibson noted that the terms “front end planning” and “project definition” were often used interchangeably in the related literature (24). In 1994, CII defined front end planning (also known as “front end loading” or “pre-project planning”) as “the process of developing sufficient strategic information for owners to address risk and decide to commit resources to maximize the chance of a successful project” (27). Accordingly, in 2017, Kermanshachi et al. defined project scoping as a series of project focused activities that develop key design parameters and other project requirements to a sufficient level...
of definition such that scope discovery is complete and a budget and letting date can be firmly established prior to programming the project in the state transportation improvement progress (19).

Review of scoping definitions shows that the major key tasks to be addressed during project scoping include identifying the purpose and needs of the project; determining safety and operational deficiencies; identifying design criteria (28); identifying environmental, utility, and right-of-way issues and mitigations; identifying alternatives; establishing the preliminary budget and assessing the benefits associated with the project; and establishing a preliminary schedule (20).

Through reviewing the existing literature and STAs’ websites, it was observed that each agency has developed its own scoping framework with different stages in the project delivery process (11; 12; 13; 14; 15). Many STAs’ guideline documents for project scoping indicate that agencies should develop a strategic plan prior to project scoping (29). The strategic plan would address current deficiencies and project needs in the state’s transportation system so that potential projects can then be identified and selected (30). Project selection is an iterative process that requires various studies and analyses, and somewhere during the iterative process, project scoping begins (31).

As success of a transportation project can be determined by evaluating such performance metrics as cost, schedule, quality, safety, environment, etc., some STAs’ scoping processes include identifying project performance metrics and target performance functions for a specific project (14; 32; 33). To make an example, environmental studies are the most commonly implemented practice, as such; environmental performance is most frequently measured among STAs in their scoping processes (34).

Through literature review, the research team identified a number of tools used by STAs as such part of their scoping process. For instance, the Caltrans has a number of tools to assist planners in making decisions, including the life-cycle/benefit-cost analysis model and the California transportation investment system (14). The life-cycle/benefit-cost analysis model provides economic analysis based on model inputs for highway and transit projects. The model requires input parameters such as traffic data, existing accident data, and estimated project cost (35). The outputs are life-cycle costs, life-cycle benefits, net present value, benefit/cost ratio, internal rate of return, and payback period. Another example is Montana department of transportation (MDT) that has used CommunityViz and Spatial Growth Model (SGM) to evaluate alternative land use scenarios (36). CommunityViz is a plugin to existing geographical information system (GIS) programs such as Esri’s ArcGIS. In addition, to the existing ArcGIS capabilities, CommunityViz allows simulating alternative future scenarios and creates an interactive three-dimensional model that helps with visualizing how the future may look in different scenarios. SGM assists planners by allowing for smart growth in the future (37).

**RESEARCH METHODOLOGY**

To achieve the objectives of this study, a six-step research methodology was used, as shown in Figure 1. The PSP framework is divided into four levels of activities as follows:

- Level 1 is project scoping.
- Level 2 consists of activities, which represent the main functions that describe a PSP.
- Level 3 consists of further hierarchical breakdowns of these three activities describe the details of activities required to perform these functions.
- Level 4 consists of the activities in order to meet the objectives of the major activities.
**Step 1.** The objective of this step was to perform a comprehensive literature review on project scoping practices and tools. Two types of reviews were conducted: First, a literature review of peer-reviewed journal articles and research reports was conducted. Second, STA websites were reviewed to determine current practices and tools for project scoping.

**Step 2.** From the existing literature, three scoping frameworks (i.e., Frameworks I, II, and III) were developed representing the current practices of the project scoping in transportation agencies.

**Step 3.** The developed frameworks were evaluated to identify the most appropriate one in terms of the level of detail. The research team used the most detailed framework as the basis for developing a final scoping model.

**Step 4.** The research team used existing literature as a basis to develop a multi-level project scoping process model using IDEF modeling technique. This model consists of four levels with three main functions as select a project, analyze a project, and advance a selective alternative.

**Step 5.** In the last step, the developed scoping process model was validated. For this purpose, the research team sent the PSP framework to active SMEs in departments of transportation (DOTs) in order to review the applicability and accuracy of the proposed framework.

