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# Linear scheduling and procurement tools to manage geotechnical risk in design-build construction projects

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**Linear scheduling and procurement tools to manage geotechnical risk in design-build construction projects**

by

**Ricardo M. Tapia**

A dissertation submitted to the graduate faculty

in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Civil Engineering (Construction Engineering and Management)

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2017

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## NOMENCLATURE

AAHSTO	American Association of State Highway and Transportation Officials
ATC	Alternative Technical Concepts
CAP	Construction Agreed Price
CMGC	Construction Manager/General Contractor
CPM	Critical Path Method
DB	Design-Build
DBB	Design-Bid-Build
DBIA	Design-Build Institute of America
DOT	Department of Transportation
DSC	Differing Site Conditions
FHWA	Federal Highway Administration
GBR	Geotechnical Baseline Report
GDR	Geotechnical Data Report
GMP	Guaranteed Maximum Price
IFB	Invitation for Bid
INDOT	Indiana Department of Transportation
LSM	Linear Scheduling Method
MSHA	Maryland State Highway Administration
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program

NCR	Noncompliance Report
NTP	Notice to Proceed
ODOT	Ohio Department of Transportation
PAC-4	Pacific Access Channel Phase 4
RFP	Request for Proposals
RFQ	Request for Qualifications
TRB	Transportation Research Board
TXDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation
USACE	United States Army Corps of Engineers
WBS	Work Breakdown Structure
WSDOT	Washington State Department of Transportation

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## ABSTRACT

By integrating Linear Scheduling Method (LSM) concepts with risk modeling methods and using state-of-the practice contractual risk management, a framework is proposed to manage geotechnical uncertainty in construction projects. LSM provides an effective tool for graphically depicting a design-build (DB) project's schedule in terms of both estimated and actual production rates in relation to physical locations on the project. When the LSM tool is combined with risk analysis calculations and geotechnical site information, it provides a vehicle for effectively allocating geotechnical risk, and when used forensically, furnishes a means to visually quantify delays during dispute resolution.

The use of alternative methods for quantifying and managing geotechnical risks is explored by incorporating the LSM format and DB procurement along with the implementation of contractual risk management tools, providing a framework for managing the uncertainty of underground conditions in a way that increases the effectiveness of communication and analysis.

A forensic approach is also proposed using the LSM format to visualize actual production data drawn from daily work reports in a single chart to accurately depict the events that occurred during construction, thus demonstrating the potential of the LSM format as a communication tool to draw conclusions from information that otherwise would not be apparent using the Critical Path Method (CPM). Additionally, a risk management and planning approach is also explored with the use of LSM combined with stochastic simulations to represent the estimated impact of geotechnical risks and integrating it with the geological interpretation of the site.

By integrating LSM, stochastic simulations for schedule risks, and state-of-the-practice contracting methods, the study contributes to the body of knowledge by providing an innovative approach to increase the effectiveness for managing the geotechnical risk in DB projects.

## CHAPTER I INTRODUCTION

### **Problem Statement and Research Hypothesis**

Traditionally, schedule risk analysis is performed starting from the format that a Critical Path Method (CPM) tool displays, in essence, a table organized by the Work Breakdown Structure (WBS) of the project. While maintaining the structure of the schedule with all its constraints and inter-activity relationships, uncertainty is then incorporated by means of probability distribution functions into the activities durations using a stochastic model (Ke and Liu, 2005).

Even though CPM scheduling is used widely across the construction industry, it has some limitations. For example, CPM ignores production-rate changes when analyzing concurrent delays (Lee, 2007) and cannot easily ensure continuous resource utilization (Harris and Ioannu, 1998). This makes it difficult to integrate the CPM scheduling tools with the risk analysis effort in order to communicate the impact of risks effectively, typically requiring relying on separate tools to represent the results of the analysis such as tornado diagrams or indexes.

One of the major sources of uncertainty on construction projects is the geotechnical risk. The subsurface conditions not only can have great impact on the project's ultimate design, but also directly affect the project's scope and schedule (Gransberg & Loulakis, 2011). Interpreting geotechnical studies and estimating the impact of subsurface conditions on production rates during construction is a complex task that requires advanced technical knowledge in both the fields of geotechnical and construction engineering. Often, underlying assumptions made to complete this task are not available to all project team members, creating a challenge when a change to the project plan occurs and re-scheduling

is required. Therefore, an opportunity exists for improving the way the subsurface data is both analyzed and graphically represented to raise the visibility of geotechnical conditions and make them relevant to the evaluation of potential design alternatives, as well as planning the overall sequence of work. By improving team understanding and familiarity with important project details, such the geotechnical risk, the potential for project success is increased (Schomburg et al., 2015).

It is imperative that geotechnical risk is equitably allocated between the parties to a DB contract before these tools are considered effective. One approach is to allow the construction contractor to make substantive input to the final design (Gransberg 2013). By definition, early contractor design involvement will occur after the DB contract is awarded, but in projects with significant geotechnical risk, that is too late because the contract itself will have established the geotechnical risk profile for both the owner and the design-builder. At that point, the geotechnical risk premium will be buried in the winner's price proposal. However, DB contracts that incorporate alternative technical concepts (ATC) during procurement permit the geotechnical risk allocations to be negotiated prior to contract award and any reduction in geotechnical risk to the design-builder by its approved ATCs are reflected in lower proposed pricing (Christensen and Meeker 2002). Hence, for the purpose of this dissertation, the allocation of the risk is studied by exploring the use of DB contracting and the effectiveness of ATCs as a way to achieve early contractor design involvement as a means to better allocate geotechnical risk.

Considering the problem discussed above, the main hypothesis of this research is as follows: *Geotechnical risk management on DB projects can be improved by applying LSM tools in combination with ATCs and risk allocation contractual provisions.*

### **Purpose and Motivation**

The purpose of this research is to develop a framework for interpreting, quantifying, communicating and managing geotechnical risks in a way that is more intuitive and comprehensive than traditional methods. Previous research found that the use of LSM to analyze complex schedules and changes encountered during production in a single chart provides a more intuitive representation of both planned and actual production (Tapia and Gransberg, 2016; Duffy et al., 2011; Lopez del Puerto and Gransberg, 2008; Lee, 2007; Yamin and Harmelink, 2001; Harris, 1998; Harmelink and Rowings, 1998). This analytic power can be applied in risk management efforts to increase the understanding of risks and to find alternate solutions within the schedule that otherwise wouldn't be readily apparent (Tapia et al. 2017). To date, there is no framework for a tool that integrates stochastic methods such as Monte Carlo simulations with LSM to produce a visual representation of the quantified risk.

Once the risks and the schedule are integrated in a LSM format, this information can potentially be combined with contractual provisions, like ATCs or differing site conditions (DSC) clauses to create an effective management tool. By incorporating contractual information into the LSM format, the potential to resolve issues that could lead to a dispute increases. For example, including the owner's geotechnical interpretation in the LSM format and comparing it to actual conditions found on site while associating that information with the project schedule provides a visual tool to quantify delays due to differing site conditions.



## Background

### Introduction of key concepts

#### *Geotechnical Risk*

The geotechnical risk in the construction context refers to the uncertainty in the ground conditions, which can cause adverse effects on several project objectives including cost, time, quality, and environmental parameters (Clayton, 2001).

Geotechnical conditions are typically estimated based on subsurface investigations by means of borings and laboratory tests to create an approximation of the actual conditions of the site before work is started. The geotechnical risk manifests itself when the actual conditions of the site differ from those estimated, therefore, directly impacting the cost and schedule of the project.

#### *Linear Scheduling*

The concept of the Linear Scheduling Method (LSM) is not as innovation by itself (Johnson 1981; Carr and Meyer 1974); it was previously called the Line of Balance (LOB) and was developed by the US Navy in the 1950s (Sarraï, 1990) and was adopted to be used by the heavy civil construction industry to keep track of production rates in the 1960s (Harmelink, 1995). Afterwards, computerized systems replaced it since it was originally a manual effort.

Linear scheduling is a method that represents time and space in the same chart, creating the opportunity to visually identify and resolve location conflicts in the schedule accounting for different production rates (Callahan et al 1992). It is a production-based method with the objective to maximize crew production across all fronts in a job by ensuring the difference in production rates of the activities do not create conflicts in space

or time. The result is a robust planning and work sequencing tool that has been used by many large US and international construction companies since the 1950's (Jones 2005).

In the linear scheduling format, the schedule is graphically represented in two axes where the vertical or "Y" axis is time and the horizontal or "X" axis represents location, and activities are represented by lines or blocks in this matrix. Consequently, production rates are represented as the slope or inclination of the lines.

#### *Stochastic Risk Analysis*

Stochastic risk analysis is the process of using computer simulations to reproduce the effect of risks as variations in the project cost or time (Ke and Liu, 2005). As applied in this research, stochastic simulation is performed using the Monte Carlo Method, which generates random scenarios within a probability distribution function to model the behavior of a given parameter and provides a result with a selected confidence level. For planning purpose, that parameter is the duration of activities as it varies due to the influence of geotechnical risks.

#### *Design-Build Project Delivery Method*

Design-Build (DB) is a project delivery method in which one party performs design and construction services in a single contract with the owner of the project (DBIA, 2009). It is considered an alternative project delivery method in comparison with the standard Design-Bid-Build (DBB) method where the owner furnishes a complete design before a construction contract is awarded.

The DB delivery method is relevant to this research due to the general perception that transferring responsibility for performing part of the subsurface investigation to the

contractor in order to complete the design is a risk allocation measure that partially mitigates the geotechnical risk to the owner.

### *Alternative Technical Concepts*

The contractual provision for ATC is a way to allow requests by proposers to modify a contract requirement in order to gain a competitive benefit towards winning the job, providing a solution that is equal or better than the owner's requirements (FHWA, 2012). This provision creates the opportunity to achieve early contractor involvement during the bidding process. This provision, combined with the allowance for proposers to conduct additional geotechnical investigation before bidding is a mitigation action towards diminishing the impact of geotechnical risks, as state-of-the-art industry knowledge is involved in the effort before agreeing in a fixed price for the job.

## **Theoretical Framework**

### **Critical Path Method vs. Linear Scheduling**

The CPM is considered the standard scheduling tool in the construction industry for most types of projects (Harmelink, 1995). The basis for determining the project duration is by calculating the longest time path of continuous activities required to complete the project. In essence, this is done by accounting for the start and finish dates for each activity and the inter-activity relationships and constraints to build a network. Location and production rates are intrinsically built in the activities and the scheduler has to account for them when building the structure of the schedule and estimating the durations.

LSM is a production-based scheduling tool that graphically depicts the schedule in terms of the location and time in which activities are performed. In this configuration, the duration, physical length and production-rate of any activity in the project can be quickly identified and assessed.

To illustrate the visualization differences between CPM and LSM, consider a hypothetical pipe-installation project consisting of the activities detailed in Table 1 as follows:

Table 1 Pipe-installation example project schedule information

Activity ID	Description	Duration (weeks)	Predecessor	Relationship
Start		0	-	-
A	Mobilization	2	Start	-
B	Trench Excavation 1 (from STA 0+000 to STA 0+200)	3	A	Finish-Start
C	Trench Excavation 2 (from STA 0+200 to STA 1+000)	5	A	Finish-Start
D	Pipe Installation	4	B, C	Finish-Start
E	Trench Backfill 1 (from STA 0+000 to STA 0+400)	2	D	Finish-Start
F	Trench Backfill 2 (from STA 0+400 to STA 1+000)	3	D	Finish-Start
G	Landscape	3	E, F	Finish-Start
H	Demobilization	1	G	Finish-Start
Finish		0	8	-

An example of the CPM network for the activities detailed in Table 1 is shown in Figure 1. The CPM network is often accompanied by a Gantt Chart, a simple example of this chart is shown in Figure 2 for the same hypothetical project.

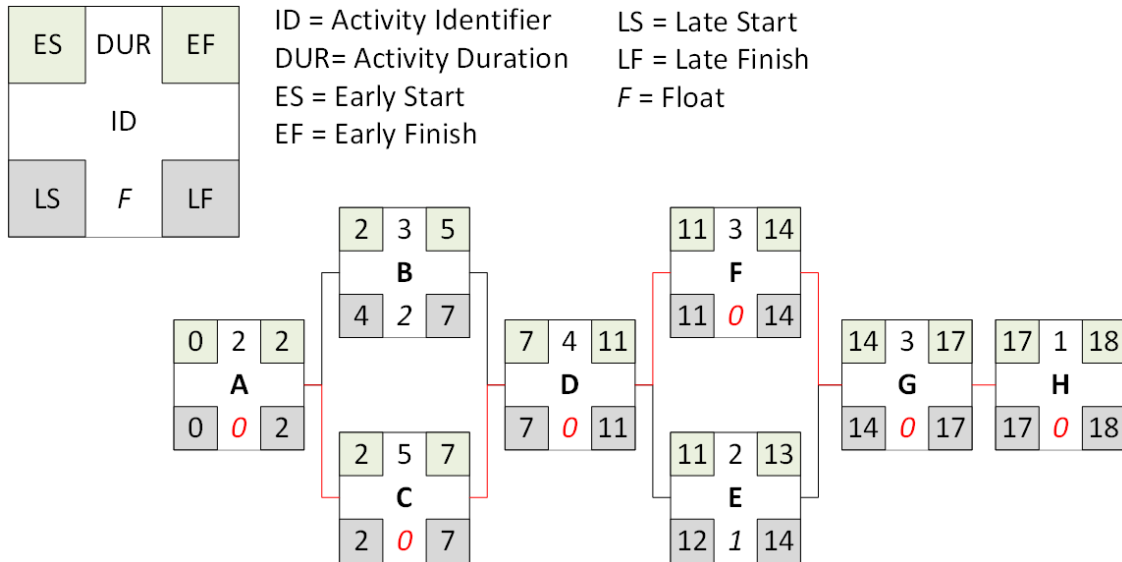


Figure 1 Pipe-installation example project CPM network

ID	Activity Description	Dur (weeks)	Pred.	Relationship	Month																			
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Start		0	-	-	◆																			
A	Mobilization	2	Start	-	■	■																		
B	Trench Excavation 1 (from STA 0+000 to STA 0+200)	3	A	FS			■	■	■															
C	Trench Excavation 2 (from STA 0+200 to STA 1+000)	5	A	FS			■	■	■	■	■													
D	Pipe Installation	4	B,C	FS					■	■	■	■												
E	Trench Backfill 1 (from STA 0+000 to STA 0+400)	2	D	FS								■	■											
F	Trench Backfill 2 (from STA 0+400 to STA 1+000)	3	D	FS								■	■	■										
G	Landscape	3	E,F	FS											■	■	■							
H	Demobilization	1	G	FS																	■			
Finish		0	8	-																		◆		

Figure 2 Pipe-installation example project Gantt Chart

The same project can be depicted using LSM, with the benefit that the location dimension can be graphically represented in the chart as illustrated in Figure 3. For example, Activity B in the hypothetical example comprises the trench excavation of 200 meters between Station 0+000 and Station 0+200. That information can only be provided in the activity description field in a Gantt Chart as illustrated in Figure 2, whereas the LSM shows it as an intrinsic parameter for the visualization of all the activities.

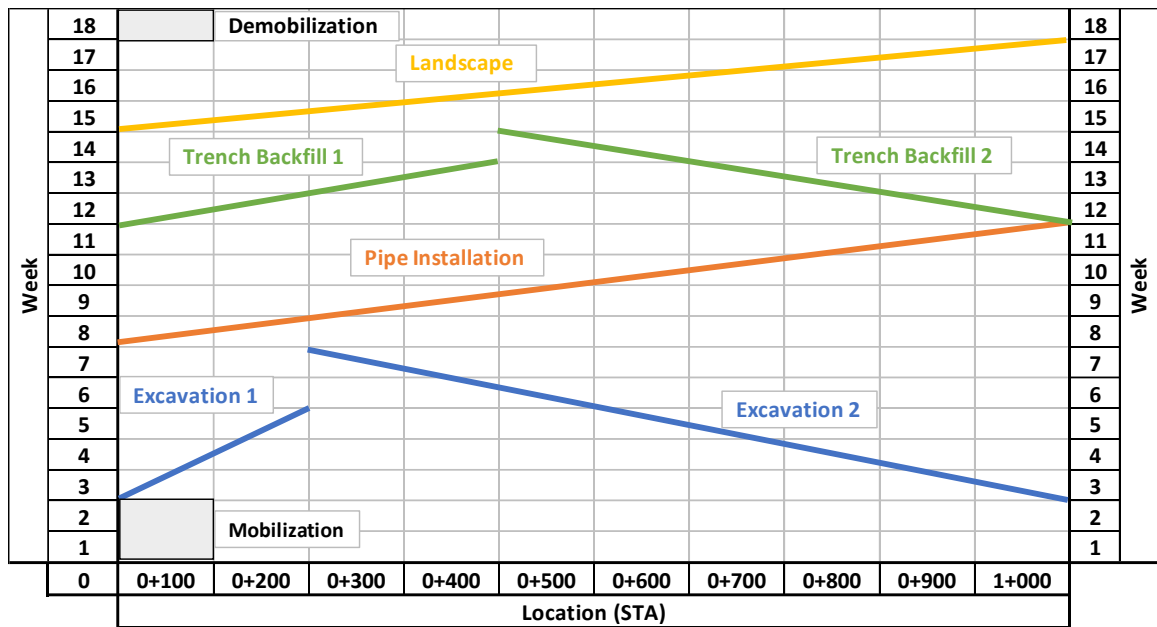


Figure 3 Pipe-installation example project LSM

CPM has proven to be a proper tool for managing construction schedules across the construction industry. However, it has some limitations when comparing varying production rates between activities identifying location conflicts with ease and ignores changes in productivities when analyzing concurrent delays (Harris and Ioannou, 1998).

The most significant strength of LSM over CPM is the visualization of the schedule and its ease of communication (Yamin and Harmelink, 2001). By being able to provide a better representation of production-rates and location of the activities, changes

in production can be predicted and analyzed (Duffy et al, 2011) and are more intuitive than in CPM. Additionally, location information can be directly related to the planning effort. LSM also has limitations in that it works ideally in projects that follow a linear path in order for the location information to be easily represented. However, there are studies where LSM has been applied to non-linear projects (Lopez del Puerto & Gransberg, 2008).

### **Schedule risk management**

Schedule risk analysis is typically performed using specialized software based on the format that the typical CPM tool displays, which is a WBS-structured Gantt chart (see illustration in Figure 2) that incorporates all the relationships and constraints required to sequence the job. Uncertainty is then incorporated into the schedule by establishing variation parameters in the project's activities using a stochastic method like Monte Carlo simulations that generates random iterations within a probability distribution function and produce a result tied to a confidence level (Ke and Liu, 2005; Cetin, 2016).

The result of this analysis is typically a function of the variation in the overall duration of the project due to the combined effect of the risks affecting all the susceptible activities in the complete schedule. These results are then tied to the source of variation by means of auxiliary tools like tornado graphs using several indexes that rank which risks and/or activities had the most impact in the overall variation of the project duration or which activities become part of the critical path more often.

### **Geotechnical risk allocation in design-build contracting**

DB contracting provides a particular opportunity for handling the geotechnical risk in that the design-builder is able to perform subsurface investigation and

accommodate actual site conditions in the design while it progresses with construction. The delivery method also presents some challenges when determining which party is responsible and accountable for the differing site conditions risk (Gransberg and Loulakis, 2011). There are two primary opposite and mutually exclusive positions in the literature regarding the allocation of the geotechnical risk in DB projects:

1) The Design-Builder is responsible for the design of the project as well as its construction. Therefore, some owners believe it is within the contractor's responsibilities to account for potential variations in the subsurface conditions when pricing the project (Christensen and Meeker 2002).

2) The project site belongs to the owner and the design-builder has no means to completely predict the subsurface conditions before submitting a price proposal. Therefore, the impact of unexpected conditions should be borne by the owner because some may contractors will not participate in projects if they face unlimited risk for differing site conditions (Loulakis et al., 1995).

The allocation of risks in a DB project revolves around the application and wording of the Differing Site Conditions Clause (DSC) and the amount and quality of the preliminary geotechnical studies provided in the bid package for proposers to base their bids. The DSC is a contractual provision that allows contractors to seek compensation in terms of cost and time for the occurrence of conditions on the site that are atypical in a construction project or materially differ from those indicated in the contract documents provided by the owner.

Variations in the way the DSC is worded and the type of information provided by the owner represent different perceptions towards the allocation of the geotechnical risks.



Auxiliary provisions, such as the incorporation of ATCs, the inclusion of a scope validation period in the contract or allowance of contractors to request additional borings in the pre-award phase among others, depict meeting-point attempts between the aforementioned mutually exclusive positions that will be explored in this dissertation.

### **Point of Departure**

The point of departure for this dissertation is to conceptualize a set of tools for effectively managing the geotechnical risk in heavy civil DB projects. Considering that the geotechnical risk impacts both time and cost, two main knowledge areas of project management are identified to have the capacity for focusing into and handling geotechnical risks: (1) project planning, scheduling, monitoring and control, and (2) owner's contracting and procurement practices. By providing a set of tools in those two areas that are specially tailored for managing the geotechnical risk, a framework can be created to potentially increase the effectiveness geotechnical risk mitigation.