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**Figure 1. Research Methodology**

- **Step 1:** Review of Existing Resources Used by STAs
  - Current practices for project scoping
  - Project scoping tools
- **Step 2:** Develop Alternative Draft Scoping Framework
  - Framework I
  - Framework II
  - Framework III
- **Step 3:** Select the Most Appropriate Framework
- **Step 4:** Develop Levels 1, 2, and 3
  - Develop A1 Function: Select Project
  - Develop A2 Function: Analyze Project
  - Develop A3 Function: Advance Preferred Alternative
- **Step 5:** Validate the Developed PSP Framework
**IDEF Modeling Technique**

The present study adopted a process modeling technique to develop the preliminary project scoping process. Business process models or diagrams are widely used to depict, understand, analyze, and improve processes. The research team decided to use the IDEF modeling technique for capturing the details of the project scoping process. The IDEF process modeling technique is a graphic description of a processor or system that leads to a better understanding of the process and provides logic to help modify the processor or system (38). The use of IDEF was the result of an established fact that improvement in a process can be successfully achieved with an effective process modeling technique (39). The IDEF model is proven to be an excellent tool for modeling processes developed through research (40; 41). IDEF uses cell modeling graphic representation, as shown in Figure 2.

![Figure 2. Basic IDEF Structure with an Example](image)

As presented in Figure 3, a tunneled arrow is mainly utilized to decompose information at a determined level that is not needed for understanding at some other levels. The parentheses notation in this figure were utilized to show that the data or objects expressed by tunneling an arrow, are not required for understanding subsequent level(s) of decomposition. So it will not be illustrated on its child diagram. On the contrary, tunneling an arrow at the unconnected end is used to indicate that the data or objects are not necessary at the next higher (parent) level and so will not be illustrated connecting to the parent box (42).

![Figure 3. Tunneled Arrows at Connected and Unconnected End in IDEF Modeling Technique (43)](image)
SCOPING FRAMEWORKS

The research team developed three scoping frameworks from the review of the literature and current practices, as shown in Figure 4.

Framework I (Figure 4a): The research team developed Framework 1 to improve right-of-way procedures and business practices based on the project development process model (44).

In Framework I, the project team needs to confirm the project purpose, evaluate fundamental project requirements, and perform supporting studies. More importantly, the project team needs to identify alternatives in response to the confirmed needs. After selecting the preferred alternative, the project is continued by the development of design schematics. The process of design schematics includes refining geometrics and alignments, preparing preliminary plans, structuring preliminary pavement design reports, performing hydraulic studies, and performing preliminary planning for bridges. Preparing draft environmental documentation is also performed at this stage, which needs determining public concerns, identifying environmental concerns, performing early and frequent interagency coordination, and collecting information from ground surveys and state agency databases.

Framework II (Figure 4b): This framework is based on Minnesota Department of Transportation (MnDOT) scoping process (45) and TxDOT’s Advance Planning Risk Analysis (APRA) (46) scoping documents. MnDOT’s scoping process (45) was adopted because this agency recently developed a detailed scoping process with particular focus on how to ensure the project is well defined. Activities in TxDOT’s APRA (46) were further investigated in relation to this project because research indicates that the ability to provide better project definition prior to programming leads to improved cost and schedule performance. The main assumption of Framework II is that long-term plans contain a sufficient amount of information about the project, including basic project requirements and federal and state requirements prior to the project selection function (A1). The project selection step in this framework focuses on evaluating candidates with respect to regional transportation plans, statewide transportation plans, local master plans and documentation, related investment studies, and reports, local entity input. Analyzing alternatives in Framework II focuses on the analysis of traffic and traffic crash data. Developing the preferred alternatives should consider design criteria, operating criteria, and maintenance considerations.

Framework III (Figure 4c): This framework is based on Washington State Department of Transportation (WSDOT) scoping framework (47), data from WSDOT in-depth follow-up interviews performed by Kermanshachi et al. (19), data from Constructability review process for transportation facilities (48), and American Association of State Highway and Transportation Officials (AASHTO) study (9). Framework III assumes that long-term and intermediate-range plans contain a sufficient amount of information about the project, including basic project requirements and federal and state requirements prior to the project selection function (A1). In general, important decisions for defining a project are made during the long-range planning phase and project scoping, as reflected in Framework III, which mainly includes identifying various alternatives and design solutions. Selecting projects in Framework III focuses on redefining the project concept and updating it with respect to long-term and intermediate plans; analyzing project focuses on conducting preliminary studies, such as traffic analysis and modeling; and advancing the preferred alternative focuses on developing detailed studies, such as environmental studies.
Figure 4. Three Alternative Project Scoping Process Frameworks
SELECT THE MOST APPROPRIATE FRAMEWORK