Figure 1 shows a schematic representation of the concept around which this dissertation is prepared. The figure shows geotechnical risk as an input; the proposed set of tools for managing it as the process; and the overall goals of optimizing risk allocation, improve communication and increase efficiency of planning towards mitigating geotechnical risks as the output.

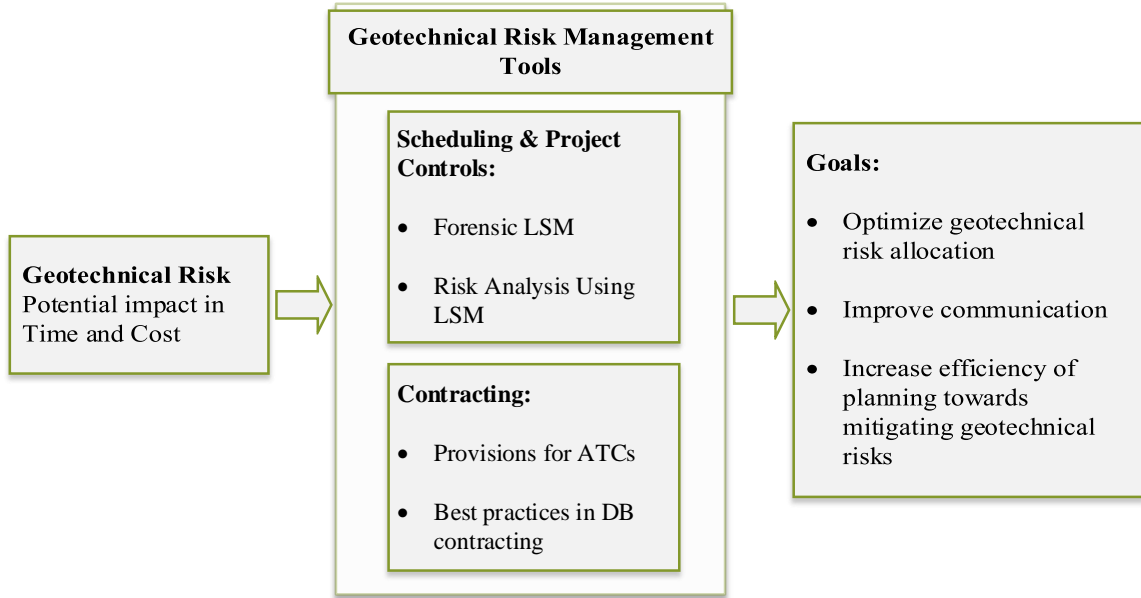


Figure 4 Schematic dissertation concept

### Research Questions and Dissertation Organization

In the scheduling and project controls area, the first approach is to explore LSM as a way to forensically represent actual events that occurred in a project from an objective source such as the project's daily work reports. By doing so, conclusions can then be drawn from the experience of past projects to better address the risk in the future. Additionally, this forensic analysis serves as an effective tool to demonstrate the occurrence of a differing site condition without subjectivity in an ongoing project. The second identified opportunity is the use of LSM to represent risks and take advantage of the location dimension of the chart by displaying the geological interpretation of the project site into the schedule. This way, the planning effort can be integrated more effectively with the management of the geotechnical risk by directly correlating sequence and duration of activities with the expected site conditions before actually starting work and later, during construction.

The following research questions are formulated from the scheduling perspective:

- a. How can the potential issues that lead to a geotechnical-related change orders or claims be effectively communicated?
- b. How can the geotechnical risk be more clearly and concisely represented and incorporating in the planning effort of a project?

In the contracting area, the first approach to mitigate the geotechnical risk is the inclusion of provisions for ATCs in order to obtain a form of early contractor involvement to take advantage of any state-of-the-art technologies that may be proposed. This approach is first explored in different project delivery methods to measure its effectiveness. The second approach in the contracting area is to explore the best practices in DB contracting to mitigate this risk. As every site and project is different and every organization has its own procurement culture, individual owners perceive the allocation of risks differently (Castro et al., 2017). Therefore, a set of tools will be described as a framework so the best fit can be determined on a case-by-case basis.

The following research questions are posed from the contracting perspective:

- c. What is the state of the practice regarding geotechnical risk management in DB projects?
- d. What provisions can an owner include in the bid documents to mitigate the effect of geotechnical risks in a project?

This dissertation consists of following four peer-reviewed papers:

1. “*Forensic Linear Scheduling for Delay Claim Analysis: 1 Panama Canal Borinquen Dam 1e Case Study*” was presented in a lectern session at the 2016

Transportation Research Board Annual Meeting and published in the *2016 Compendium*.

2. “*Alternative Technical Concepts: A Geotechnical Risk Management Tool*” was published in 2016 by the *Journal of Structural Integrity and Maintenance*.
3. “*Managing Scheduling Risk Due to Geotechnical Uncertainty Using Linear Scheduling*” was presented at the 2017 Transportation Research Board Annual Meeting and published in the *2017 Compendium*.
4. “*Case Studies in Managing Geotechnical Risks During Procurement for Design-Build Projects*” was submitted to the American Society of Civil Engineers’ *Journal of Construction Engineering and Management* in March 2017.

## CHAPTER II RESEARCH METHODOLOGY

This dissertation consists of four papers, each with its individual method and instruments for research. The summarized logic behind the methodology is depicted in Figure 5.

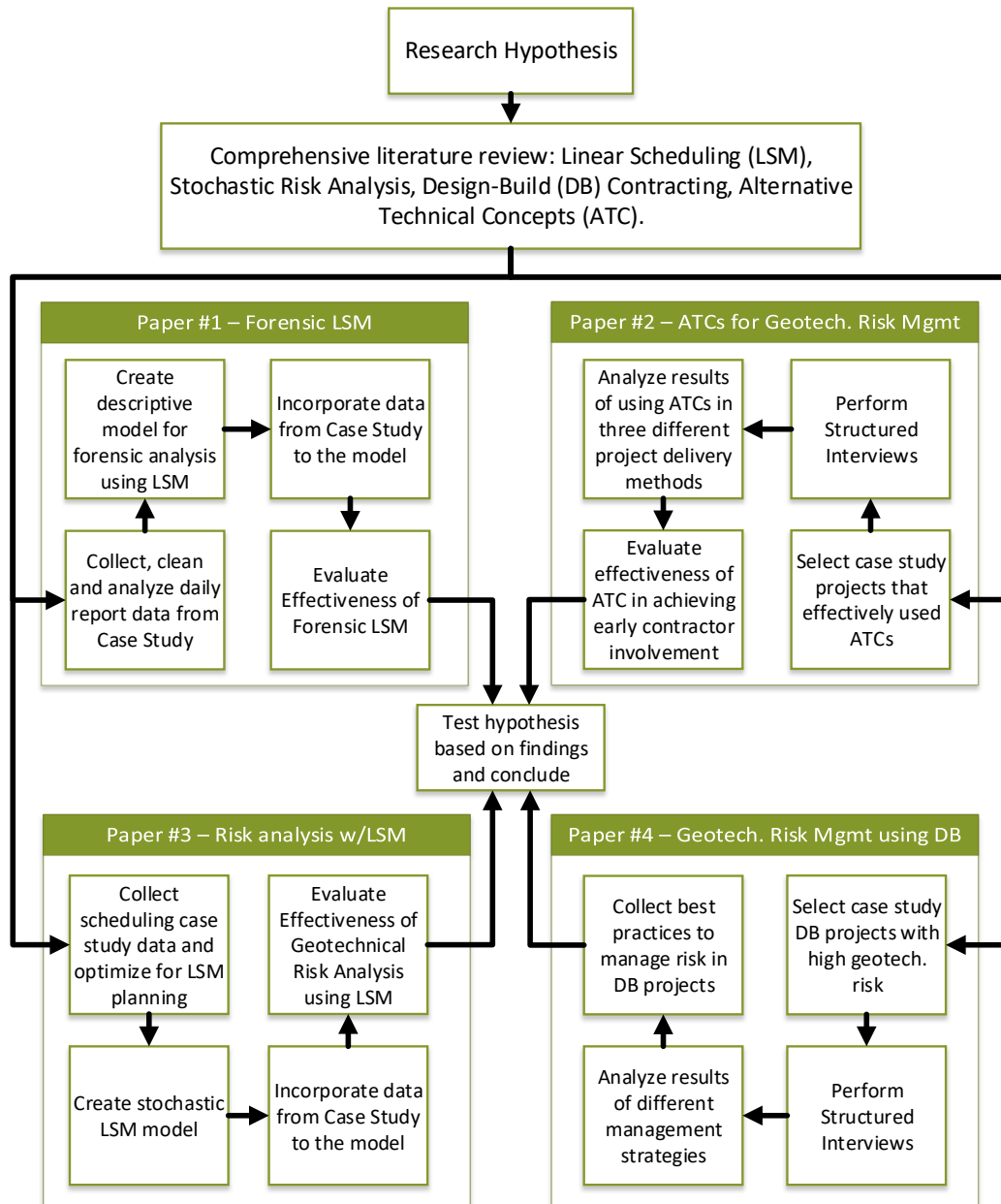


Figure 5 Overall research methodology.

In this section, the specific methodology followed for each paper will be explained in detail.

### **Paper #1 Research Methodology: Forensic Linear Scheduling for Delay Claim Analysis**

For this paper, and this research in general, a comprehensive literature review on the LSM tool was performed and the results were applied to a real project: the Borinquen 1E earthen dam that was part of the Panama Canal Expansion Program. The LSM tool was used to depict the actual production events that occurred in the project. The output was used to analyze the events that could lead to claims by plotting factual data from over 650 daily work reports. The literature review also confirmed that there is no previous study for this specific application of LSM.

In order to accurately represent everything that occurred in a day in a LSM format, the following attributes were required for all the activities performed:

- Date
- Activity name
- Start station
- Finish station

More than 3,000 data points were collected from the project's daily reports to accurately represent the activities that took place to construct the dam. Since collecting of this large amount of data from physical reports is prone to human error, the data had to be analyzed and cleaned to remove invalid or incomplete entries by plotting results and

comparing with expected behavior. Any data point missing one of the four attributes mentioned above was removed from the data set.

The model was built using Microsoft Excel in combination with a specialized linear scheduling software called Tilos® (Linear Project GmbH/Trimble, 2014), which provides the advantage of being able to automatically plot blocks as well as lines and has the LSM format built-in; however, this model can be constructed with any software that plots data in two axes. It is a simple matrix layout with location in the horizontal axis and time in the vertical axis; the units used for this model are stationing every 100 meters and months respectively. The format allows the analyst to add any supporting information in each of the axes to draw conclusions from the information in the chart, as long as the units of measurement match.

By incorporating all the data in the model in an organized, color-coded fashion, events, such as rainfall, quality control information, and geotechnical conditions, could be accurately represented in the model., The conclusions drawn from the model were then compared with actual events that occurred to validate the LSM model's output.

### **Paper #2 Research methodology: Alternative Technical Concepts: A Geotechnical Risk Management Tool**

The departure point for this paper is NCHRP Synthesis 429: *Geotechnical Information Practices in Design-Build Projects*, (Gransberg and Loulakis, 2011) which included a nation-wide content analysis of DB projects and NCHRP Synthesis 455: *Alternative Technical Concepts for Contract Delivery Methods* (Gransberg, et al. 2014) which explored the use of ATCs in different project delivery methods. Supplementary literature review was performed for this paper and three case studies were selected to

demonstrate the use of this provision in DB, design-bid-build (DBB) and construction manager/general contractor (CMGC) project delivery methods.

Using case studies as a research instrument in this paper is instrumental in capturing the uniqueness of the three project delivery methods and exploring the reasoning behind including geotechnical ATCs in each case. In order to collect the case study information, a structured protocol for interviewing project participants was used to ensure that the same information is collected with common points of comparison and ensuring repeatability for each separate interview. The interview questionnaires and protocol were sent to the interviewees ahead of the scheduled interviews to provide the opportunity for collecting supporting information. The collected information was then analyzed, summarized and used to depict the context and benefit of using ATCs in each of the mentioned project delivery methods.

### **Paper #3 Research Methodology: Managing Scheduling Risk Due to Geotechnical Uncertainty Using Linear Scheduling**

The point of departure for this paper was a comprehensive literature review on LSM on the specialized topic of previous applications of LSM to perform risk analysis and stochastic simulation methods. General schedule risk analysis practice information was also sought.

Data collection was performed from the baseline schedule and risk analysis parameters of the Panama Canal Expansion's Borinquen 1E Dam project to evaluate the geotechnical risk associated with the dam's construction. The collected data corresponds to a pressure grouted curtain in the foundation of the dam, and its subsequent impact on the next activity on the project's critical path, which was the construction of the



embankment core. Risk assessment information was also collected from studies performed by the Panama Canal Authority (ACP) and its consultants (URS, 2013) The analysis only included the specific geotechnical risks that were estimated to affect foundation works. The risk assessment data consisted of estimated probabilities and three-point estimating values for the impact of the risk. Additional data was collected from the dam project's contract documents to represent the geological interpretation of the site. The ACP team included this information in the LSM format and used it to correlate with the effect of realized risks to make decisions on the sequence of work and appropriate mitigation actions.

The dissertation research then took the ACP model as a foundation on which to construct stochastic simulations which represent each estimation in terms of values with confidence levels. Due to the relatively high number of series, the researcher then used Visual Basic for Applications® programming in Microsoft Excel® to develop the linear schedule chart using scatter plotting. The result depicts a spectrum of possible values tied to confidence levels ranging from 50% to 95% for each activity in the model.

After incorporating the case study data in the model, the geological profile of the dam foundation was included in the horizontal axis of the linear schedule in a simplified color-coded representation. This led to a more thorough analysis of re-assessing the overall sequence of the job to better accommodate the predicted variations in the estimated underground profile and serves as good indicator of the potential for differing site conditions impacting production.

**Paper #4 Research Methodology: Geotechnical Risk Management Strategies for Design-Build Contracting in Transportation Projects.**

The study presented in this paper relied on four different research instruments to assess the current practices in managing the geotechnical risk in DB projects. The first step was to perform a literature review of publications in the subject and a formal content analysis of 59 RFPs across 29 state departments of transportation (DOT) that procure projects using DB. While performing the RFP content analysis, a survey was conducted to collect general information from agencies and contractors across the US regarding practices for managing geotechnical risks in DB projects (Castro et al. 2017).

This paper focuses on case studies that were selected based on the results of the content analysis and the survey. Eleven (11) DB projects with high geotechnical risks were identified to obtain details of commonly observed practices and assess their effectiveness on a case-by-case basis. The case study methodology has proven to be effective in collecting, categorizing and analyzing emerging technologies and practices (Eisenhardt 1989). This research instrument is appropriate since it allows the in-depth analysis of a project with all of its details while providing an understanding behind the rationale followed by the agency when selecting a specific mechanism to manage the project-specific geotechnical risks.

The case study data collection is performed by means of structured interviews that follow a standard protocol to ensure replicability and the ability to compare the different cases. Following Yin's (2008) protocol on the case study research instrument, the interviews are performed in face-to-face meetings having sent the interview protocol ahead so the interviewees can prepare and collect supporting information. This tool has

been proven its robustness when emerging technologies or practices are being analyzed (Eisenhardt 1989). It allows the researcher to glean in-depth information to facilitate the understanding of the rationale behind the distinctive characteristics in a cross-case comparison (Yin 2008).

The completed case studies provide different practices regarding the management of the geotechnical risks will be detailed and put in context so their effectiveness can be assessed and conclusions can be drawn with respect to each tool's efficacy in providing a contractual base for managing the geotechnical risks in DB projects. Figure 3 shows the methodology process for this paper.

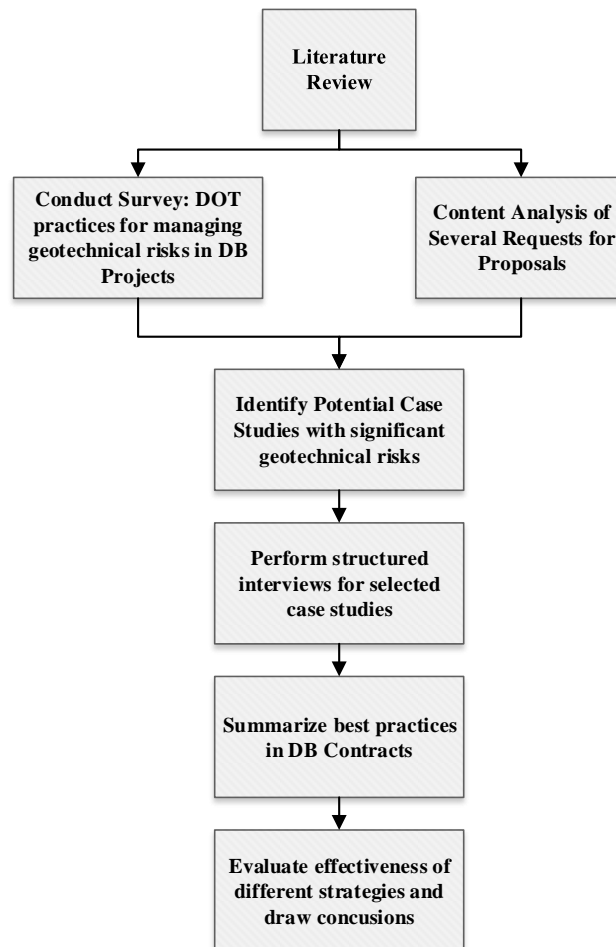


Figure 6 Paper 4 Methodology Flowchart

**CHAPTER III**  
**FORENSIC LINEAR SCHEDULING FOR DELAY CLAIM ANALYSIS:**  
**PANAMA CANAL BORINQUEN DAM 1E CASE STUDY**

**Tapia, R.M.** and D.D. Gransberg, “Forensic Linear Scheduling for Delay Claim Analysis: Panama Canal Borinquen Dam 1E Case Study”, *2016 Transportation Research Board Annual Meeting Compendium of Papers*, Paper 16-0557, National Academies, January 2016, Session 492, 15pp.

**Abstract**

Traditionally, linear scheduling is used as a visual representation of a construction schedule for projects that follow a linear production path with a large number of repetitive activities such as, roads, bridges, pipelines and dams. The linear schedule displays work sequence information similar to that on a critical path method schedule or Gantt chart in a way that is easier and more intuitive to interpret. This paper explores the potential for broadening the applications of this tool for critical decision-making analyses by displaying and correlating information that would be less apparent otherwise. A case study of the use of forensic linear scheduling to quantify delay is offered as an example of for the technique was applied on the Borinquen Dam 1E construction, a 5 million cubic meter (6.54 million cubic yards) earthfill dam constructed by the Panama Canal Authority, as part of the USD 5.2 billion Panama Canal Expansion Program. The case study demonstrates how as-built information can be introduced into a linear schedule for performing forensic claim analysis and support. Variables such as daily rain precipitation, geological conditions at foundation and unattended available areas to work are introduced forensically and clearly identified in a single linear schedule to graphically depict the

project's as-built schedule in a manner that supports the public agency's defense of a delay claim on the project.

### **Introduction**

Equipment-intensive heavy civil construction projects' schedules are by definition driven by production (Callahan et al 1992). Linear scheduling, (also termed a March Chart or Time-location Diagram) is an alternative tool for programming construction works by plotting activities in a graph that shows physical alignment (stationing) in the x-axis and time in the y-axis. This configuration for a construction schedule allows the scheduler to visually identify physical restrictions and production activity conflicts that might otherwise be lost in a traditional Critical Path Method (CPM) schedule or a Gantt Chart (Lopez and Gransberg 2008). Ensuring that one production crew does not physically interfere with or delay another production is key to achieving an on-time completion for the owner and the realization of the contractor's target profit margin on the job.

CPM has long been the accepted industry standard for construction scheduling. However, the CPM scheduling algorithm is activity/relationship based and necessarily assumes that the scheduler will ensure that there are no conflicts between activities in space through the precedence logic. Thus, CPM only uses production rates to calculate activity durations (Marchman 1997) and has no means to identify spatial conflicts on the project site. One author describes the issue as follows:

*“One of the disadvantages of network schedules and bar charts is their inability to distinguish rates of progress among individual activities. The number of units that can be completed in any one activity within any period is not apparent. LSM [linear*

*scheduling method], however, measures the number of units that will be completed within any period of the activity' duration. This form of a project schedule is practical in understanding the changes of productivity visually.” (Lee 2007)*

### **Linear Scheduling fundamentals**

The linear scheduling method graphically depicts both time and space in the same chart, allowing the scheduler to visually deconflict production activities on the project's spatial representation (Callahan et al 1992). Linear scheduling is production-based rather than activity-based like CPM. Although, some authors have proposed algorithms to determine the critical path of a linear schedule (Callahan et al 1992), the objective of linear scheduling is to maximize the production of all crews on a job by ensuring that one activity's production rate does not unintentionally control the production of another one. The result is a robust planning and work sequencing tool that has been used by many large US and international construction companies since the 1950's (Jones 2005). This is accomplished through the use of a graphical approach rather than the network diagramming approach used in CPM. The graph has two axes: time is on the “Y” axis and location is on the “X” axis. Thus, a linear schedule not only tracks the project in time, it also ensures that there are no conflicts between crews on the actual ground.