These three frameworks were first presented in the brainstorming session based on the applicability and functionality of the three proposed model among the ten members of the research team. Components and functions for each framework were initially discussed independently and then cross-compared to determine what functions best describe the scoping process. After a general discussion about the alternative frameworks, Framework III was selected and further transformed into the final proposed framework. Framework III was identified as the most appropriate with the level of detail and information collected to support the functions.

DEVELOPMENT OF MULTI-LEVEL SCOPING MODEL

IDEF model starts with a top-level context diagram. The subject of the model is indicated with single box including the bounding arrows on the four sides. This is termed the A0 diagram. The A0 diagram is important because it allows the user to set the model scope. The context diagram typically includes a purpose and viewpoint statements.

Level 2 (A1, A2, and A3), as shown in Figure 5 represents the three main functions that describe a project’s process. Further hierarchical breakdowns of the functions (level 3) describe the details of these functions.

Figure 5. Output of IDEF Modeling Technique of Scoping Framework at Level 2

Figure 6 illustrates the third level of PSP (A11 through A37). The main steps of this level are as follows:
- Extracting the information corresponding to project purpose and needs
- Improvement and requirement studies
- Right-of-way considerations
- Proposed project limits and rough schematics,
• Project benefit-to-cost and feasibility studies
• Environmental issues
• Public involvement and participation plan
• Integrity conditions (quality and serviceability of the physical transportation infrastructure) from the long-range and intermediate-range plans

The STAs use this information and refines the project concept to make sure it is in line with its strategic goals.

Figure 6. Developed PSP Framework (Level 3)

**A1 Function**

The overall purpose of A1 function, as illustrated in Figure 6, is to determine which projects should be considered for scoping and ultimately inclusion into the Statewide Transportation Improvement Program (STIP) in order to make sure that the agency is fulfilling the aims and objectives outlined in local, regional, and state plans.

As there is a limitation of space, only one function is explained in different levels. As shown in Figure 6, A1 function consisted of five sub-activities as listed below:
• Refine Project Concept (A11)
• Solicit Input from Public (A12)
• Prepare Conceptual Cost Estimate (A13)
• Perform Preliminary Budget/ Cost Analysis (A14), and Select Project for Scoping (A15)
Through implementing sub activity A11, the project team should determine the original purpose of the project and verify whether the project is aimed at improvement, preservation, or safety and mobility. Then, in step A12, every project has to consider public involvement to inform the people of project scope challenges and concerns and to know public opinions regarding the development process. Through implementing A13, precise cost estimation must be conducted. According to the type and timing of the project, it might be important to consider alternative funding sources, such as public improvement districts.

**A2 Function**

The purpose of A2 function is to analyze feasible alternatives for conducting the project and to select the most appropriate one. As illustrated in Figure 6, A2 function consisted of seven sub activities, which named Develop Preliminary Schematics (A21), Develop Conceptual Transportation Management Plan (A22), Conduct Right-of-Way (ROW) Research (A23), Survey Existing Conditions (A24), Input from Public Parties (A25), Provide Preliminary Scoping Estimate (A26), and Select Preferred Project alternative (A27). Just one function is explained in multiple levels, due to the limitation of space.

In the adoption of A21, developing preliminary schematics includes activities such as refining alignments and geometrics, preparing preliminary plans and layouts, and developing preliminary pavement design reports would occur. In the case of implementing A22, the transportation management plan is developed as a program of activities for alleviating or minimizing work-related traffic delays by the effective application of traditional traffic-handling practices and an innovative combination of various strategies. Through adoption of A23 sub activity, a high-level assessment of potential corridor right-of-way requirements is required to identify properties that need to be acquired and restrictions such as existing ROW limit, easement, and property owners from records maintained by local public entities.