Figure 7 shows a typical representation of a linear schedule with activities as lines with patterns for identifying different activities or crews. The system utilizes two other symbols:

- A “block” to identify periods where production cannot proceed through the given location on the project site, such as the specified “no loads” time for curing freshly laid concrete shown in Figure 7.
- A “bar” to identify periods in which a single crew will occupy a specific location and interfere with production activities of other crews, such as the construction of culverts between stations 2+00 and 4+00 in Figure 7.

As will be demonstrated in the case study, additional information can be added to the chart to enhance ease of interpretation and to synthesize key factors in optimizing production. Typical examples are to insert the project’s plan and profile drawing below the X-axis or to build a histogram of material requirements to the side of the Y-axis.

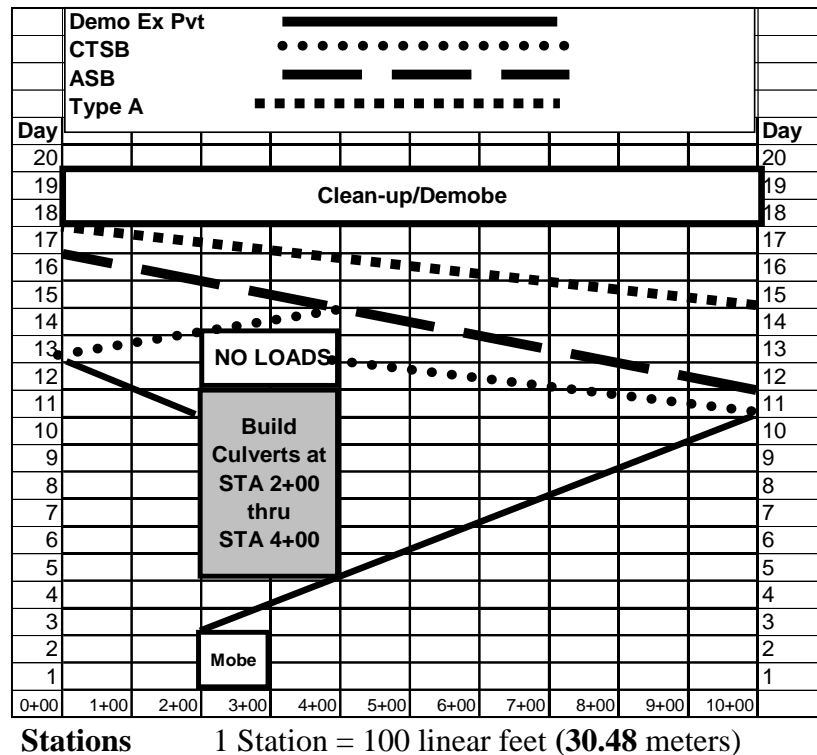


Figure 7 Linear schedule for example highway rehabilitation project (Lopez del Puerto and Gransberg 2008).

## Forensic Linear Scheduling

The linear scheduling concept is not new (Johnson 1981; Carr and Meyer 1974). According to Sarraj (1990) it was originally developed by the US Navy in the 1950s, which called it Line of Balance (LOB) and applied it to the production of large seagoing vessels. The method was adopted for production-based planning and scheduling of highway construction by US heavy civil contractors before critical path method (CPM) scheduling was developed in the 1960's (Harmelik 1995). It wasn't until the mid-1970's when computing moved from high cost mainframes to personal computers that CPM became ubiquitous throughout the world as the preferred construction scheduling tool (Weaver 2006). CPM has a number of limitations that must be recognized when used to conduct a forensic schedule analysis of concurrent delays. Lee (2007) maintains that "one of the disadvantages of network schedules and bar charts is their inability to distinguish rates of progress among individual activities... [Another] weakness in this approach is that it ignores the changed productivity of the activities in the process of identifying concurrent delays."

However, when considering forensic schedule analysis, simplicity is a key factor for determining which tool is more convenient and applicable to which purpose in a given case, especially in an ever-changing and fast-moving environment such as a construction project. "Linear schedules can communicate even the most complex construction schedules easily" (Yuksel and O'Connor 2000). Linear scheduling can provide enough flexibility to adapt to various applications and analyses in a construction project and is simple enough to be updated and interpreted quickly. More importantly, it is visual and



intuitive, an asset if the delay claim ends up in court to be decided by a jury of citizens with little or no understanding of construction scheduling (Lee 2007).

Because of the matrix-type layout of linear schedules, activities can be represented as various shapes and differentiated by colors or patterns which make the schedule easy to interpret. Also, an important advantage of this method is that information can be easily correlated with the graph's axes in a way that any information that either follows the alignment of the project (such as the ground profile for example) or that changes in time (such as stockpiled materials for a specific activity) can be incorporated into the same matrix as the graph itself. These two features expand the potential for this tool to provide correlation with the schedule for any information that can be imagined that meets the above criteria. Depending on the information that is displayed on the axes, the linear schedule can be adjusted to various purposes, such as forecasting and developing a construction schedule, tracking progress of the works, or forensic analysis either for analogic estimation or claim defense.

This paper explores the application of linear scheduling in forensic claim analysis efforts and shows how correlating information with the schedule in this way can make key factors and effects be clearly identified in a single graph and, therefore, decision making and strategy selection is facilitated.

### **Forensic Linear Scheduling for Claim Analysis: Borinquen Dam 1E Case Study**

Linear scheduling has several different uses when managing a construction project. One of the most useful applications of this tool -asides from pure scheduling- is claim analysis. That is because the history of the project can be easily represented and key events can be related to physical conditions in a single chart.

Since linear scheduling is best applied to projects that follow a linear path, and detailed analysis is needed for technically complex projects in order to resolve disputes, the Borinquen 1E dam at the Panama Canal Expansion Program is well suited for this application. The Borinquen 1E dam is part of the Pacific Access Channel Phase 4 (PAC-4) Project and is a 2.3 kilometer (km)(1.4 miles) long multi-zone rockfill dam with an impervious clay core that sits on a complex foundation, in terms of geological features and required treatments, which includes a 16 meter (m)(52.5 feet) deep grout curtain. This dam is the largest of the Panama Canal Expansion Program and it will hold the water for the approach channel to the new locks on the Pacific end of the Canal, therefore, it is an important project with lots stakeholders and technical difficulties that challenge the construction progress every day.

In a massive earthwork project of this nature built in the tropics, one can expect that a large number of disputes are going to occur due to site conditions and rainfall. NCHRP Synthesis 429 (Gransberg and Loulakis 2011) found that for all intents and purposes the owner will be held liable for differing site conditions issues. The same is true for unusually severe weather delays. Thus, given the high probability that a weather-sensitive geotechnical project will encounter circumstances that are not adequately described in the contract, it is particularly important that the owner and contractor agree on the as-bid schedule to furnish the baseline against all potential delays will be measured. Since the as-bid linear schedule memorializes the contractor's production assumptions in a graphical matter, it is ideal to be able to sort out complicated concurrent delays. In other words, if the contractor's as-built production is less than its as-bid

production, then at least a portion of a delay to due weather or site conditions is directly attributable to the contractor's concurrent production loss delay.

Thus, given the project's technical complexities, the party that has more objective data to support its position will most likely prevail. But just having the data is not enough. The data must be processed, analyzed, and represented in a simple and objective way in order to explain the conclusions drawn from it. This is key for getting the truth out in a claim analysis process. The factual data must be organized in a fashion that makes it apparent to the persons who have not been involved in the project but will ultimately decide the case. The old cliché that 'a picture is worth a thousand words' rings true for forensic linear schedule output. As compared to explaining the application of the "measured mile delay theory", it is easier to show a non-technical arbiter or judge that when one line does not extend from its as-bid starting point to its as-bid ending point that something has changed and that if the contractor was behind its planned production when the differing site condition or any other situation was encountered, assigning an exact proportion of the total delay to the contractor.

Model:

The analysis that this paper presents consists of using the actual data from every lift of clay placed on the Borinquen 1E dam's core in a given timeframe, and display it in a linear schedule format to see, in a single chart, how the construction was developed and to identify the reasons for delays. In order to identify those reasons, additional data is incorporated into the linear schedule, such as blanket material placement (a requirement that needs to be met in order to keep progressing on the clay core), foundation treatments,

monthly rain quantity data, issued non-compliance notices, instrumentation locations in the dam, and the foundation profile to see the topographic restrictions that apply. This approach is different than the typical linear scheduling technique, in that there is no production-driven lines in the graph, just actual data of work performed per day, which creates the opportunity for displaying and analyzing what actually happened during a determined period in a specified section of the project.

The Borinquen 1E Dam is under construction since May 2012 and has been subject to several disputes due to its complex nature, for issues related to: material management, dewatering, underground conditions at the foundation and embankment construction requirements. For the purpose of this paper, an analysis is made from the start of the embankment construction in July, 2013. Prior to that date, many preparation works were required to get the foundation of the dam suitable for embankment construction, and a significant section of the grout curtain that goes below the dam had to be completed. Some of the issues that will be analyzed come from those previous activities, but their effects are still apparent as the embankment construction develops.

The data used for the model consists of about 3,400 actual records of lifts placed on the Borinquen 1E dam core and blanket zones and foundation treatment sections finish dates, around 650 daily records of rainfall data (precipitation in millimeters) in the area, and topographic surveying of the dam foundation. The data is then plotted in a linear schedule format showing the x-axis as the alignment of the dam using 100 meters (m) units and the y-axis is time using monthly units ascending vertically, activities are represented as follows:

- Horizontal orange lines: core-zone lifts.
- Horizontal dark-grey lines: blanket-zone lifts.
- Green dots: foundation treatments such as shotcrete and final backfill concrete.
- Blue-grey rectangles: grout curtain activities in sections from start date to release date.
- The rainfall data is included as a scatter chart aligned with the time unit of the linear schedule (next to the y-axis).
- The topographic profile of the dam foundation aligned with the distance unit (next to the x-axis).

Figure 8 shows the typical cross section of the dam, with the zones selected for the linear schedule represented on their assigned color code, these activities are the ones that drove the critical path of the project. Figure 9 shows the complete case study linear schedule with the dam construction and foundation treatment data following the same color code.

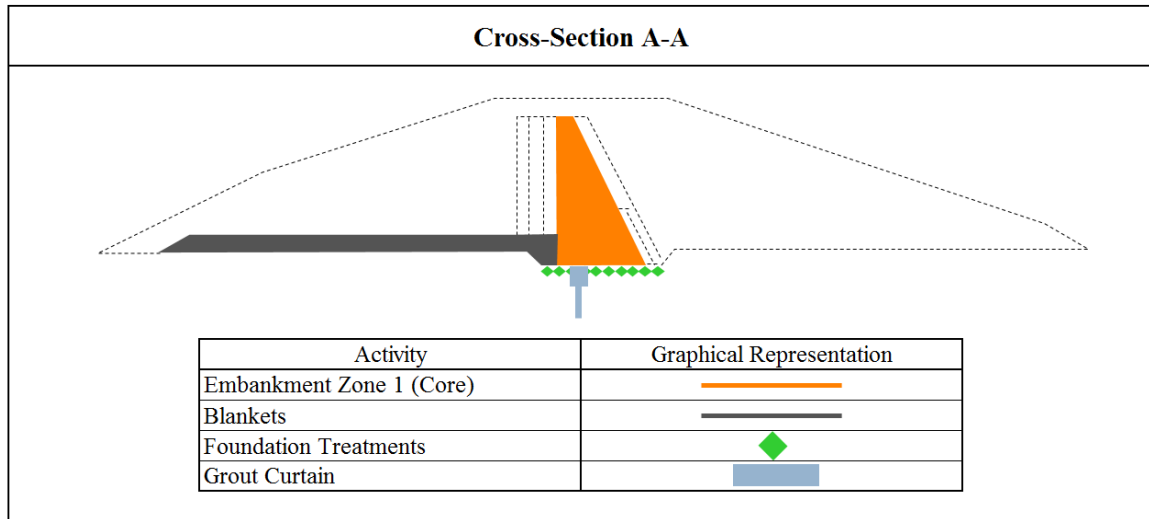


Figure 8 Cross Section A-A as shown in Figure 9 and the legend for reading the Linear Schedule

Analysis:

In this type of charts, especially for a forensic analysis, a rule of thumb is that if an activity is above another one in the same horizontal position, then the activity below is most probably a required predecessor of the one above. In this case, every activity that is represented in a different color or shape affects in some way the one above, so any gaps between different activities in the same horizontal location has to be explained somehow. That's the way to start identifying situations and delays that occurred during the execution of the project that are root causes for claims and for which one of the parties must have responsibility, except in cases of force majeure.

In order to facilitate the visualization of the different situations explained in this paper, Figure 9 is broken down in detailed insets for each analysis, including additional mark-ups and information.

Situation A:

The blue-gray rectangles in the linear schedule (Figure 9) represent the duration of grouting activities for the curtain in the dam foundation in a given section, from the first bore hole to the section release. It is evident that the construction of the grout curtain took exceptionally long to complete. This was one of the biggest issues in this project; the grout curtain that is specified below the dam is a pressure grouted curtain, which means the quantities required for completing this activity are dependent of the geological features of the site. After the construction of the grout curtain started, it was evident that the required work was significantly more than originally estimated due to the unfavorable geological conditions of the foundation, no one was able to accurately predict the required quantities for this activity. This is included in the chart to show that this activity with exceptional uncertainty was the driver for the start of the embankment construction in several sections.

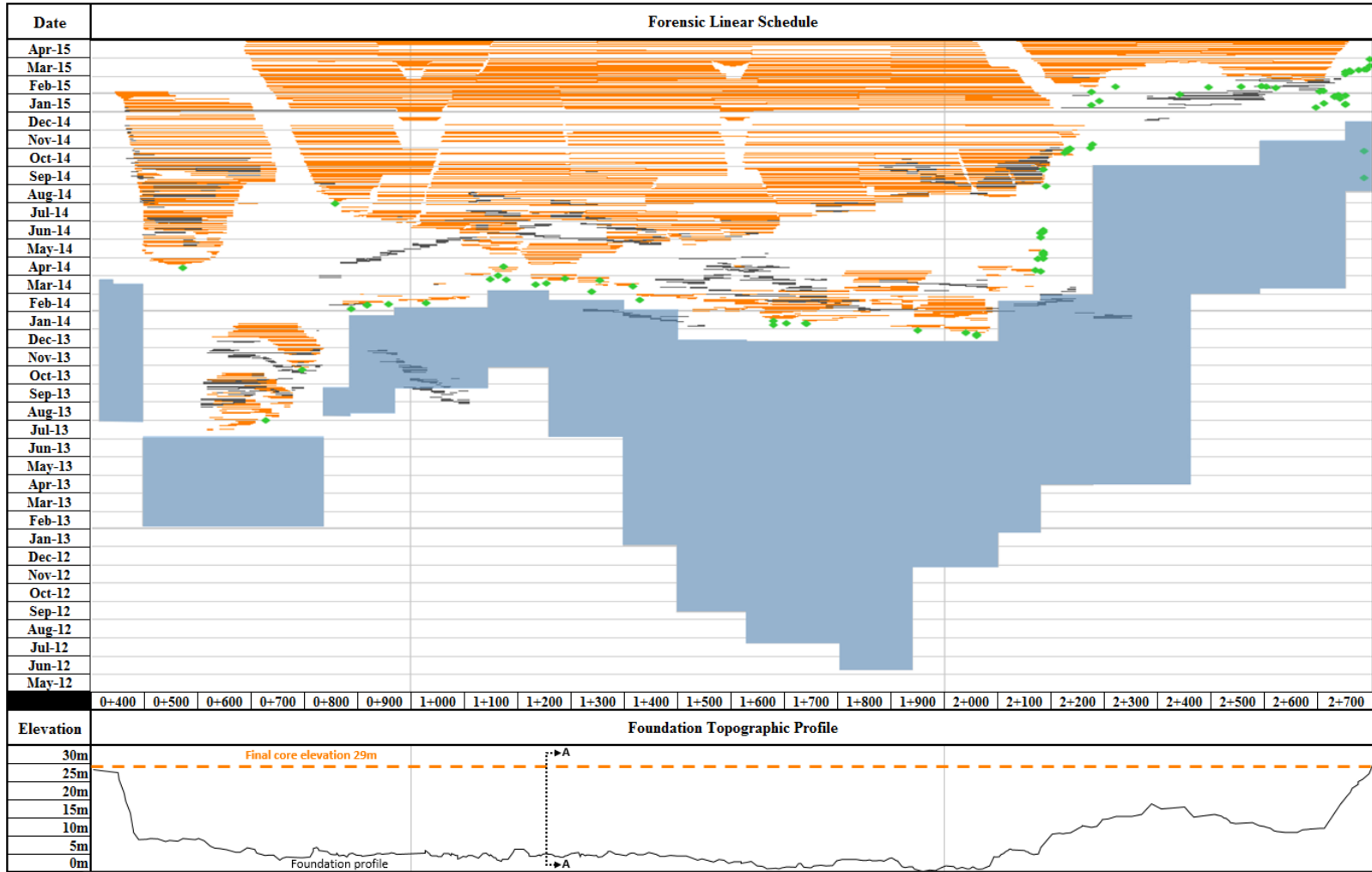


Figure 9 Forensic LSM Borinquen 1E Dam



The time difference marked-up as “ $\Delta t$ ” in Figure 10 shows the time required to start the first lift of the embankment (0+600), considering that the grouting started in another area (1+800) which took even more time to complete. By identifying these gaps in the linear schedule, it can be quickly determined specifically where this issue delayed the construction of the embankment, so this reason is not attributed to areas where the delay is caused by other factors.

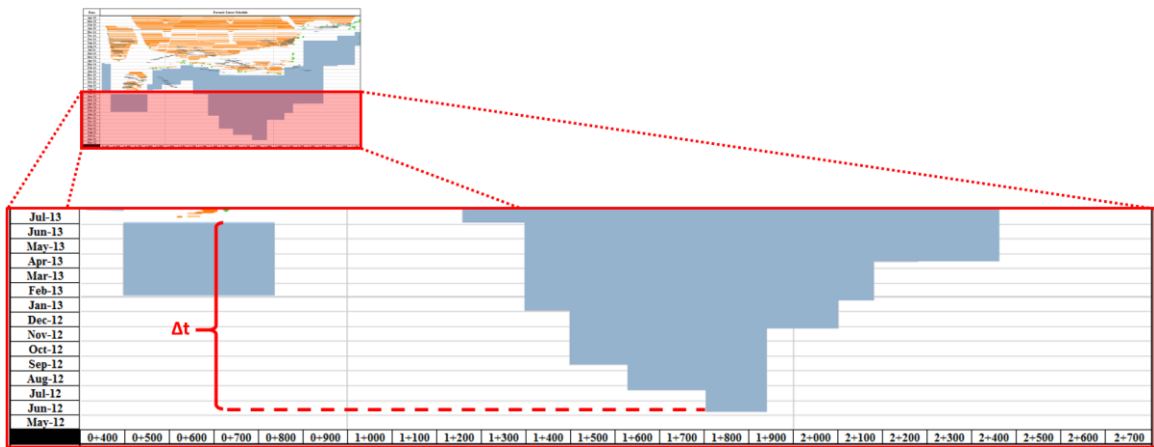


Figure 10 Situation A: grout curtain duration uncertainty (Figure 9 inset).

#### Situation B:

The embankment construction started restricted by the condition explained on Situation A and by topographic constraints since the embankment has to be built starting from the lowest points. Once these two constraints were surpassed, there was no reason for restricting production of core embankment placement (lifts shown as orange horizontal lines). However, the records show that the embankment lifts were being placed in a somewhat chaotic fashion. Figure 11 shows a comparison between two points in time when core lift placement was performed. It is evident that the lines representing

embankment lifts (core and blanket) do not follow a logical order to maximize production rates in the beginning of the embankment (Figure 11, first inset), as they do later on in the project (Figure 11, second inset).

The comparison between the way the embankment lifts were placed at the beginning of the dam and the way it was done further on is evidence that the applied means and methods were not optimal when the construction started. This situation represented a delay of several months attributable to bad planning and resource allocation not driven by production.

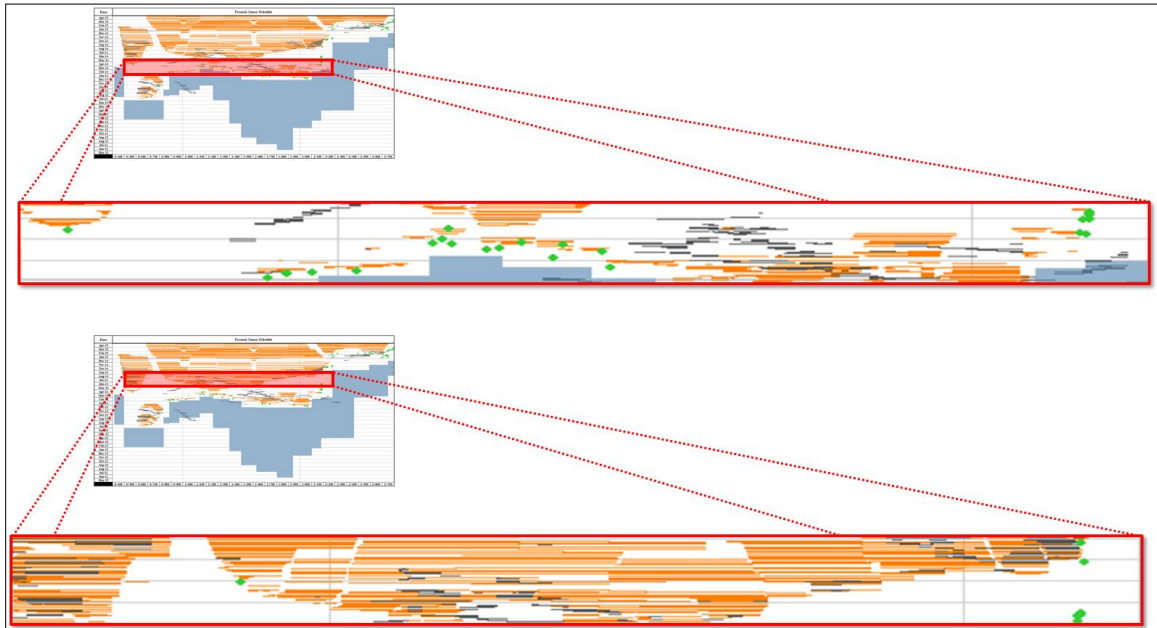


Figure 11 Situation B: Production-based lift placement sequence and resource allocation (Figure 9 insets)

#### Situation C:

Another example of planning-related issues is the gaps marked in yellow circles in Figure 12. These gaps occurred where instrumentation was required to be installed on

the dam according to the design. In a properly planned execution, the required instruments would be submitted, approved and purchased with an installation plan long before the time when the embankment construction reached the required level in which they were needed to be installed by design. The gaps in the chart show that this did not happen and lift placement production was delayed in some sections due to instrumentation-related issues. In conclusion, embankment placement production rates were held back and lift lengths were again not optimal due to a completely avoidable condition.

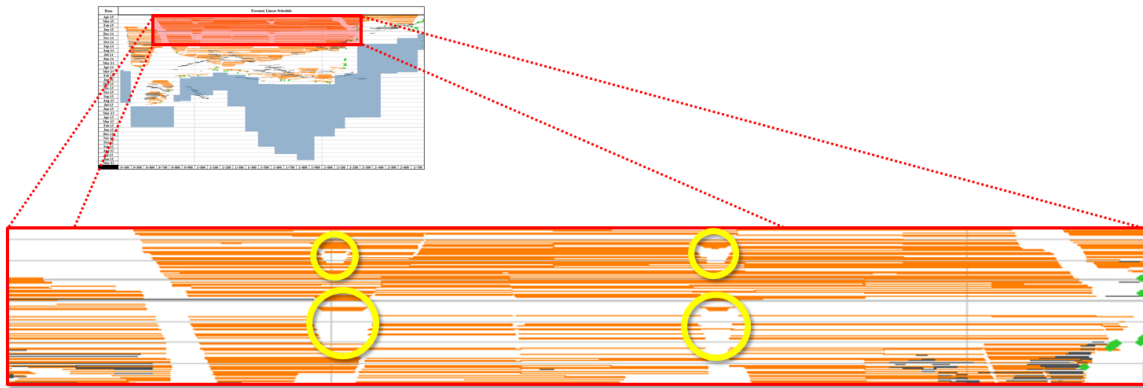


Figure 12 Situation C: Impact on production due to delays in instrumentation installation.

#### Situation D:

Due to its importance and complex technical requirements, this project has a robust quality management system required by contract. It consists of a detailed set of specifications, a quality control system by the contractor and a quality assurance system by the owner. Regarding the dam embankment construction, quality issues almost always means re-work. This is something that can also be assessed graphically in a linear schedule. By incorporating Non-Compliance Reports (NCR) issued by the owner into the

chart in their respective locations and time, the delays on the execution of the project related to quality issues can be represented. Figure 13 identifies these cases as red text indicating “NCR”.

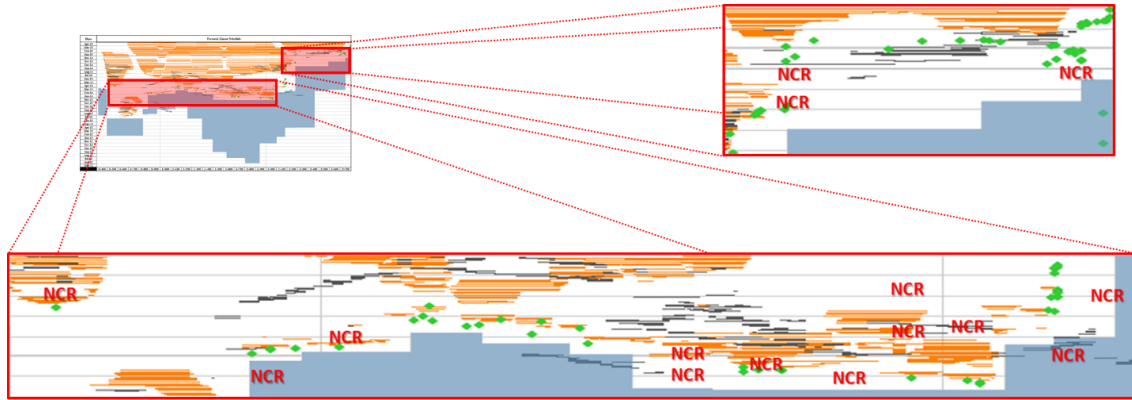


Figure 13 Non-Compliance Reports locations and dates, quality related issues that affect production.

#### Situation E:

Linear schedules can directly provide and correlate information in a way that certain influencing factors become more tangible and apparent. For this case study, two types of information are added to the schedule: rainfall data and monthly production rates for core embankment placement.

Panama has only about three (3) continuous months of dry season in average; the rest of the year is wet season. The Panama Canal area is especially rainy throughout the wet season and this imposes a challenge to any project that is exposed to the weather.

Water is a major issue for this project and is a well identified risk and a dewatering system was included in the scope of the contract in order to build the dam in a

dry environment since its foundation sits below the natural water table of the area. A specific line in the bid schedule was dedicated to this system. This activity was challenging and took effort even before the start of the dam's embankment construction.

Once the embankment construction started, rainfall became the main water-related issue since the dam requires specific humidity and compaction conditions for its core, so performance could be diminished due to the strict quality control that is required to meet the specifications.

A linear schedule helps to correlate the many impacts of heavy rainfall with the production rates of key activities if there is data collected in the same time intervals used on the chart. In this case study, daily records of precipitation in millimeters (mm) were collected as part of the Canal operations and the data was aligned with the monthly unit of the chart. The monthly rainfall data during the embankment construction is introduced in the linear schedule as relative horizontal blue bars attached to the vertical axis at the right. The highest raining month during the project was October 2013 with a summed precipitation of 113 millimeters (mm), and the lowest was 0 mm at the dry seasons, which is below the historical average of the past 25 years according to ACP's measurements. This way, it can be easily assessed whether or not the Contractor took advantage of the dry seasons and how much it was affected by different rain intensities.

Production rates in this type of project (earth movement) are easily measured; topographic surveys are performed every month for payment purposes and each individual zone of the dam is calculated. Besides from the visual representation of every lift placed on the dam's core, the linear schedule can incorporate data in a table format in

its y-axis to show monthly production rates. In this case study, the volumes are tabulated in cubic meters (m<sup>3</sup>) with a color coded background where low production rates are red, medium production rates are yellow and high production rates are green. The rates achieved throughout the duration of the project are shown in two different ways in the same chart, in other words, the entire linear schedule is an explanation of what happened in the project in order to achieve the monthly rates shown in the volume table.

Figure 14 shows how this data can be added to the linear schedule in a simple, yet effective, fashion.

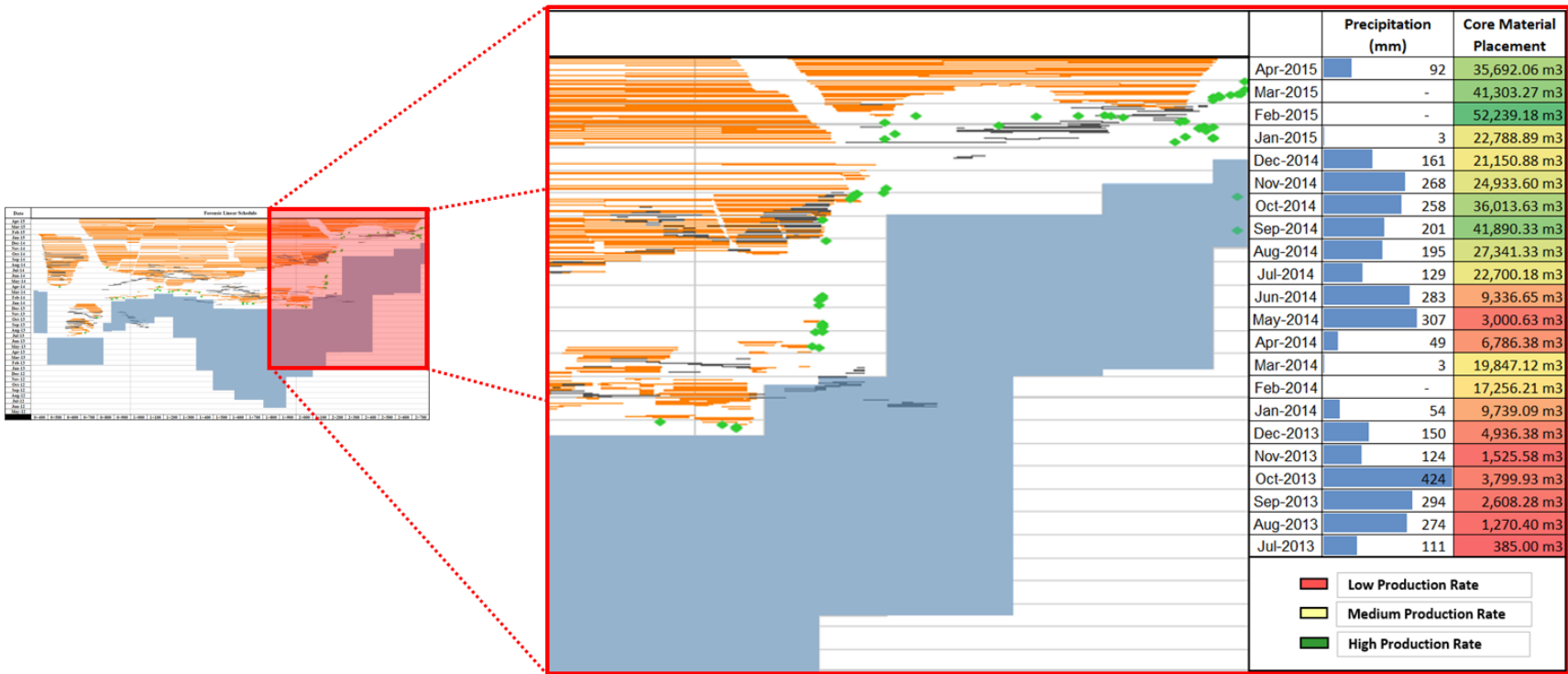


Figure 14 Situation E: Monthly rainfall and core placement production data added to the linear schedule.

### **Conclusion**

The case study shown in this paper illustrates how a linear schedule format can be used in non-traditional ways to provide accurate information for delay claim analysis. A tool like this can determine the way a claim is prepared or defended; using it can help to demonstrate a case more clearly by identifying what happened in a project and how events developed as they did.

The correlation of information is the biggest advantage of this method, as the effect of influencing factors in way the activities were performed is sometimes not apparent. Therefore, using this tool to represent those factors alongside the entire schedule can mean whether or not an effect is identified as such, which subsequently can determine the outcome of a dispute.

This method is a great communication tool for explaining how events developed in a complex project; in a way that it can be easily read by people not familiar with the details of the execution. This saves time and sends the message objectively, such an effective communication technique is a great advantage in any situation, especially for resolving a dispute or claim.



**CHAPTER IV**  
**ALTERNATIVE TECHNICAL CONCEPTS: A GEOTECHNICAL RISK**  
**MANAGEMENT TOOL**

Gransberg, D. D., & **Tapia Pereira, R. M.**, “Alternative technical concepts: a geotechnical risk management tool.” *Journal of Structural Integrity and Maintenance*, 1(1), pp. 43-49.

**Abstract**

The nature and unpredictability of geotechnical conditions on a construction project site is a major concern for designers and builders in almost every type of construction project. The risk of encountering conditions that differ from the information contained on the contract could potentially have very high impact on both the project’s cost and schedule. This makes the parties want to protect themselves from the consequences of the risk. For example, some owners approach the issue by increasing the extent of pre-award studies included in the contract, others include less and incorporate risk-transferring clauses in the contract, while most contractors allocate this uncertainty in their price as a contingency. These conventional solutions to the problem often result in creating friction between the parties that can lead to legal disputes and additional costs to the project. This paper proposes an additional solution that integrates the efforts between the owner and the contractor to achieve a common goal of effectively mitigating the risk of differing geological site conditions by means of implementing contractual provisions for Alternative Technical Concepts (ATCs) in the procurement phase of the project.

Keywords: Geotechnical uncertainty, risk management, alternative technical concepts, construction

## Introduction

Contractual allocation of geotechnical risk in a construction project has always been a challenge for owners. Many have major concerns over their liability for the accuracy of the information contained in procurement solicitations like design-bid-build (DBB) invitations for bids (IFB) or design-build (DB) requests for proposals (RFP) (Loulakis et al. 2015). In US construction contract law, the Spearin Doctrine establishes the principle that the owner provides an express warranty that the construction documents are free from error furnishing proposers the right to rely on the information to develop their bid (Spearin 1918). Therefore, any subsurface condition encountered during construction that materially differs what was provided in the solicitation is resolved using the standard set forth in the differing site conditions clause (DSC) which in most cases is settled in favor to the contractor.

One approach to mitigate this risk is to shift the liability to the contractor by incorporating clauses in the contract that minimize the possibility of a claim under the differing site conditions clause. These include clauses that specify a term for notice or require specific inspection to validate the condition. Owners will often attempt to mitigate their exposure to differing site conditions risk by incorporating language in the IFB or RFP that is meant to limit the extent to which contractor can rely on information provided during the bidding process. For instance, a clause indicating that the geotechnical information is included in the solicitation for reference only. However, this approach is not always effective. Gransberg and Loulakis (2011) came to the following conclusions after analyzing recent US case law representing the type of issues that are

raised and have the potential to bring down a case when an owner contests the existence of a differing site condition:

“ ...

- *The design-builder is entitled to rely on the geotechnical information contained in the DB RFP, and the DSC furnishes a mechanism under which the design-builder can claim additional costs and time if the RFP information does not reasonably match the actual conditions.*
- *To be successful in a DSC claim, the design-builder must rigorously adhere to the notice conditions contained in DSC clause.”*

The Washington State Department of Transportation’s (WSDOT) takes a different approach in regards of the liability towards geotechnical uncertainty for Design-Build projects by stating the following in their Guidebook for Design-Build Highway Project Development: “Ultimately, WSDOT will own responsibility for changed and differing site conditions” (WSDOT 2004).” Assuming responsibility for differing site conditions by the owner is the first step towards a collaborative solution that integrates the owner’s intent to minimize risk and the contractor’s practical expertise to develop an optimum solution that benefits both parties.

A previous study found that “allowing the constructor to be involved in the design from conceptualization” (Yates and Battersby 2007) was the most effective way to assure project constructability and promote high quality construction documents. Soliciting construction contractor design input can be attained by various means and is termed “early contractor involvement” (ECI) in the literature (Rueda-Benavides 2014;

Scheepbouwer and Humphries 2011; Gransberg 2013; Christensen and Meeker 2002). For instance, DB project delivery by definition involves the construction contractor in the design process by directly allocating that responsibility to the DB team. Allowing contractor value engineering change proposals is a post-award version of contractor design involvement commonly used in DBB and DB projects (Smith 2012). However, from the owner's perspective, contractor design input via value engineering is only applicable after the prime contract is awarded, and while DB provides an opportunity for contractor design input during procurement, the majority of the contractor involvement occurs after award during actual design, leaving the owner liable for the accuracy of the geotechnical information furnished in the RFP (Loulakis et al. 2015).

This paper posits a collaborative solution to address the risk of differing geotechnical site conditions through ECI via the employment of alternative technical concepts (ATC) in the procurement process of projects delivered using all potential delivery methods. The Federal Highway Administration (FHWA) defines an ATC as “a request by a proposer to modify a contract requirement, specifically for that proposer's use in gaining competitive benefit during the bidding or proposal process... [and] must provide a solution that is equal to or better than the owner's base design requirements in the invitation for bid (IFB for DBB) or request for proposal (RFP for DB) document.” (FHWA 2012). In February 2011, the Missouri Department of Transportation (MoDOT) explained, in a preproposal meeting for interested contractors, that the reason for including ATCs in the DBB project to replace the Hurricane Deck Bridge over the Lake of the Ozarks in the following equation that encapsulates the MoDOT approach to ECI: “BOLD Approach = Industry + MoDOT = One Team = Best Value” (MoDOT 2011)

### **Alternative Technical Concepts**

NCHRP Synthesis 455 found that ATCs can be used in all forms of project delivery and that they “provide a contractual mechanism ... to approach the agency with possible design solutions to complicated design issues and greatly reduce the risk that an innovative design approach would ultimately be disapproved after award of the DB [or DBB] contract” (Gransberg et al. 2014). The synthesis also found no existing case law specifically regarding the design liability for changes enacted by an ATC and as such, precedents set by non-ATC cases, such as Spearin, are presumed to govern the court’s interpretation of federal and state law in any future ATC-invoked disputes. Therefore, an agency seeking to use ATCs as a tool to address geotechnical risk would be prudent “to review prevailing confidentiality restrictions, legal framework and federal requirements, and then determine how to apply such restrictions and framework to a procurement using ATCs” (Gransberg et al. 2014).

Before investing the time and resources necessary to prepare a significant ATC, the contractor must trust that the ATC’s intellectual content will to be protected and more importantly, that the owner’s system for ensuring confidentiality can be relied on to keep its competitors from being given the benefit of the idea. “Confidentiality in the ATC process is very important for the success of the ATC process. Great care needs to be taken when exchanging files and emails” (Hitt 2012). The confidential one-on-one meetings associated with ATCs are an avenue for the contractor to get clarification of the solicitation document’s intent from the owner without revealing its ideas to one’s competition through the traditional request for information process. More importantly in the geotechnical risk context, these meetings also provide the owner an appraisal of just

how contract risks are perceived by the competing contractor. This insight could potentially lead the owner to make a change in project delivery method or to delay the procurement to provide time to conduct further subsurface investigations to avoid potential cost growth due to subsurface uncertainty.

The California and Minnesota DOTs also use confidential one-on-one meetings as a means to identify the need for further information to address the risks perceived by the competing design-builders but were not recognized during the RFP development process (MnDOT 2012; Trauner 2007). Virginia DOT also liberally uses the concept of proprietary meetings for its two-phase DB selection processes, with the expectation that proposers will, as they deem appropriate, identify any perceived gaps in the geotechnical data that may produce high potential contingencies if the gaps are not filled by further investigation or some risk-sharing scheme (Miller et al. 2000).

### **Geotechnical risk management**

In the Geotechnical Information Practices in Design-Build Projects synthesis, Gransberg and Loukakis (2011) performed a survey to benchmark the policies that US state departments of transportation (DOT) use in their DB contracts for managing geotechnical and other subsurface risk. Focusing on parameters such as contract geotechnical risk clauses, geotechnical performance warranties and specific geotechnical incentives, the survey findings depict how sensitive each of the studied states are to the geotechnical risks in their contracts. Table 2 summarizes the result of the aforementioned survey, marking with X the occurrence of a given category and the responses obtained from Yes/No questions.

Table 2 makes it is evident that each US DOT allocates geotechnical risk in its own way. On one end of the spectrum is the North Carolina DOT (NCDOT). In making the decision to deliver a project using DB, NCDOT includes an assessment of geotechnical investigation needs, as well as potential delays caused by the need to obtain permits to perform subsurface investigations. If the project is selected for DB delivery, NCDOT will then perform what it calls “prelet geotechnical investigations” and include the results in the RFP (Kim et al 2009). The NCDOT also conducts confidential one-on-one meetings with each short-listed firm to identify any gaps in the geotechnical information and to assess the need for further studies to mitigate the risk. Based on the outcome of those meetings, NCDOT may choose to perform the supplementary geotechnical investigations, which it then supplies to all competitors. The other end of the spectrum is the Kentucky DOT which appears to make no specific efforts to directly address geotechnical uncertainties during the procurement process.