**A3 Function**

The purpose of the A3 function is to structure and document the most appropriate alternative for readiness of planning the project into the STIP. A baseline budget and letting date are also set through implementing this activity. As indicated in Figure 8, this function consisted of seven sub-activities: Develop Preliminary Drawings/Models (A31), Determine ROW Requirements (A32), Develop Final Environmental Documentation (A33), Develop Final Traffic Management Plan (A34), Conduct Public Meetings (A35), Prepare Baseline Schedule and Cost (A36), and Prepare Scoping Report (A37). As there is a limitation of space, only one function is explained in different levels.

Adoption of sub-activity A31 leads to develop preliminary drawings that will be used in design considerations (e.g., design life), operating considerations (e.g., operating timetable), and maintenance considerations (e.g., scheduled shutdown frequencies and duration programs). Then, the sub-activity of A32 is implemented for the establishment of the preliminary design phase in simultaneous with gathering the information for developing the alternative alignments. Later in the preliminary design phase, data collection is required to refine preferred alignments to mitigate the impacts of ROW on properties.

**Developed Framework for Level 4 of Project Scoping**

Twenty activities at Level 3 were further broken down into 84 sub-activities at level 4 as shown in Table 2.
Table 2. Developed Framework of Level 4 Project Scoping

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>A111: Update purpose</td>
<td>A21: Gather right-of-way maps</td>
<td>A311: Identify owner approval requirements</td>
</tr>
<tr>
<td>A112: Identify alternatives</td>
<td>A22: Gather easement records</td>
<td>A312: Identify deliverables</td>
</tr>
<tr>
<td>A113: Identify stakeholders</td>
<td>A23: Assemble research results</td>
<td>A313: Identify model requirements</td>
</tr>
<tr>
<td>A114: Alternative consideration</td>
<td>A24: Evaluate project definition</td>
<td>A314: Produce preliminary drawings</td>
</tr>
<tr>
<td>A121: Identify stakeholders</td>
<td>A25: Identify project stakeholders</td>
<td>A321: Gather data to refine alternative</td>
</tr>
<tr>
<td>A122: Record input from stakeholders</td>
<td>A26: Identify required deliverables</td>
<td>A322: Survey existing right-of-way</td>
</tr>
<tr>
<td>A123: Revised based on inputs</td>
<td>A27: Identify types of determine</td>
<td>A323: Prepare right-of-way map</td>
</tr>
<tr>
<td>A131: Determine cost estimate</td>
<td>A28: Develop TMP* cost estimate</td>
<td>A324: Assess relocation assistance needs</td>
</tr>
<tr>
<td>A132: Prepare cost estimate</td>
<td>A29: Perform administrative review</td>
<td>A325: Prepare property descriptions</td>
</tr>
<tr>
<td>A133: Set contingency</td>
<td>A30: Finalize scoping report</td>
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<tr>
<td>A134: Review cost estimate</td>
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<tr>
<td>A135: Approve cost estimate</td>
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<tr>
<td>A141: Review strategic plan</td>
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<td>A142: Identify quantifiable criteria</td>
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<td>A143: Weight each criteria</td>
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<td>A144: Prioritize alternatives</td>
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<td>based on criteria scoring</td>
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<tr>
<td>A151: Collect information for potential</td>
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<td></td>
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<tr>
<td>projects</td>
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<tr>
<td>A152: Assess project definition</td>
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<tr>
<td>A153: Assign project manager</td>
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<tr>
<td>A21: Gather right-of-way maps</td>
<td>A23: Align horizontal and vertical elements</td>
<td>A331: Identify stakeholders</td>
</tr>
<tr>
<td>A22: Gather easement records</td>
<td>A24: Develop cross sectional elements</td>
<td>A332: Notify affected populations</td>
</tr>
<tr>
<td>A24: Assemble research results</td>
<td>A25: Identify project stakeholders</td>
<td>A333: Finalize mitigation plan</td>
</tr>
<tr>
<td>A23: Revised based on inputs</td>
<td>A26: Notify affected populations</td>
<td></td>
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<tr>
<td>A25: Prepare draft mitigation plan</td>
<td>A27: Prepare draft final document</td>
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<td>A26: Identify project stakeholders</td>
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<tr>
<td>A27: Prepare base estimate for alternatives</td>
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<tr>
<td>A28: Summarize alternative analyses</td>
<td>A28: Conduct ranking analysis</td>
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<tr>
<td>A29: Identify stakeholders</td>
<td>A29: Select project alternative</td>
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<tr>
<td>A30: Approve estimate for alternatives</td>
<td>A30: Evaluate project definition</td>
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<tr>
<td>A31: Revised based on inputs</td>
<td>A31: Identify stakeholders</td>
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<tr>
<td>A32: Evaluate project definition</td>
<td>A32: Notify affected populations</td>
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<tr>
<td>A33: Approve estimate for alternative</td>
<td>A33: Finalize scoping report</td>
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TMP = Transportation Management Plan
Level 4 activities became the foundation for developing the guidance content. After identifying Level 4 activities, developing details continued with determining IDEF inputs, mechanisms, controls and output for each Level 4 activity using IDEF modeling technique. All of the activities involved in Level 4, should be identified based on the collected project data, project requirements, and project definition.