After deciding to use ATCs as a risk management tool, the next step is to determine what geotechnical information will be contained in the solicitation. NCDOT reports that its “pre-let” investigations for DB projects cost from “0.18% to 1.15% of total contract price,” which is less than the typical “3% to 5% NCDOT spends on conventional [DBB] contract projects” (Kim et al 2009). The study also noted a “gap in the degree of conservatism or level of risk between the NCDOT in-house foundation design and the foundation design by some design–build teams,” indicating that the industry appeared to be willing to tolerate more geotechnical risk than the DOT. This further underscores the value of confidential one-on-one sessions as an opportunity to calibrate the perceived level of geotechnical risk by industry competitors.

Another approach to getting ECI during procurement is used by the Vermont Agency of Transportation and the Maine DOT, which issue a draft RFP to bidders on the short-list and solicit comments before finalizing the RFP (VTrans 2010b; Maine DOT 2003). Competing contractors are given an opportunity to point out those areas of the solicitation that need clarification and in the context of this paper, more geotechnical characterization information before preparing their proposals. Industry input during the procurement process serves to reduce contingencies for geotechnical risk. One contractor describes the effort as follows:

“[Owners] can reduce costs by ‘doing their homework’ and by utilizing proper partnering, flexibility, risk allocation, and processes.... Proper ‘homework’ preparation includes developing sound geotechnical and environmental data prior to the bid phase.... included hiring the best possible geotechnical and environmental firms to provide early, pre-bid data on the project” (Christensen and Meeker 2002).



Table 2 Summary of State Policies for the Geotechnical Aspects of Design-Build Projects (Gransberg and Loukakis, 2011).

DOT	Authorized Project Delivery Methods				DB Geote Manual	Est. GeotecU ncer-tainty?	GeotecRi sk Contract Clauses?	Score geot?	Part-nering req'd?	DB Contract Payment Provisions			Geotec War-ranty?	Geotec Incent-ives?	Contractor Perform-ance eval?	Use DB-significant geotech issues?
	DB B	CMG C	D B	Other						Lump sum	LS GMP	LS w/unit price				
Alabama	X			Toll roads - DB	No											
Alaska	X	X	X		No			No	Yes	X			No	No	No	No
Arkansas	X		X	DB proj> \$50M	No											No
California	X		X		No	No	No	No	Yes	X			No	No	No	Yes
Colorado	X	X	X		No	Yes	No	Yes	Yes	X	X		No	No	No	No
CT	X															No
Florida	X	X	X	P3		Yes	No	Yes	Yes	X	X	X	Yes	No	Yes	Yes
Idaho	X	X	X		No											
Illinois	X				No											No
Indiana	X		X		No	Yes	Yes	Yes	Yes	X			No	No	Yes	No
Iowa	X															No
Kansas	X			A+B	No											
Kentucky	X		X		No	No	No	No	No	X			No	No	No	No
Louisiana	X		X		No	No	No	Yes	Yes	X			No	No	No	Yes
Maine	X		X		No	No	No	Yes	Yes	X			Yes	No	No	Yes
Maryland	X		X		No	No	No	Yes	Yes	X			No	No	No	Yes
Massachusetts	X		X		No											Yes
Michigan	X	X	X		Yes	Yes	Yes	Yes	Yes			X	No	No	Yes	Yes
Minnesota	X		X		No	Yes	No	Yes	No	X			Yes	Yes	No	Yes
Mississippi	X		X		No	No	No	Yes	Yes	X			No	No	No	No

Table 2 (Continued): *Summary of State Policies for the Geotechnical Aspects of Design-Build Projects* (Gransberg and Loukakis, 2011).

DOT	Authorized Project Delivery Methods				DB Geote Manual	Est. GeotecU ncer-tainty?	GeotecRi sk Contract Clauses?	Score geotech?	Part-nering req'd?	DB Contract Payment Provisions			Geotec War-ranty?	Geotec Incen-tives?	Contractor Perform-ance eval?	Use DB-significant geotech issues?
	DB B	CMG C	D B	Other						Lump sum	LS GMP	LS w/unit price				
Missouri	X		X		No			Yes		X			No	No	No	No
Montana	X		X		No	Yes	No	Yes	No	X			No	No	No	Yes
Nebraska	X	X			Yes											No
Nevada	X		X		No	Yes	Yes	Yes	Yes				No	No	No	Yes
New Jersey	X		X		No			No		X			No			No
New Mexico	X		X		No	Yes	Yes	Yes	Yes	X			No		Yes	Yes
New Hampshire	X		X		Yes											No
North Carolina	X		X	P3	No	Yes	No	Yes	Yes	X			Yes	No	No	Yes
North Dakota	X		X		Yes	No	No	No	Yes	X			No	No	No	No
New York	X				Yes	Yes	Yes	No								No
Ohio	X		X			Yes	No	Yes		X			No	No		Yes
Oklahoma	X			A+B	No											
Oregon	X	X	X	A+B	Yes	Yes	No	Yes	Yes	X			No	No	Yes	No
South Carolina	X		X		No	No	No	No	Yes	X			Yes	No	Yes	Yes
South Dakota	X		X		No											No
Tennessee	X		X		Yes			No		X			No	No	No	No
Texas	X	X	X	P3	Yes	Yes	No	Yes	Yes	X			No	No	No	Yes
Utah	X	X	X		Yes	Yes	Yes	Yes	No	X			Yes	No	No	Yes
Vermont	X		X		No											Yes
Virginia	X		X	P3	Yes	Yes	No	Yes	Yes	X			No	No	Yes	Yes
Washington	X		X		No	Yes	Yes	Yes	Yes	X			Yes	No	No	Yes
Wyoming	X			Nego-tiated:< \$100K.												No

The president of a large national construction company maintains that there are only three ways to manage risk on a DB project. The first is “Make it go away by either throwing money [a contingency] at it or remove it from the project.” The second is “subcontract [the risk] out, and the third is “refuse to accept it” by not competing for the contract (French 2006).” Another consideration is that in DBB, “low-bid competition ... results in a [construction] contract where the contractor is basically out to protect themselves from losing money on the first day that they begin the project” (Bernstein et al. 2011).

Having the option of submitting ATCs allows the contractor to propose changing the design, which essentially “removes” unacceptable risk, replacing it with a more controllable risk, defined by the details of the proposed ATC. Plus, the need for including risk-centered contingencies is also reduced. NCHRP Synthesis 429, *Geotechnical Information Practices in Design-Build Projects*, confirmed French’s risk management rules in a series of contractor interviews. The study found:

“More than half of the contractors stated that they developed their [DB] proposals with the idea that they would not be able to use their preferred approaches to geotechnical design and construction either because of specific exclusion in the RFP or because they sensed that the owner’s personnel would not relinquish control of the process. The contractors’ remedy was to increase the proposal contingency accordingly” (Gransberg and Loulakis 2011).

### **Methodology**

Three case studies of projects delivered using ATCs to gain ECI are evaluated. They include the use of DBB, DB and construction manager/general contractor (CMGC) contracts as a means to gain substantive contractor input on materials, means, and methods during procurement. Civil engineering researchers often prefer quantitative to qualitative research methods (Flyvbjerg 2006), arguing that case study research is difficult to generalize due to the small sample sizes inherent to developing an in-depth understanding of the issue under research (Tellis 1997). However, this research instrument has proven to be a robust tool for collecting, categorizing and analyzing emerging business practices like ATCs (Eisenhart 1991). Case studies permit the researcher to answer questions about how things are done in detail and assist both the researcher and the reader grasp the rationale that was used to make key decisions in a given project. This is especially true when exploring more than one case study project (Yin 2008). Case study research was indispensable in this study to capture the unique natures of the three project delivery methods while understanding the rationale for using ATCs on each project as a geotechnical risk management tool. To accomplish this objective, the research team created a justifiable, repeatable methodology to govern the case study interview and data collection process. The methodology was formalized and recorded in the case study protocol for the project. The case study protocol conformed to the one detailed in Yin's (2008) book on the research instrument.

The protocol was founded on the field data collection process. The protocol procedures standardized the conduct all of the case studies and facilitated both consistent and comparable output for cross-case comparison. Structured interviews using a standard

case study questionnaire was the primary approach to data collection (DOE1997). Prior to each interview, the interviewees were sent the questionnaire. Since each case study used a different project delivery method, the interview process was designed to capture that uniqueness and produce standardized output. To that end, yes/no questions and matrices of checklists were used to the extent practical while allowing the opportunity for the interview to diverge as necessary to capture individual nuances for each case study. Field protocol also used a flowchart to control the order of key questions to enhance repeatability between interviews completed by different researchers. Table 3 provides the major details of the three projects analyzed in the paper.

Table 3 Selected case study project details

<b>Project name:</b>	<b>TH 61 Hastings Bridge Project</b>	<b>Tuttle Creek Dam Stabilization Project</b>	<b>New Mississippi River Bridge</b>
Owner:	Minnesota DOT (MnDOT)	US Army Corps of Engineers (USACE)	Missouri DOT (MoDOT)
Location:	Hastings, Minnesota	Manhattan, Kansas	St Louis, Missouri
Delivery Method:	DB	CMGC	DBB
Engineer's Estimate:	\$220 million	\$197 million	\$ 259 million
Awarded Amount (with ATCs):	\$120 million	\$122 million	\$229 million (main span) \$22 million (Missouri approach)

### **TH 61 Hastings Bridge Project**

The project consists of replacing a bridge where the foundation on one side had been plagued by severe differential settlement over its three decades of service. MnDOT felt a need to a solution different from its traditional approach project delivery based their

inability to permanently rectify past settlement issues by jacking up the bridge on three occasions for a total of nearly one meter. In that context, MnDOT incorporated two contractual figures to incentivize cooperation between the proposers and the agency. The first is what MnDOT calls “preapproved elements” (PAE) which are basically elements of the project whose specific requirements could not be defined in the DB RFP by the agency, and were left open for the DB to solve in their proposal, allowing MnDOT to work through complex issues with the DB teams before the bid during confidential one-on-one meetings. The second approach was to include ATCs to capture potential innovative design solutions that would not be responsive to the proposal design criteria without prior review and approval by MnDOT. The ATC process differs from PAE process in that PAEs must conform to the published criteria in the RFP and the ATCs were proposals to deviate from the original contract requirements to obtain a proposed solution that was equal to or better than approaches that conformed to the RFP criteria. Once accepted and approved, the ATCs are authorized to be included in the proposing contractor’s DB proposal in the same manner as PAEs.

Among the PAEs and ATCs proposed in this geotechnically complex DB project, was a proposed PAE to replace the conventional foundation design for the approach with the settlement issues with a previously untried design for a “column-supported embankment.” The same contractor also proposed an ATC to furnish and install instrumentation to permit the agency to monitor settlement over time as a part of a three-year warranty against settlement that was offered if the PAE was accepted by MnDOT. It should be noted that the RFP required the contractor to furnish a 60-day settlement

warranty for the conventional foundation. Interviews with the contractor indicated that the reason for adding the instrumentation was twofold:

1. The extended warranty was intended to demonstrate the contractor's confidence in the column-supported embankment and installing the instrumentation was a highly visible way to illustrate their level of confidence to MnDOT.
2. The instrumentation ensured that both parties were using the same settlement data, eliminating a future dispute about the accuracy of settlement measurements made by two different surveyors.

The two design changes proposed in this project vividly illustrate the notion that ECI can generate innovative design and construction solutions that were not conceived by either the owner or its design consultants. Neither MnDOT nor its consultant had ever heard of the column-supported embankment design and if the agency had not chosen to use ATCs, it would not have realized the cost savings shown in Table 3. It should be noted that not all the savings were not completely due to the change, but MnDOT believes that the approved PAE and ATC were responsible for roughly \$80 million of the \$100 million savings shown in Table 3.

One key factor for this success is that MnDOT provided the option for confidential, one-on-one meetings with each proposer to discuss any contractual or technical aspects related to a potential ATC. In doing so, it open the door to frank discussions of geotechnical risk as well as providing the proposers the confidence that proposing a better solution will result in a competitive edge. In the final analysis, the Hastings Bridge PAE/ATC process resulted in a highly sophisticated geotechnical risk, identification, mitigation, and retirement process. The instrumentation will permit

MnDOT to make direct measurements of settlement after the 3-year warranty has expired, providing a long-term capability to monitor and manage geotechnical risk on this complicated project. Thus, data on the long-term performance of the column-supported embankment will provide MnDOT the ability to quantitatively evaluate the concept for possible use in similar situations.

### **Tuttle Creek Dam Stabilization Project**

This project consisted on remediating the foundation of an earthen dam, which had the potential for liquefaction and was deemed likely to fail if subjected to a relatively minor seismic event. The project was the largest dam safety, ground modification project on an operational dam ever performed by the US Army Corps of Engineers (Trevicos 2010). The uniqueness of the geotechnical conditions, combined with its quasi-urgent nature demanded a solution that relied on developing new technology, which was not completely proven. Because the owner realized that addressing the geotechnical risks during construction was beyond both its in-house experience and capability, it needed the state-of-the-art construction means and methods for in situ soil stabilization and experience that only the contractors in the jet grouting industry could provide. Therefore, it selected CMGC project delivery with ATCs as its mechanism for attaining ECI. As an aside, the Corps actually calls its federal acquisition regulation-compliant version of CMGC: ECI.

The CMGC project delivery method was chosen because the owner's design staff believed that a highly-specialized technology would be required to accomplish the in situ soil stabilization on this large a scale and they believed they needed to remain open to all possible alternatives for as long as possible, permitting sufficient time to thoroughly



review potential technologies which the agency had no previous experience. It also wanted to maintain strict control of design details by completing the design using in-house design assets. Since CMGC allows the ATC review and approval period to start during procurement and be fully developed after the CMGC contract is awarded, the delivery method permits the level of flexibility necessary to test potential technologies on the project itself. The urgency required in this project demanded a contractual ability to literally try more than one technology before settling on the final choice via the awarding of early work packages to the contractor to conduct full-scale testing which provided the performance data necessary to make the final decision. All of the other traditional project delivery methods would require ATCs to be somehow approved before the bidding process is completed, making it impossible to account for technology that has yet to be tested to the scale and magnitude required for this project.

In this particular case, the contractor and the owner/designer literally ended up inventing a new variation of jet grouting and deep soil mixing technology. The early work package approach provided full-scale test sampling of both the constructed product and the means and methods needed to construct the feature of work. The outcome was a very robust, experimental approach to managing geotechnical risk which ultimately made it possible to finish the project two years ahead of the planned completion, accruing a savings of about 30% below the original estimate.

### **New Mississippi Bridge Project**

This project consisted on constructing a new, four lanes, long span, cable-stayed bridge across the Mississippi River at Saint Louis, Missouri, and it's a good example of how MoDOT's bold approach to project delivery utilizes the ATC process in DBB

projects. It is important to mention that MoDOT made a business decision to complete the design of approved ATCs as a way to avoid potential contractor design liability issues. Proposed ATCs were first evaluated as Conceptual ATCs using an expedited process that gave the contractor the necessary information as to whether or not the CATC could potentially be approved. If it passed this hurdle, the contractor prepared a detailed ATC proposal which was more carefully assessed and either approved for inclusion in the project or rejected. If approved, MoDOT's design consultant would advance the design to a point where biddable quantities could be calculated, and if that contractor won the project, the MoDOT design consultant would complete the redesign based on the successful ATC, seal it, and formally incorporate the change into the construction documents.

The MoDOT process begins with an industry outreach meeting that provides interested contractors with the details of how the process will operate followed a posting of the 30% plans in the MoDOT electronic plan room. In the New Mississippi River Bridge project, this took place a year in advance of the scheduled letting to give the contracting community time to generate and vet possible ideas for ATCs. A series of confidential one-on-one meetings were held at the request of interested contractors to discuss potential options and allow the contractor the chance to gauge whether or not MoDOT might possibly approve a given idea. In this case, early indication that the contractors were concerned about the potential for settlement of the friction-bearing drilled shafts on the Illinois side of the river was received, thus sensitizing MoDOT to the need to address geotechnical risk in more depth. Additional subsurface investigations were undertaken and the results were posted in the electronic plan room. The open dialog

with the industry achieved by making the project information available far in advance of the letting process led to an ATC which directly mitigated the perceived geotechnical risk by replacing the original fourteen 10-foot diameter side friction drilled shafts in the design to six 12-foot diameter side friction and end bearing designed drilled shafts. The foundation design change represented an approximate additional cost of \$73,000 of redesign costs to MoDOT, but generated at least \$7.5 million worth of savings. More importantly, the end-bearing drilled shafts greatly reduced the fear of settlement that would have required the contractor to restore to original dimensions under the 12-month construction warranty.

In summary, the three projects vividly demonstrate three possible approaches to managing specific geotechnical risk through the judicious use of ATCs. The Hastings Bridge ATC provided a technology transfer of the column-supported embankment from Illinois to Minnesota and reaped an enormous windfall in terms of cost savings in a major DB project. The Tuttle Creek Dam ATC literally developed new technology through a joint effort by the owner and its CMGC contractor, and finally the MoDOT bridge project demonstrated how ATCs can be used to directly address uncertainty of subsurface conditions in a DBB project. In comparison, the implementation of this type of solution in contracts without provisions for ATCs would have required post-award change orders that would have to be negotiated with a single contractor instead of taking advantage of the competitive environment inherent to the pre-award process. Without ATC provisions, solutions that furnish improvements in quality, schedule or cost might remain unknown to the owner.

### Conclusions

The use of ATCs in a construction project creates an environment of thoughtful collaboration which benefits both the owner and the contractor benefit and where the risks inherent to the project, such as the geotechnical risk, can be mitigated more effectively.

By implementing the ATC process in their contracts, the owners can make use of cutting edge technology and know-how from the industry and, as Smith (2012) stated: “Builders will lobby for ATCs, a result of the belief that their team will identify advantage through innovation.” from the contractor’s perspective, ATCs provide an effective risk management tool and an additional way to use state-of-the-art knowledge to create advantage in a competitive process.

The case studies analyzed in this paper serve as examples of the benefits of implementing ATCs in construction projects as a way to create ECI to mitigate complex geotechnical risks, regardless of the project delivery method. In the words of Jergeas and Van der Put 2001), “Benefits of enhanced constructability are achieved by implementing ...up-front (Early) involvement of construction personnel, use of construction-sensitive schedules, and use of designs that facilitate construction efficiency.”

**CHAPTER V**  
**MANAGING SCHEDULING RISK DUE TO GEOTECHNICAL UNCERTAINTY**  
**USING LINEAR SCHEDULING**

**Tapia, R.M.,** D.D. Gransberg and A. Touran, “Managing Scheduling Risk Due to Geotechnical Uncertainty Using Linear Scheduling”, *2017 Transportation Research Board Annual Meeting Compendium of Papers*, Paper 17-01389, National Academies, January 2017, Session 222, 13pp.

**Abstract**

Every project is most vulnerable to risk at its initial stages when the uncertainty and potential impact in its outcome is at its highest level, and the earliest risk in a construction project is typically the geotechnical risk. The risk of differing site conditions must be carefully analyzed using as much information as possible to develop a project’s initial estimates and schedule. This paper focuses on the scheduling aspect of geotechnical risk and proposes an alternative method for identifying and managing it. The alternative method is compared to the traditional format that involves expert interpretation of subsurface information in order to communicate the process properly. The alternative is based on linear scheduling that graphically represents a schedule along with the location of activities. A model was developed using this tool and incorporating stochastic simulations in a way that the impact of geotechnical risk is assessed as a function of the expected underground conditions, which can be displayed directly in the linear schedule. The paper demonstrates its efficacy by applying the linear scheduling model to a case study project from the Panama Canal Expansion Program. The analysis finds that the method effectively provides a better understanding of the risk management effort and introduces a way to incorporate variables into the assessment that otherwise

would not be available for quick reference, such as the interpretation of the geological profile of the project site. The paper's contribution to the body of knowledge is to graphically connect the project's geotechnical profile with the linear schedule in a stochastic environment.

### **Introduction**

Linear scheduling is an alternative production-based tool for managing schedules in projects that is particularly useful in the heavy civil construction industry. This method shows time and space in the same graph, in a way that makes it easy to identify and resolve conflicting production rates of the activities in their spatial representation (Lopez del Puerto and Gransberg, 2008). The graph consists of plotting time in the "Y" axis and location or distance in the "X" axis in any applicable unit represent activities as lines or blocks. Therefore, the duration, physical length and production rate of any activity can be quickly identified in the chart. The typical linear schedule format is shown in Figure 7 using lines with different patterns and blocks to identify activities and/or crews. This configuration provides an advantage over the more widely used Critical Path Method (CPM), which only displays production rates as a parameter inherent to the activity duration (Marchman, 1998). CPM has been shown to be inadequate as an accurate representation of production in the construction industry (Lee and Diekman, 2011) and does not show physical-spatial conflicts directly.

Schedule risks are modeled in the construction industry by incorporating uncertainty as a variance in the project's activities durations based on an educated analysis of the potential for an activity to exceed its planned duration. Durations are modeled as random variables and the project duration is then calculated analytically or

using a simulation approach. As an example of this stochastic approach, the Project Evaluation and Review Technique (PERT) assumes that the critical path is the path with the largest mean value. It should be noted that when uncertainty is incorporated into the project, this may not always be the case, as the critical path can change when impacted by risks (Nasir et al., 2003). The inherently abstract nature of the risk analysis effort makes it difficult for a person who was not involved in the process to actually comprehend the analysis and the impact of risks.

Linear scheduling is production-based rather than CPM's activity basis and as a result has been found to be practical for understanding the impact of changes in production rates (Lee, 2007). By quickly identifying production conflicts and representing a physical dimension in a single chart, it has the potential to show conflicts and critical path shifting that arise when risks are incorporated into a complex schedule. Therefore, representing risks in this format creates an opportunity for increasing the understanding and utilization of risk analysis efforts in the scheduling knowledge area of project management.

The concept of using linear scheduling for representing risks is applicable to any activity in a project that follows a linear path, for any given risk. For the purpose of this paper, and to better explain the benefits of having location information displayed graphically, the geotechnical risk will be assessed in a real case study baseline analysis. The impact of this risk correlates directly with the geological information included typically in construction contracts, which can be easily represented in a linear schedule to demonstrate the utility of having the location dimension available in the chart. This

creates the opportunity for a better risk allocation and impact assessment along with identifying potential mitigation actions or re-adjustments to the model.

## **Background**

Linear scheduling is not a new method, it has been used in the industry since the 1950's (Johnson, 1981) mainly for highway construction by heavy civil contractors in the United States (Harmelink, 1995) and, at its beginnings, it was also called the Line of Balance Method (Arditi and Albulak, 1986). Once computing systems became widely available, this method was replaced by the CPM solutions that are the mostly common used tools today, mainly because linear scheduling was considered a manual method against its high-speed computational rivals. Despite the ubiquitous use of CPM, it has some limitations when it comes to comparing production rates between activities. CPM also ignores changes in productivities when analyzing concurrent delays (Lee, 2007) and cannot ensure continuous resource utilization easily (Harris and Ioannou, 1998). This makes it difficult to integrate the CPM scheduling tools with the risk analysis effort in order to communicate the impact of risks effectively.

Schedule risk analysis is typically performed starting from the format that a CPM tool displays, which is basically a table organized by the Work Breakdown Structure of the project accompanied by a bar chart or Gantt Chart. Maintaining the structure of the schedule with all its constraints and relationships and incorporating probability distribution functions into the activities durations using a stochastic model (Ke and Liu, 2005). This process is done either integrated in the CPM scheduling tool or imported into a stand-alone package. Although the stochastic model maintains and uses all the parameters of the schedule, the results are typically shown in a separate graphical



representation, such as tornado graphs or displaying the resulting probability distribution function for the overall project duration.

This way to show the results is adequate in most cases but it requires knowledge of the process and is not intuitive to a person that is not familiar with the details of the project or the risk analysis effort, which is typically the case for the stakeholders that may be the ones to approve any required mitigation action. Therefore, communication of the risk analysis results must be as clear as possible without relying too much in the detailed technical and mathematical aspects of the effort.

The most significant strength of linear scheduling over CPM is the visualization of the schedule and its ease of communication (Yamín and Harmelink, 2001). Therefore, by being able to better represent production and location of activities, linear scheduling provides an advantage over CPM in analyzing and communicating changes in production, which makes it possible to represent the impact of the risks in the same chart where the schedule is, so the effects of the analysis are depicted immediately, and solutions that potentially would not be apparent in the conventional method could be identified.

Several studies have been performed in the past to automate the process and incorporate uncertainty in linear scheduling. Harmelink (Harmelink, 1995) developed a model to create a linear schedule based on CAD software which also determines the controlling path of a linear schedule (Harmelink and Rowings, 1998). El-Sayegh (El-Sayegh, 1998) created deterministic and probabilistic estimates to produce a linear schedule. Also, linear scheduling has been used to create models for predicting changes in production rates due to time and the location dimension of a project (Duffy et al.,

2011). These studies provide a foundation for further development of the method, including this research.

### **Methodology**

The analysis that this paper presents consists of using linear scheduling to provide a more intuitive risk assessment tool than the traditional outputs from stochastic simulations such as tornado graphs or probability/cumulative density functions. Based on the same fundamental calculations as traditional risk modeling techniques, a new risk assessment model is proposed by incorporating a different visualization scheme in order to make it easier for stakeholders to assess and understand the risks and their impacts in a project schedule. The model is created to illustrate how a stochastic analysis of the individual activities durations can be represented in a linear scheduling format. This creates the opportunity to identify physical and logical conflicts arising from the impact of risks in the schedule in a visual manner, which helps in understanding the effect of risks in the project schedule more intuitively.

The risk analysis is first performed using Monte Carlo simulations to incorporate uncertainty into the duration of the project activities (Khedr, 2006). In order to achieve that, every risk identified in the project must be quantified in terms of its impact in the duration of the activities that are going to be impacted. Since the analysis is based on a Monte Carlo simulation, a probability distribution function is assigned to the impact of the risks, which are multiplied by their probability in order to obtain the expected value in terms of duration. The impacted activity duration is then represented in a linear schedule format as additional lines with a different shade or color than the original duration.

In that scheme, the impacted duration can be depicted as several lines representing different confidence intervals for the risk impact. This creates the advantage of not only representing the impact of a risk in the schedule itself, but to represent a sensitivity analysis for the different confidence intervals that can be selected for specific risks. A decision maker could prefer to assume more risk by choosing a lower confidence interval if a conflict is identified, giving the opportunity to have a tangible justification for choosing a confidence interval in the risk assessment process. This degree of confidence is important for establishing a project's schedule contingency (Mulholland and Christian, 1999).

By identifying the activities that create additional logical or physical conflicts with their successors due to the impact of risks, mitigation actions can be tailored to specific activities or locations in the project based on supporting information that can be introduced in a linear schedule format. However, the stochastic simulation of risks in a project must be performed by combining the effects of risks in all the activities in the schedule at the same time to produce an overall impact to the completion date. This method does not intend to replace that effort, but provides an additional tool for deciding the parameters used to model risks in specific locations or time in a project schedule.

It is important to note that, due to the nature and underlying assumptions of linear scheduling, this method works best for risks that impact the production rates of activities; and that impact is assumed to be linear along the physical length of the activity. Risk events can also be included in the analysis but there is no additional benefit from using this method when risks are events not related to changes in production rates (Higbee, 2004).

Having the model built, a validation process is performed with an actual project as a case study to demonstrate the linear schedule representation of the project risks and their impact on the project schedule. The overall results are expected to be the same, but the representation of the output will be evaluated as a communication tool for understanding the impact of risks in each specific activity and to identify any immediate logical or physical conflicts due to risks -if any- that could be easily avoided if identified.

### **Linear Scheduling Risk Representation Model**

In order to represent risks in the linear scheduling format, a spreadsheet was built using commercial software. The impact of the risks and their probabilities are tied to specific activities in the schedule. The impact values of the risks are modeled within the spreadsheet using Monte Carlo simulation software to create a stochastic simulation. In order to simulate the uncertainty, more than one value must be entered in the model in order to represent the behavior of the risks either historically or within estimated ranges from a subject matter expert.

For the purpose of illustrating the process, three-point estimation from subject matter experts was assumed to be the input and Optimistic, Pessimistic, and Most Likely values are obtained (Craigie and Gransberg, 2016). Another assumption is that a triangular distribution function will be used to model the variation. This distribution function is deemed appropriate to represent the skewness in the perception of the risks (Pittenger et al., 2012). Regardless of these assumptions, the methodology can work with any distribution function that better represents the behavior of the source of information.

Having all the information of the risk impact and the stochastic model run to a proper number of iterations to fit the function, the activities of the schedule are then

represented in a scatter chart. In order to compare the impact of risks with the original schedule, the activities are plotted using both their original durations, represented as black lines, and their impacted durations at different levels of confidence, represented as colored lines.

### *Hypothetical example*

A hypothetical project has six sequential activities both in time and location, all with the same duration of 10 days and length of 200 meters. Additionally, assume that all of them are affected independently by a risk with a 50% probability of occurrence and the following estimated impacts in time: Minimum Impact = 5 days; Maximum Impact = 20 days; and Most Likely Impact = 10 days. These values are then introduced in the model as input for a triangular probability distribution function. If the desired levels of confidence in the linear schedule are 50%, 60%, 70%, 80%, 85%, 90%, 95%; the risk impact will be represented as a spectrum of lines next to each activity corresponding to each of the levels of confidence. The effect of risks on each activity is modeled independently from the cumulative impact carried from its predecessor, i.e., the original start dates of the analyzed activities are maintained. This intends to show how the risk impacts each activity in the original schedule to provide insight on how the activity impacts its location-based successor. The result of this hypothetical model is the chart depicted in Figure 15.

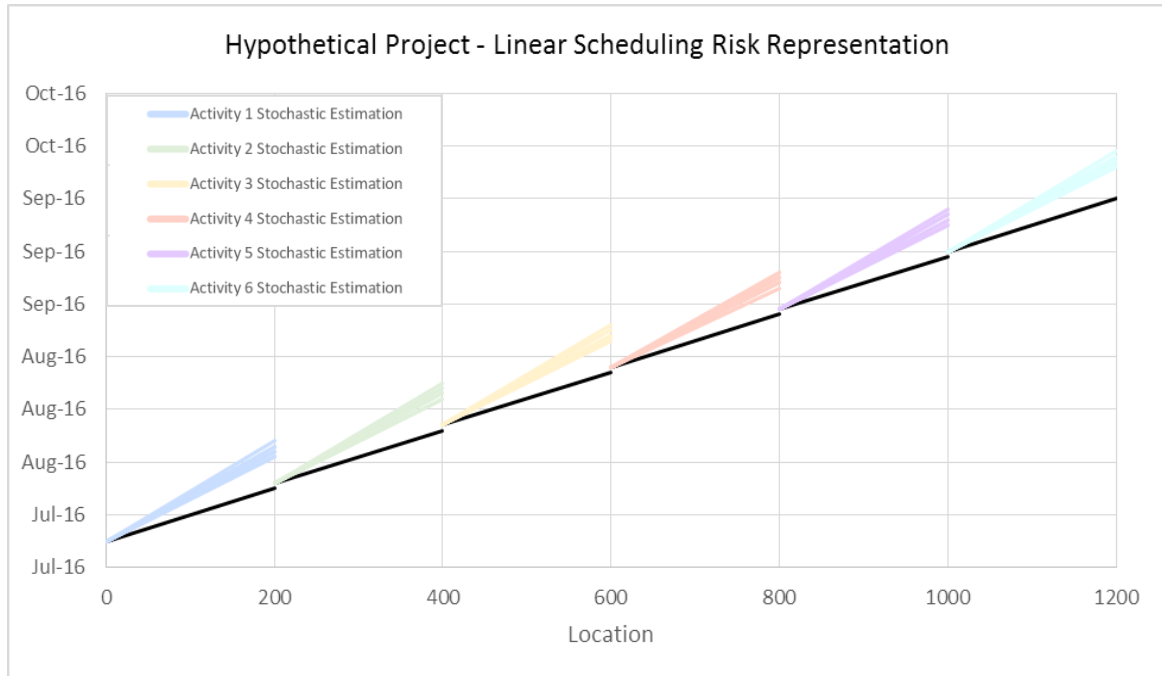


Figure 15 Hypothetical Linear Schedule with risk representation

The hypothetical example serves a way to illustrate how the risks are represented in the proposed format, but it's not intended to be an illustration of a real construction schedule. In a real construction schedule in which linear scheduling is useful, additional activities will most likely occur in the same locations (or with different physical lengths) but in different time, with dependencies established by a sequence of logic, making a tool like the one proposed in this paper useful by increasing the understanding of how the risk in one activity impacts the possible start of a subsequent activity.

If a subsequent additional activity is expected to be performed at the same space and time as the one where the spectrum of risk impacts is represented in the chart, a conflict between the two activities will occur if the risk is realized. If conflicts occur due to the risks, several actions can be taken to mitigate or avoid its impact, some of them are detailed as follows:

1. Increase production by assigning more resources to the high-risk activity, thus reducing its duration to accommodate for the potential impact of realizing the risk.
2. Modify the logic of the schedule to avoid the risk impacting the critical path of the project.
3. Allocate float, if any, to the activity with potential occurrence of a risk-induced conflict.
4. Analyze the model's sensitivity to confidence interval selected for the risk simulation.

In order to assess the effectiveness of any of the above mitigation actions, supporting information regarding the project schedule structure and those conditions that might influence the activities is required. For most risks, linear scheduling provides a way to display such information in the same chart, promoting expeditious decision making, as well as providing a visual explanation of potential risk impacts.

*Panama Canal's Borinquen Dam example.*

The following section will illustrate the proposed model with an example from an actual project, the Borinquen Dam at the Panama Canal Expansion program. This project had extensive risk analysis during its execution and the schedule has been studied by the authors to make reasonable assumptions to simplify the model to fit the TRB paper limitations. It is also important to note that the primary author was the cost and schedule control engineer for the Panama Canal Authority during the construction project. Thus, the simplifying assumptions are made from in-depth knowledge of the project. The Borinquen Dam is part of the \$5.3 billion Panama Canal Expansion Program. It is a 2.3-

kilometer long rockfill dam with a residual soil impervious core and several zones for filters and blankets. It features extensive foundation treatment works and a 16-meter deep grout curtain. The project has been recently completed and it has been subject to a number of changes due to the occurrence of identified risks. The Panama Canal Authority performed monthly risk assessments of this project during its entire life time and continuous monitoring was enforced in order to take mitigation actions as soon as it was possible.

For the purposes of this paper, the geotechnical risk is analyzed by incorporating the stochastic simulation of the duration uncertainty associated with geotechnical-related risks identified in the project's risk register on the baseline schedule in a linear scheduling format (Kim et al, 2009). Additionally, the interpretation of subsurface investigation included in the contract documents is incorporated into the chart at the "x" axis to provide a reference for further assessment of the risk impact and mitigation actions. The interpretation is presented in a color code format that derives from the geological profile in the dam's foundation alignment, where the color red represents 'severe conditions', yellow represents 'adverse conditions', and 'good conditions' are represented by the color green. This interpretation was performed by Canal Authority experts of the initial subsurface conditions. As this is a planning tool, it is based on preliminary studies, acts as a baseline for all the activity duration estimates. A segment from the geological profile of the project and the superimposed color code is shown on Figure 16 as a conceptual illustration:



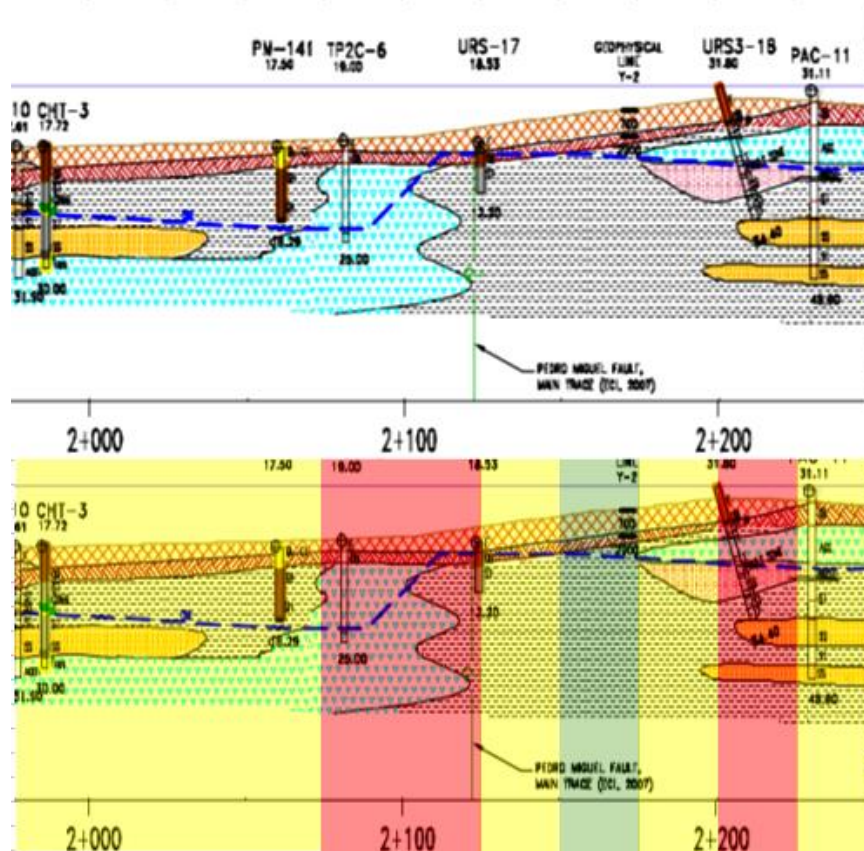


Figure 16 Color coding for a section of the Borinquen Dam 1E foundation geological profile.

To demonstrate the method, two critical activities are selected from the schedule in five summarized work fronts along the entire dam to make the chart readable in a paper format, while maintaining the logic, durations and location true to the project baseline schedule. The first activity selected for this case is the construction of a grout curtain below the foundation of the dam, which is highly affected by geotechnical conditions at the site; and the second activity is its successor: the construction of the embankment's impervious core. The details of the selected activities are shown in Table 4 as follows:

Table 4 Activities from the Borinquen Dam Baseline Schedule

Activity	Crew	Duration (days)	Start Date	Finish Date	Start Station*	End Station*
Grout Curtain 1	Grout-1	175	19-Jun-11	11-Dec-11	0+455	1+000
Grout Curtain 2	Grout-2	175	19-Jun-11	11-Dec-11	2+800	2+400
Grout Curtain 3	Grout-1	175	12-Dec-11	4-Jun-12	1+000	1+400
Grout Curtain 4	Grout-2	175	12-Dec-11	4-Jun-12	2+400	2+000
Grout Curtain 5	Grout-1	142	5-Jun-12	25-Oct-12	1+400	2+000
Embankment 1	Bank-1	181	2-Aug-11	30-Jan-12	0+455	1+000
Embankment 2	Bank-2	181	2-Aug-11	30-Jan-12	2+800	2+400
Embankment 3	Bank-1	181	13-Feb-12	12-Aug-12	1+000	1+400
Embankment 4	Bank-2	181	13-Feb-12	12-Aug-12	2+400	2+000
Embankment 5	Bank-1	109	13-Aug-12	30-Nov-12	1+400	2+000

\* Stations are shown in metric units.

The representation of the activities in the linear schedule format is depicted in Figure 17, the color code from Table 4 will be maintained as a quick reference of the activities in the linear schedules, and a similar format must be used when this method is applied due to the complexity of construction schedules and the visual nature of the tool. To clarify, Figure 17 shows that on June 19, 2011 the Grout-1 crew starts at Station 0+455 working toward the center of the dam while the second grout curtain crew (Grout-2) starts on the opposite end and works toward the center at the same time.

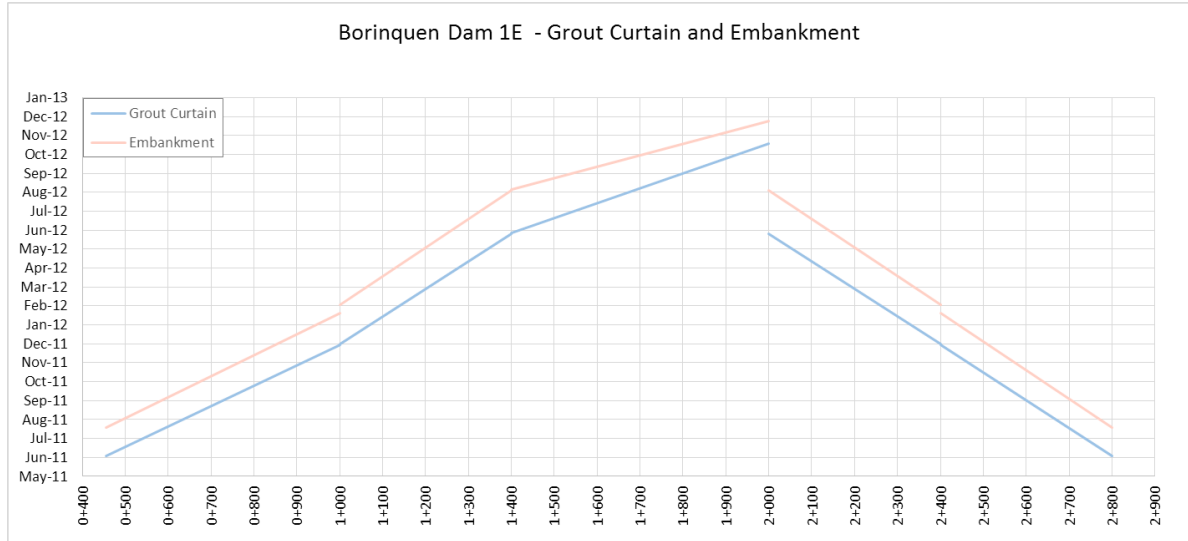


Figure 17 Simplified Borinquen Dam Activities in the linear scheduling format.

In order to illustrate the impact of risks in the schedule using this format, the risks shown in Table 5 were selected from the Borinquen Dam risk register used in the project.

Table 5 Selected risk events with their associated probabilities and impacts.