VALIDATION OF THE SCOPING MODEL

The research team sent the final PSP framework to seven DOT professionals for their review and feedback. The reviewers’ demographic information is listed in Table 3. The overall feedback from these reviewers was positive and everyone expressed agreement that this effort addresses the current need for a structured project scoping process within many STAs.

Table 3. List of Professional Selected for Review of Developed PSP Framework

<table>
<thead>
<tr>
<th>Reviewer #</th>
<th>Current Role in Company</th>
<th>Affiliation</th>
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<tbody>
<tr>
<td>1</td>
<td>Project Consultant</td>
<td>Texas DOT</td>
</tr>
<tr>
<td>2</td>
<td>Chief Procurement &amp; Deputy Administrative Officer</td>
<td>Texas DOT</td>
</tr>
<tr>
<td>3</td>
<td>Risk Manager</td>
<td>Washington DOT</td>
</tr>
<tr>
<td>4</td>
<td>Executive Manager of Arizona Department of Transportation</td>
<td>Hennepin County Public Works Department, Minneapolis</td>
</tr>
<tr>
<td>5</td>
<td>Resident Engineer</td>
<td>Colorado DOT</td>
</tr>
<tr>
<td>6</td>
<td>Director of Central Office Highway Design</td>
<td>Kentucky Transportation Cabinet</td>
</tr>
<tr>
<td>7</td>
<td>Director of Central Office Highway Planning</td>
<td>Kentucky Transportation Cabinet</td>
</tr>
</tbody>
</table>

The reviewers stated that each of the three main functions of the project scoping process requires communication with the public and other stakeholders to verify project needs and requirements and to avoid surprises during the subsequent steps. Each of the three main functions of the PSP requires communication with the public and other stakeholders to verify project needs and requirements and to avoid surprises during the subsequent steps.

CONCLUSION

Through the review of existing literature and related resources, it was revealed that there is a need to have a comprehensive and structured PSP framework, which can be applicable and usable for all STAs’ infrastructure projects. Therefore, the objectives of this study were to assess the current practices of project scoping processes adopted by transportation agencies for highway projects and develop a multi-level scoping process framework for transportation infrastructure projects. In this respect, the results of the analyzed data through comprehensive literature review, STA scoping documents, and expertise of the active transportation practitioners were utilized to develop three alternative project scoping frameworks. These frameworks were implemented and adopted by various transportation infrastructure projects. The most appropriate and applicable framework was then selected for further development to achieve a generic project scoping process model with sufficient level of detail. Among various modeling tools and techniques, the IDEF modeling was
identified as the appropriate technique to generate the developed framework. Eventually, SMEs validated the usefulness and effectiveness of the developed scoping framework.

This study concluded that the key tasks to be addressed during project scoping process model is to identify the purpose and needs of the project as well as establish the preliminary schedule and budget. In this regard, the developed framework consisted of three functions (A1, A2, and A3). The First function (A1) establishes scope, cost, and schedule baselines for all state transportation agencies. The second function (A2) focuses on the analysis of alternatives, development of preliminary schematics, and the conduct of preliminary studies to make proper design decisions. Next, the purpose of A3 function is to conduct a thorough study of environmental and right-of-way requirements.

The developed PSP framework provides guidance on the required level of engineering and design completion for project readiness at the project authorization decision point. Adoption of this framework leads to identification of key personnel, their level of involvement, and when these personnel are needed. This staffing of personnel involved in scoping must provide adequate time to perform project scoping as determined by project type and size. The outcome of this study will assist transportation agencies to estimate accurate project budget, schedule, and plan for the subsequent project delivery activities during the execution process.

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