Risk Event	Activity to Impact	Probability	Minimum Impact (days)	Maximum Impact (days)	Most Likely Impact (days)
Variation in production rate for grouting	Grout Curtain	50%	-21	175	0
Variation in embankment production	Embankment	50%	-40	40	0

Once all the risks are quantified with their three-point estimates and probabilities, the stochastic model can be built and the values associated with different confidence intervals can be obtained and plotted in the linear schedule. The selected confidence intervals are the same as the ones used for building the hypothetical linear schedule in

Figure 15, and the color code for the impacted activities is the same as in Table 4, while the non-impacted activities are represented as black lines. Additionally, the soil profile color codes from Figure 15 are added to the x-axis to provide a third point of visual reference. The resulting linear schedule is shown in Figure 18 as follows:

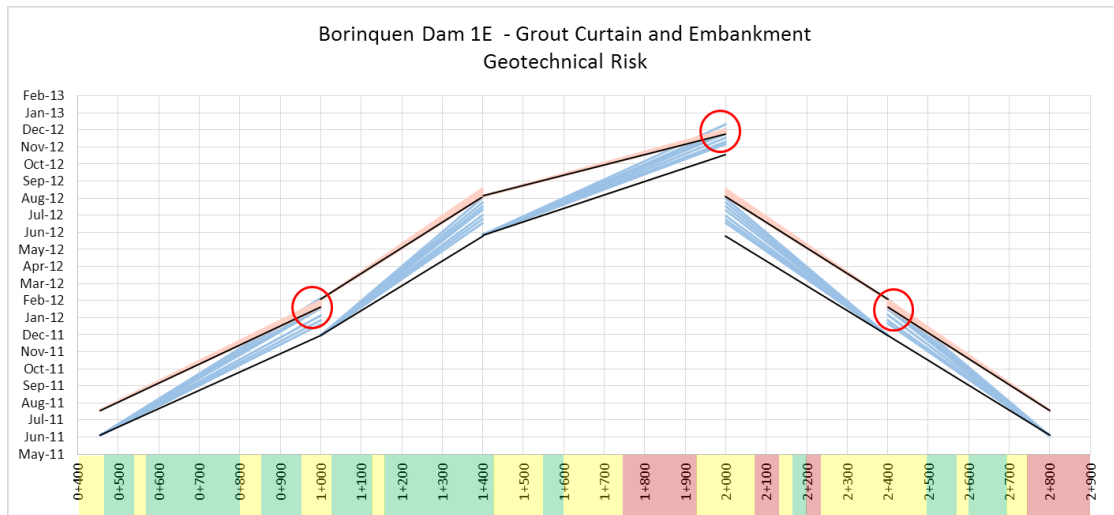


Figure 18 Stochastic linear schedule for the Borinquen Dam

The points in time where realized risk could create activity conflicts are shown by the red circles in Figure 18. These three spots are points where the grout curtain activity's spectrum of potential risk shown in blue overlaps with the scheduled start of the subsequent activity (black line). That means the risk associated with the grout curtain for an individual activity can potentially create a delay in the subsequent activity at that location and set back the entire schedule if the identified risks are realized. To analyze the impact of each individual risk in the entire schedule, every start and finish date of subsequent activities must be recalculated while maintaining the logic and resource allocation from the baseline assumptions. The colored spectrum of lines in each of the segments shown in Figure 18 represent the initial step of that recalculation as if each

segment were to be analyzed separately. This provides information regarding the degree in which the risk associated to each activity contributes to the cumulative delay due to location conflicts, which is important information that cannot be derived when analyzing the overall impact to the schedule by recalculating the start and finish dates of all the activities. As shown in Figure 18, some sections of the project contribute more than others in the overall delay due to direct conflicts with their successor activity in terms of location, not just the cumulative delay carried from previous activities.

Knowing this the scheduler can consider taking corrective actions to mitigate the risk of delay. Among the possible remedies would be to add resources to the grout curtain crews and increase their production rates to the point where the overlap no longer exists, essentially planning to crash the activities that begin at stations 0+455 and 2+800 to create enough float to be able to reach station 2+000 before October 25, 2012, which permits the embankment to be completed as scheduled by November 30, 2012. A second possibility could be to reorient the sequence of work for the Grout 1 crew by having it start at station 2+000 where the most difficult soil conditions exist and proceed to station 0+455. This option would have both grout curtain crews working in the worst soil regimes where production rates would be expected to be lower at the start of the job (Gransberg and Gad, 2014). Then once each crew passed through the red zones shown in Figure 18, the schedule could be reassessed to determine if crashing of subsequent grout curtain activities is necessary to complete on time.

Perceiving the individual impact of risks graphically in the schedule as shown in Figure 18 permits the following conclusions to be drawn:

1. The geotechnical risk has the potential to impact the project's critical path and overall duration due to its impact on production rates.
2. From the geological interpretation displayed in the horizontal axis in color code, it can be observed that there are three different geotechnical conditions according to the preliminary studies. Each soil condition will impact the production of the grout curtain crews and should be considered in the original duration estimates. This also means that the exposure to risk is not the same across every section of the project. Therefore, the geotechnical-related risks should be treated according to the expected conditions in order to avoid over or under estimating the risk and its impact on the project.
3. The spectrum of confidence levels in the example schedule were selected for convenience. Hence if information is available, an expected probability could be associated with each of the three soil conditions interval, allowing the impact of risk to be reassessed. In the example, if the desired level of confidence for each soil condition could be capped at 70%, the impact of the realized risk in a specific section would not cause an appreciable delay in the project completion.
4. Mitigation actions can be planned to minimize the impact of the risk by increasing planned production rates, changing the sequence of work, or crashing individual activities as described in the previous section. By representing the risks as changes in production rates in a linear schedule, an analysis can be performed to determine which activity should be accelerated to avoid delays on the project, since production rates are easily identified as the slope of the lines.

## Conclusions

Due to the nature of stochastic modeling, risk analysis is typically one of the knowledge areas of project management that is not widely understood by all the stakeholders involved in a project, and the results of the analysis are sometimes underestimated when there is not a comprehensive understanding of the process. By incorporating linear scheduling concepts in the effort, the details inherent to the project planning and execution are integrated into the results of the analysis, making the assessment a visual one, which is hopefully more intuitive and easier to interpret by stakeholders not well-versed in risk-based scheduling.

As shown in this paper, linear scheduling provides an effective format to analyze the geotechnical risk construction projects by correlating the expected/actual site conditions with the schedule and the risk assessment effort. This quality makes it possible to tailor the assumptions used in the risk analysis model to specific activities or locations, and to make adjustments to the logic or production rates based on the identified impact of each risk.

The Borinquen Dam example illustrated the applicability of the concept and can act as a simplified reference which is provided for further implementation of the method. The fundamental value of the method was demonstrated as a seminal example of the analytic capabilities derived from the graphical nature of linear scheduling.

This method should be applied to projects that follow a linear path such as roads, bridges, pipelines or dams in order to maximize its efficiency. Applying this method to non-linear projects rapidly increases the complexity and makes the analysis more

abstract, diminishing the benefits that result from an easy-to-follow graphical tool, which is its primary advantage over conventional risk analysis methods.

The complexity and number of activities or desired confidence levels that can be analyzed with this method depends purely on the ability to easily interpret the results. The example used a reduced number of activities to clearly communicate the concept in this paper. However, there is no theoretical limitation beyond that found in the software platform used to develop the linear schedule. Given the computing capacity, the risk analyst can apply the principles described in this paper to evaluate the combined effect of risks on the overall project or at a lower level, the risks in several subnets of a schedule can also be produced and integrated.



**CHAPTER VI**  
**CASE STUDIES IN MANAGING GEOTECHNICAL RISKS DURING**  
**PROCUREMENT FOR DESIGN-BUILD PROJECTS.**

Tapia R. and Gransberg D.D., Case Studies in Managing Geotechnical Risks During Procurement for Design-Build Projects (Submitted for publication in the *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 2017)

**Abstract**

The risk associated with the subsurface conditions in a construction project can only be quantified accurately if a thorough geotechnical investigation is performed or subsurface work has already started. In projects delivered using Design-Bid-Build (DBB) the design is completed before awarding the contract, allowing the opportunity to mitigate the geotechnical risk by means of geotechnical investigations tailored to the design. Projects delivered using Design-Build (DB) present a challenge since the design is not completed at the time of contract award, changing the way risks are allocated between owner and contractor. Previous studies have demonstrated that despite owner attempts to contractually shift the geotechnical risk to the DB contractor, courts often assign the risk of differing site conditions to the owner. This paper presents the results of 11 DB project case studies aiming to benchmark the state-of-the-practice for managing geotechnical risks during DB project procurement. The paper proposes 12 tools that can be used to reduce the uncertainty associated with subsurface conditions and improve the way geotechnical risks are allocated among the parties in DB contracts.

## Introduction

Geotechnical risk in the construction context refers to the uncertainty in subsurface ground conditions which can cause adverse effects on project cost, time, quality, and environmental objectives (Clayton, 2001). Every construction project that relies on the characteristics of the soil for its design and constructability will have a degree of uncertainty with regard to subsurface characteristics inside the project footprint until work starts and the subsurface soil is uncovered. This is especially important for projects in the transportation industry where large project footprints are required, making the impact of having actual conditions differ from those assumed during design critical to achieving project cost and time objectives (Gransberg and Loulakis 2011).

The analysis presented in this paper focuses on the unique risk profile that occurs when projects are delivered using the Design-Build (DB) method. DB is a contracting scheme in which one party performs both design and construction services in a single contract with the owner of the project (DBIA, 2015). It is considered an alternative project delivery method to the standard Design-Bid-Build (DBB) low bid approach where the owner furnishes a complete design before a construction contract is awarded.

The nature of DB contracting provides a unique opportunity for sharing the geotechnical risk because the design-builder is able to perform its own subsurface investigation and accommodate actual site conditions in the design while it progresses with construction. On the other hand, the delivery method also presents some challenges when determining which party is responsible for the differing site conditions risk (Gransberg and Loulakis, 2011).

There are two opposite and mutually-exclusive positions regarding the allocation of the geotechnical risk in DB projects:

- 1) Position 1: The Design-Builder is responsible for the design of the project as well as its construction; therefore, some owners believe it is within the contractor's responsibilities to account for potential variations in the subsurface conditions when pricing the project (Christensen and Meeker 2002).
- 2) Position 2: The project site belongs to the owner and the Design-Builder cannot be reasonably expected to accurately predict the subsurface conditions before submitting a price proposal, therefore, the impact of unexpected conditions should be borne by the owner. Moreover, some contractors will not participate in projects if they face unlimited risk for differing site conditions (Loulakis et al., 1995). The unintended result is less competition and higher construction costs.

Public owners typically deliver projects using DB when there is a need to accelerate process by streamlining the design and construction process (Songer and Molenaar 1996). This *time is of essence* approach alongside the fact that the geotechnical activities are amongst the first to be performed after contract award, typically makes geotechnical task critical path activities in a construction schedule (Smith 2008). Therefore, the geotechnical risk must be addressed earlier in the DB project development process than it is in DBB construction projects. (Gransberg and Loulakis 2011). In most cases, that means during the development of the DB RFP before the project advertised. The criticality of the geotechnical work exacerbates the above cited conflicting positions on liability for differing site conditions, and contributes to conclusions from existing

literature in that geotechnical risk could be the most difficult aspect to manage when using alternative project delivery methods (Christensen and Meeker 2002; Clark and Borst 2002; Hatem 2011; and Schaefer et.al 2011).

Therefore, the purpose of this paper is to identify effective practices for managing the geotechnical risk in DB projects from US public agencies and their DB contractors, synthesize the findings and propose a set of tools for allocating the geotechnical risk in DB project procurement.

### **Background**

DB project delivery has proven to be effective in accelerating project schedules in the transportation industry by allowing construction to start before the design is complete (FHWA 2006). Taking advantage of that benefit, the use of DB has significantly increased in the recent decades with 48 states currently implementing this delivery method in their infrastructure projects (DBIA 2015). Despite its increasing popularity, many agencies are challenged by DB projects with high subsurface condition uncertainty. The primary issue is the lack of information available from not having a geotechnical design report during the procurement phase. Thus, the incomplete geotechnical scope of work hinders the ability to characterize the actual subsurface site conditions in the Request for Proposals (RFP) (Beard et. al 2001).

Several past studies support the need to identify, quantify and mitigate the risk of differing site conditions before the DB contract is awarded (Christensen and Meeker 2002). McLain *et al.* (2014) suggest expediting the review of geotechnical designs during execution as well as improving communication between owner and contractor through a

thoughtfully developed differing site conditions clause. The subject has also been studied from the legal perspective and improvements have been proposed to mitigate the risk by incentivizing early contractor design (ECDI) through contractual provisions such as alternative technical concepts (ATC) (Papernik and Farkas 2005). Gransberg and Loulakis (2011) found in that regardless of the specific contractual language, the Design-Builder is entitled to rely on the information provided in the RFP and that differing site conditions (DSC) clauses constitute the provision under which the Design-Builder can claim compensation for the time and cost associated with encountering conditions differing from the information provided by the owner in the RFP.

The wording and information included in the RFP plays a critical role in the successfully allocating subsurface risk in a DB project with significant geotechnical issues. A well-written RFP provides the proposers with either sufficient information to price the job accurately or with fair mechanisms such as the DSC to claim compensation if the risk materializes (USACE 2009). The study presented in this paper seeks to identify and provide the effective practices to contractually allocate, manage and mitigate the geotechnical risk in the procurement phase. By proposing a set of tools rather than a utopian single solution allows owners to adapt their practices to incorporate improvements while remaining within their policies and risk profile.

### **Case Study Analysis**

As described in the methodology, a content analysis of DB RFPs and a nationwide survey were conducted and based on those efforts and a comprehensive literature review, projects eligible for case studies were identified. A case study protocol was developed with the objective of identifying, analyzing and understanding the current

models for successful geotechnical risk management on projects delivered using DB.

This protocol is then used to conduct structured face-to-face interviews, producing results with established points of comparison and a high level of reliability.

Interviews were performed on eleven (11) case study projects across nine (9) states in the US: California, Indiana, Maryland, Missouri, North Carolina, Ohio, South Carolina, Texas and Utah. All of these case studies are projects that involved significant geotechnical risks and several differences and similarities were found in the way the DOTs managed them, which provided valuable insight towards identifying different tools and methods that are currently being used to handle the geotechnical risk. Table 6 provides summary information on each case study project as well as key geotechnical risk mitigation practices that were identified during the structured interviews.

Table 6 Case Study Projects and Summary of Mitigation Practices Used.

Case No.	DOT	Case Study Project	Contract Award Year	Contract Amount \$million	Geotechnical Risk Mitigation Practice
1	MO	I-64 Daniel Boone Bridge over the Missouri River	2012	\$111	Provide as much information as possible to proposers, accepting requests for additional investigation.
2	CA	I-15/I-215 Interchange at Devore	2012	\$208	Perform additional studies if the project requires it. Prescriptive requirements.
3	IN	PR 69 from Taylor Ridge Road to 1435 west of CR 750E	2013	\$110	Perform as much geotechnical investigation as DBB. Mandatory soil improvement design.
4	UT	I-15 Corridor Reconstruction Project	1997	\$1,600	GDR nearly 100% AASHTO. Increase settlement warranty requirement.
5	UT	SR-73 Pioneer Crossing, Lehi	2009	\$282	Exclude owner's studies from DSC clause. Mandatory specifications and extended warranty for settlement.

Table 6 (Continued) Case Study Projects and Summary of Mitigation Practices Used.

Case No.	DOT	Case Study Project	Contract Award Year	Contract Amount \$million	Geotechnical Risk Mitigation Practice
6	TX	Dallas, Horseshoe Project	2012	\$818	DSC clause with caps. Two NTPs. Not limiting contractor's geotechnical investigation. Mandatory pavement designs.
7	MD	IS-270 Innovative Congestion Management Project	~2017	\$100	Progressive DB. Scope validation period. Appropriate amount of studies (not extensive).
8	OH	Columbus Crossroad - Project 1	2011	\$200	First \$250,000 of DSC is considered incidental. Requirement for contractor to provide GBR for tunneling.
9	OH	Cleveland Innerbelt CCG1 (I90WB Bridge)	2010	\$287	Robust subsurface exploration. Requirements for deep foundations and drilled shafts. A \$500,000 DSC threshold was included.
10	SC	Port Access Road	2016	\$220.7	Extensive geotechnical and environmental investigation (including deep boring). Threshold for Hazmat. Seismic parameters provided. Elimination of geotechnical DSC.
11	NC	I-40 Landslide Project	2004	\$10.5	Provide as much raw data as possible in the contract. Allow requests for more borings. No DSC clause. Nested DB.

Detailed information from each of the case studies follows including the rationale for inclusion in this study, the geotechnical risks involved, and the approach followed by the agency to manage the geotechnical risk in the procurement phase.

*Case Study 1: I-64 Daniel Boone Bridge over the Missouri River – St. Louis, Missouri*

Rationale: This project was selected as a case study to illustrate the benefits of incorporating the proposers' criteria in the geotechnical risk identification before awarding the contract and how the Missouri DOT (MoDOT) handles projects with high potential of geotechnical risks. Although MoDOT treats every major bridge as a project

with significant geotechnical risks, in this case study the proposers identified the risk of liquefaction in one of the abutments during the two-phase letting process.

Location: St. Louis, Missouri

Award Year: 2012

Contract Amount: \$111,000,000

Status: Completed

Scope of work: The project consists of building a new bridge over the Missouri River to connect St. Charles and St. Louis, replacing the existing 80-years old structure which is required to be removed, and constructing a bicycle pedestrian facility to connect the Katy Trail State Park to the Monarch Levee Trail.

Geotechnical Risks: MoDOT considers that every bridge project has a higher geotechnical risk as compared to other projects. The risk analysis initially performed by MoDOT included the identification of Differing Site Conditions, Scour and Settlement as geotechnical risks related to this project. Table 7 shows MoDOT's Risk Assessment Worksheet for this project where a quantitative analysis was performed for each identified risk. This case study stands out for analysis since a complex geotechnical risk such as the potential for liquefaction was identified by the proposers during the procurement process.



Table 7 MoDOT Risk Assessment Worksheet – Geotechnical / Daniel Boone Bridge  
Project

Risk element	Impact to Project Goals Low—Med— High			Effort to Mitigate Risk Low—Med— High			Probability of Impact (if no action taken) 0—1.00	Risk Factor A*B*C
	0	3	6	0	3	6		
Differing Site Conditions		6			6		.3	10.8
Scour		6			3		.3	5.4
Subsurface Investigations		6			6		1	36
Settlement of St Louis Approach		4			3		1	12
Settlement of St. Charles Approach		2			2		.5	2

Agency approach to manage the geotechnical risk: The overall approach to manage the geotechnical risks in this project was to provide as much information as possible to the proposers in the form of a geotechnical baseline report (GBR). This includes performing additional borings -as requested by the proposers- before awarding. The agency considers that the main geotechnical risk factor in DB contracts is the lack of a detailed design when the contract is awarded. In this case, the agency had to estimate the location of the piers or the final alignment of the bridge to perform the geotechnical studies

*Case Study 2: I-15/I-215 Interchange – San Bernardino, California*

Rationale: This project was selected as a case study due to the highly complex geotechnical conditions that were identified and addressed prior to advertising the RFP. This project is located in an area between two major faults (San Andreas and Jacinto) and the geotechnical report that was prepared during preliminary engineering identified two potential faults within the project limits. Therefore, it was decided to perform a fault trench study to confirm the presence of a fault and estimate the degree of fault rupture. In

addition, adequate subsurface explorations (borings) were conducted at strategic locations to help provide reasonable geotechnical parameters to the bidders. This was expected to reduce the geotechnical risks.

Location: San Bernardino, California

Award Year: 2012

Contract Amount: \$208,000,000

Status: Completed

Scope of work: The project consists of designing and building improvements to the I-15/I-215 interchange by eliminating existing lane reductions on I-15, reducing operational issues due to weaving trucks, reducing interchange operational deficiencies such as non-standard design features, and correct arterial highway deficiencies.

Geotechnical Risks: The project site is located in the highly seismic Southern California region within the influence of two fault system (San Jacinto and San Andreas) that are considered to be potentially active. The owner anticipates that the project site will periodically experience ground acceleration due to of small to moderate magnitude earthquakes. The geotechnical report prepared by the owner during the preliminary engineering design identified the two potential faults within the project limits as well.

Agency approach to manage the geotechnical risk: Although this project was the first design-build project in their district, the agency knew that there was an inherent risk that needed to be dealt with. In order to manage the geotechnical risk, the agency decided to do a fault trench study to determine and confirm the presence of a fault and to estimate the degree of fault rupture. In addition, adequate subsurface exploration was conducted at strategic locations to help to provide reasonable geotechnical parameters to the proposers.

*Case Study 3: PR 69 from Taylor Ridge Road to 1435 west of CR 750E– Greene County, Indiana*

Rationale: This project was selected for a case study being a DB contract that had significant geotechnical challenges that were identified in the preliminary engineering. These arise from the geology of the site, consisting of bedrock hills with a thin layer of windblown and residual soils, which includes depositions during post-glacial recession of deep lacustrine deposits from the glacial slack water from tributaries to the White River valley. The construction in the valley included stage construction of embankments with high strength geotextile, ground modifications/improvements, Bridge with 13 spans spanning this valley and an array of geotechnical instrumentation monitoring. The variability of the soil profile and the combination of extremely high embankments with extremely weak soil made this project a good example of a geotechnically-complex DB project.

Location: Greene County, Indiana

Award Year: 2013

Contract Amount: \$110,000,000

Status: Completed

Scope of work: The project consisted of the construction of embankments with high strength geotextile, ground modifications/improvement (mandatory design), the construction of a bridge with 13 spans, and an array of geotechnical instrumentation monitoring which was a strong aspect of the design.

Geotechnical Risks: The agency considered the project to have a high geotechnical risk given the project site which is a valley. The geological profile not only was variable, but

also inadequate to support future structures due to the combination of extremely high embankment with extremely weak soil. In addition, the design of environmental specifications to be made was considered as a geotechnical risk.

Agency approach to manage the geotechnical risk: Knowing that the project was considered to have a high geotechnical risk profile, the agency approach was not only to conduct as much geotechnical investigation is made as DBB project delivery, but also to do it right. INDOT consulted the geotechnical risk with its pre-qualified consultants, and specified a mandatory soil improvement design in the contract.

*Case Study 4: I-15 Corridor Reconstruction Project – Salt Lake City, Utah*

Rationale: This project was the first major DB project developed by Utah DOT, it was selected for inclusion to illustrate the differences in managing the geotechnical risks as compared with a more recent case study in this research. The project consisted of reconstructing 16 miles of the I-15 corridor in Salt Lake City, widening to 5 lanes each way by including a High Occupancy Vehicle (HOV) lane and a general-purpose lane, the construction of a new interchange and significantly reconfigure all existing interchanges. The project was considered to have a high geotechnical risk due to the presence of soft compressive soil and the overall magnitude of the job.

Location: Salt Lake City, Utah

Award Year: 1997

Contract Amount: \$1,600,000,000

Status: Completed

Scope of work: The work consisted of reconstructing the I-15 Corridor extending approximately 26 km (16 miles) which included widening, a new high occupancy vehicle (HOV) lane and several intersections.

Geotechnical Risks: This project was considered to have a high geotechnical risk because the presence of soft compressive soil was identified in the preliminary studies, which creates the potential for settlement. Despite the accuracy of the information provided in the RFP, a change order had to be issued by the DOT after a claim was filed due to the occurrence of settlement in the structures adjacent to the project due to the weight of the embankment. The solution to the problem was to redesign the embankment so the dimensions are reduced and the load on the soil lowered.

Agency approach to manage the geotechnical risk: Being their first large DB project, UDOT approached the geotechnical risk by providing a GDR including nearly 100% AASHTO standard borings which they consider uncommon for a project delivered under the DB scheme. Additionally, having identified the risk of settlement in the preliminary studies, UDOT decided to increase the settlement warranty requirement for this project to three years instead of their standard two years.

*Case Study 5: I-15 SR-73 Pioneer Crossing – Lehi, Utah*

Rationale: This project is the second case study obtained from Utah DOT and is particularly interesting to this research to illustrate how geotechnical risks are currently being handled as compared to their first large DB project in 1996, the I-15 Corridor Reconstruction Project in Salt Lake City. This project was not initially identified as one

with a high geotechnical risk, but the presence of a wetland in the area combined with the implementation of an ATC increased the risk and ended up requiring a geotechnical-related change order.

Location: Lehi, Utah

Award Year: 2009

Contract Amount: \$282,361,000

Status: Completed

Scope of work: The project included six miles of a new connector featuring a new Diverging Diamond Interchange, a new 60-in. waterline for the Central Utah Water Conservancy District, a 5- to 7-lane urban arterial with concrete pavement, new bridges over the Jordan River and Union Pacific Railroad, new concrete box culverts at the Dry Creek and Lehi Trail crossing, noise walls, retaining walls, aesthetics/landscaping, drainage, utility relocations, and traffic signal work.

Geotechnical Risks: This project was not initially considered to have particularly high geotechnical risks when estimated by UDOT. The presence of a wetland was identified but the original alignment was not intended to use that area. During the procurement process, an ATC was received to shift the alignment. The ATC was approved but the new alignment did cross through the wetland area resulting in encountering soft soil conditions which led to a claim that was settled in favor of the contractor by means of a contractual change order.

Agency approach to manage the geotechnical risk: UDOT provided a Geotechnical Data Report (GDR) in the contract with an estimated cost of 0.5% of the total project amount and dedicate around six (6) months to perform the preliminary

studies. Additional studies were allowed to be performed by the proposers if requested, which did not occur in this project. Along with the GDR and the contractual provisions for ATCs and the DSC clause, UDOT provided specifications that had to be followed to mitigate differential settlement and also required at least 2 years of warranty against settlement.

*Case Study 6: Horseshoe Project – Dallas, Texas*

Rationale: This project was selected for inclusion due to the complex foundation work and high geotechnical risk involved, and the selected project delivery method where the majority of work is to be performed as a Design-Build Project but one of its components, the Margaret McDermott Bridges designed by Santiago Calatrava, was a Design-Bid-Build portion within the project. The geotechnical conditions of the site along with the design of the Margaret McDermott Bridges presented challenges and required a contractual change order. The contractor proposed an ATC before winning the contract to use a different correlation chart to design the drilled shaft based on site-collected data.

Location: Dallas, Texas

Award Year: 2012

Contract Amount: \$818,000,000

Status: Completed

Scope of work: The U-shaped \$818 million bridge and roadway project near Dallas' Central Business District is referred to as The Horseshoe Project. TxDOT replaces bridges that cross the Trinity River on Interstate 30 and I-35E, as well as upgrade the connecting roads just south of downtown Dallas. The Horseshoe improves

safety and increases capacity on these bridges and roadways, which are central to the vitality of the Dallas economy.

Geotechnical Risks: This project is considered to have high geotechnical risks due to the high uncertainty related to presence of around 30 to 40 feet of loose clay and soft soil (poor soil conditions) in the site. These conditions present a challenge, especially for the foundations of the Margaret McDermott Bridges due to their inclined design

Agency approach to manage the geotechnical risk: Given the inherent geotechnical risk, TXDOT procured the project as a DB delivery in order to encourage innovation. In addition, TxDOT managed the geotechnical risk by not limiting geotechnical investigations to be performed by the contractor, promoting the proposal of ATCs, and letting the contractor decide on geotechnical solutions like using a bridge instead of a retaining wall. However, some mandatory design parameters are included as a mitigation action, such as standard pavement designs and a full geotechnical manual that has to be followed except for approved ATCs as occurred in this project (Allowable Skin Friction vs Texas Cone Penetrometer Chart).

TxDOT also included liability caps to the DSC clause to clearly establish the shared responsibility of the geotechnical risks and incorporated two notices to proceed (NTP) in the contract; the first NTP included preliminary work and studies, and the second NTP corresponds to all other work pertaining the Project.

*Case Study 7: Innovative Congestion Management Project – Montgomery and Frederick Counties, Maryland*



Rationale: This project was selected for inclusion to analyze the benefits of delivering a project using Progressive DB, a new concept in highway projects. This new project being procured by Maryland State Highway Administration (MSHA) has the potential to eliminate the inherent risk associated with decision making based on one-sided preliminary geotechnical studies by segmenting the project and progressively issue notices to proceed as preliminary studies and design advance under a guaranteed maximum price.

Location: Montgomery and Frederick, Maryland      Award Year: 2017 (Est.)

Contract Amount: \$100,000,000      Status: Not awarded

Scope of work: The project consists of a 32-mile corridor, being delivered using Progressive Design-Build, there is no specified scope of work in the RFQ, but mobility, operation and safety are the overall goals. The progressive DB contract consist of a two-phase, fixed value contract. The first phase is for the Design-Builder to provide design and preconstruction services up to a point where specific work packages can be priced. At which point the Design-Builder negotiates a Construction Agreed Price (CAP) price and, if approved by the owner, then a NTP for the second phase is issued and the Design-Builder is able to start construction. The owner reserves the right to not proceed with the second phase is a CAP is not agreed upon.

Geotechnical Risks: Given that this project is procured using Progressive-DB, the Design-Builder and the owner have the flexibility to negotiate the geotechnical scope of the project. This project is considered as a common project with regards of the

geotechnical risk. Considering that the contract has not been awarded at the moment of this study and the scope is broad at this point; there are no specific geotechnical risks identified.

Agency approach to manage the geotechnical risk: Progressive DB is considered a way to manage the geotechnical risk since the uncertainty associated with the subsurface conditions is resolved by the contractor early in the project. Additionally, a scope validation period is incorporated in the contract to allow the contractor to incorporate any differing site conditions early in the project. The agency also considers that there should be a balance in the amount of information that is given to contractors, as too much information or interpretation can give foundations for change orders during the project execution. Giving the DB additional information could reduce the initial cost but cause a change order down the line. Additionally, a scope validation period is incorporated in the contract to allow the contractor to incorporate any differing site conditions early in the project, no DSC claims are allowed outside of this period.

*Case Study 8: Columbus Crossroad - Project 1 – Columbus, Ohio*

Rationale: This project was the first of two selected as case studies to illustrate the way the Ohio DOT manages large DB projects with regards of geotechnical risks. The project is considered to have a high geotechnical risk due to its magnitude, and there were some significant considerations such as the need for dewatering due to a high water table, and the contractual requirement for a baseline tunneling report for micro tunneling work.

Location: Columbus, Ohio

Award Year: 2011

Contract Amount: \$200,350,000      Status: Completed

Scope of work: The work involved realignment of I-670 EB so through traffic stays to the left and traffic to I-71 exits to the right and work on I-71 from over Jack Gibbs to Long Street. Includes 21 mainline, ramp and overhead bridges. Includes one bridge cap on Spring St and two bridge caps on Long St.

Geotechnical Risks: Given the overall size of the project, the geotechnical risk was considered higher compared to other projects. In addition, other risks were the high water table on northern section of project, the required dewatering to occur prior to construction, the micro tunnel required with location of pre-determined receiving pits.

Agency approach to manage the geotechnical risk: The first \$250,000 of differing site conditions was to be considered incidental. Micro Tunnel required with location of pre-determined receiving pits defined. Requirement to provide a geotechnical baseline tunneling report from Design-Builder to address risks with tunneling.

*Case Study 9: Cleveland Innerbelt CCG1 (I90WB Bridge) – Cleveland, Ohio*

Rationale: This project was the second of two selected as case studies to illustrate the way the Ohio DOT manages large DB projects with regards of geotechnical risks. The project is considered to have a high geotechnical risk due to its magnitude, and there were some significant considerations such as the need to stabilize landslides, abandoned foundations, deep layer of poor quality soil, and vibration impact on nearby structures.

Location: Cleveland, Ohio

Award Year: 2010

Contract Amount: \$287,400,000      Status: Completed

Scope of work: Replacement of the I90 Bridge over Cuyahoga River valley in downtown Cleveland. Includes associated roadway work to reconfigure the Interchanges adjacent to the bridge work. First project includes new bridge which will initially carry bi-direction I90 traffic, but in the future will carry only I90WB traffic. The project included approximately 2 miles of mainline interstate reconstruction, including a 4,000'-long viaduct over the Cuyahoga River Valley, system ramps, on/off ramps, local street grid modifications. The work includes reconstruction of 15 bridges and 17 retaining walls.

Geotechnical Risks: ODOT only identified the stabilization of landslides (west slope adjacent to Cuyahoga River) as complex geotechnical activity. However, given the size of the contract, the project was considered as a complex. In addition, geotechnical risks identified were: abandoned foundations; 150' average depth of poor quality soils above bedrock, for main viaduct bridge; vibration impact on existing structures; control over foundation and wall types; and mitigation of unsuitable soils.

Agency approach to manage the geotechnical risk: the agency conducted a robust subsurface exploration program in advance of the procurement, prescribed the west bank slope stabilization with sealed construction plans in the contract documents, and provided scope language requiring deep foundations to bedrock for the main viaduct bridge, and drilled shaft foundations for main viaduct substructures located within the Cuyahoga River west bank zone. A \$500,000 differing site conditions threshold was included in the contract.

*Case Study 10: Port Access Road – Charleston County, South Carolina*

Rationale: This project was selected as a study due to the high geotechnical risk involved. The project is located in a highly seismic location and the subsurface conditions consisted of liquefiable soils, soft compressive clays, high variability due to dipping stratum, and the potential for environmental contamination. The site is considered to have higher seismic acceleration than California.

Location: Charleston County, South Carolina

Award Year: 2016

Contract Amount: \$220,700,475

Status: Ongoing

Scope of work: The Project consists of the construction of a new fully directional interchange on I-26, a Bainbridge Connector Road, the extension of Stromboli Avenue and associated roadway improvements to surface streets to serve the proposed Naval Base Terminal (NBT) in Charleston County, South Carolina.

Geotechnical Risks: The risk was perceived to be very significant, therefore, extensive geotechnical and environmental testing was completed prior to advertising the project to assess the potential risk. The project is located in a highly seismic area. Underground conditions consist of soil potential for liquefaction, soft compressive clays, variable conditions and dipping stratum, and the potential for environmental contamination.

Agency approach to manage the geotechnical risk: A total of about \$1.2 million and more than 7000 man-hours were used for performing the geotechnical and

environmental investigations in this project, around a third of the cost was due to deep boring for seismic consideration.

There is interpretation of the data, though it doesn't specifically reference DSC clause and is provided for information only. Interpretation of the data is used in part in developing the RFP to determine liquefaction potential and preliminary stability analysis.

Some additional actions are detailed as follows:

- More information was made available to the proposers, including deep boring. As much drilling as the agency could do was performed, up to approximately 70% of what would have been done for a DBB. Regular projects are around 20-30% or enough to meet environmental testing.
- The alignment was narrowed down for this project, so the contractor did not have too much freedom to change it.
- Seismic parameters were provided. Liquefaction or loss of shear capacity and slope stability.
- An attempt to reduce overall risk was made by conducting relatively extensive geotechnical and environmental testing prior to issuing an RFP. A specified dollar allowance was included in the RFP Agreement for testing and handling of hazardous materials (environmental contamination).
- Differing Site Conditions rights due to geotechnical/geological issues were eliminated from the contract.

*Case Study 11: I-40 Landslide Project – Haywood, North Carolina*

Rationale: This project was selected for inclusion to demonstrate how the North Carolina DOT (NCDOT) managed the geotechnical risks in a time-sensitive and complex project. This project consisted of an emergency repair on I-40 due to several landslides in the area, the Project Delivery Method used was Design-Bid-Build with a 'nested' Design-Build component. NCDOT does not allow change orders due to Differing Site Conditions. Due to the emergency nature of the project, a geotechnical designer was selected by NCDOT for the 'nested' DB component and the General Contractor had to work with them.

Location: Haywood, North Carolina Award Year: 2004

Contract Amount: \$10,584,740.53 Status: Completed

Scope of work: The 2004 hurricane season wreaked havoc in western North Carolina from four different storm events with immense rainfall. These rains caused a massive amount of damage to the communities and transportation facilities in western North Carolina. The Pigeon River, swollen with runoff from Hurricanes Jeanne and Ivan and a flood release from the Walters Dam scoured away the toe of several embankment slopes supporting Interstate 40 near the North Carolina-Tennessee border. On September 17, 2004, several landslides occurred between Mile Markers 1 and 4. Portions of eastbound I-40 fell into the river. I-40 was closed in both directions and traffic was rerouted. The NCDOT was faced with the challenge of re-opening all lanes of traffic on I-40 to the traveling public as soon as possible. Numerous units from the Design Branch and the Division Construction staff of the NCDOT had to work together within a tight schedule in order to accomplish this task.

Geotechnical Risks: NCDOT realized that the required tie-backs for the retaining wall were going to have to be long, a risk was identified for the case that the required length ends up being longer than expected due to the site conditions. In addition, the potential was identified for finding underground boulders on the site, which would impact the project execution.

Agency approach to manage the geotechnical risk: NCDOT provides as much raw geotechnical data (no interpretation) as possible in their contracts. In this project, due to the emergency nature, four different geotechnical firms were contracted to perform borings and collect data at each landslide location. A total of 35 borings were performed in a 3-week timeframe, which was the time spent for letting and awarding the contract. The geotechnical studies in this project represented around 5% of the project total amount, when the typical value for NCDOT's DB projects is around 1%.

The proposers are typically able to request additional borings to be performed by NCDOT during the letting process. The results of these additional borings are made available to all competitors, but sometimes the agency performs more borings to avoid giving away the location requested by a proposer so the competitive advantage is retained.

### **Tools for Managing Geotechnical Risks in DB Projects**

Considering that there is no unified approach towards managing the geotechnical risk in DB projects and every agency and project will have distinctive characteristics that may constrain agencies from implementing all possible pre-award mitigation actions available, the main contribution of this study is a set of tools that can be independently



implemented to accommodate the risk profile of a given project. Based on the findings of the case studies intersected with the results of the content analysis of 59 RFPs across 29 DOTs, the proposed tools are separated in two main groups.

The first group is comprised of tools that are commonly used in the transportation industry, Table 8 shows a synthesized list including the state in which they were found in the case study analysis and the relative frequency in which the same tools were found in the content analysis. The relative frequency is presented as a ratio (%) of the frequency and the total number of analyzed RFPs (59).

Table 8 DB Geotechnical risk management commonly used tools

Tool	Source	
	Case Studies	Content Analysis (% relative frequency)
Allow proposers to request/perform additional studies during procurement.	MO, CA, IN, UT, TX, MD, OH, SC, NC	42%
Request of geotechnical ATCs	MO, CA, IN, UT, TX, MD, OH, SC, NC	58%
Provide enough geotechnical investigation data to thoroughly describe the site before advertising.	MO, CA, IN, UT, TX, OH, SC, NC	64%
Include differing site conditions clause	MO, CA, IN, UT, TX, OH, SC	59%
Incorporate prescriptive design parameters on critical aspects (e.g. seismic risk).	CA, IN, TX, OH, SC	63%
Include differing site conditions clause, allow claims based on owner's studies	MO, CAL, IN, OH	17%
Require additional performance warranties	UT	7%
Include owner's interpretation of the geotechnical data in the contract (GBR)	SC	8%

The second group is comprised of those considered emerging tools found in the case study analysis, which are shown in Table 9. These tools are characterized by innovation and represent the current direction in which agencies pursue an increase in effectiveness when managing the geotechnical risk in DB projects. APPENDIX A presents contractual extracts from the case studies to provide additional insight on the provisions used to implement each of the emerging tools.

Table 9 DB Geotechnical risk management emerging tools

Tool	Case Studies
Multiple NTPs with one designated for geotechnical investigation, design, and a second specifically to commence other works.	CA, TX
Monetary allowance included in the contract for the event of finding differing site conditions/contaminated materials. An amount is specified in the contract as the contractor's responsibility, any cost exceeding such amount is paid by the owner.	TX, SC, OH
Progressive DB: two (or more) phases DB contract, scope is developed and prices are agreed upon as the design progresses and preliminary engineering is performed by the Design-Builder, the owner retains option to not proceed with the project (or its components) if prices are not agreed.	MD
Scope validation period: a timeframe is specified in the contract after the NTP is issued for the contractor to perform design and preconstruction services to thoroughly verify and validate its understanding of the scope of work and site conditions. No DSC is allowed outside of the scope validation period.	MD

### Conclusions

The case study bottom-line is that geotechnical risk is best managed by getting project excavations underway as soon as practical so that any differing site conditions can be identified and resolved. The worst way to approach geotechnical risk is to attempt to shed it using exculpatory contract clauses because the courts have repeatedly ruled against owners who naively address this risk in an adversarial manner (Loulakis et al. 1996). Therefore, risk management and mitigation tools that facilitate the sharing of geotechnical risk and those that seek to accelerate the start of geotechnical design and project excavation appear to be potentially more efficient than those that rely on additional subsurface investigations during preliminary engineering. Put another way, increasing the boring and testing effort will reduce the differing conditions risk, but it does not reduce the impact of a differing site condition established after award of the DB contract. Means like the scope validation period found in the MSHA progressive DB project delivery method provide a mechanism to jointly identify and address geotechnical risk early in project execution and appear to be quite effective in mitigating the impact of difficult geotechnical conditions.

It is important to note that even though some tools are found to be more widely used than others and might be interpreted as the ‘tested and proven’ approaches, the more innovative tools like Progressive DB, Scope Validation Period, Multiple NTPs, or Monetary Allowances are the ones pushing forward towards finding a solution to effectively mitigate the geotechnical risk. This is consistent with the overall perception collected from the case studies that the involvement of potential contractors early on the

process allows for better risk sharing and problem solving, increasing the effectiveness of any mitigation action that the owner might implement on its own.

Each project will have its own context and no single tool will eliminate the geotechnical risk entirely before the work starts and the subsurface conditions are uncovered. However, a combination of the proposed tools, as shown in the case studies, does provide an effective way to mitigate the effects of the risk by incorporating innovative approaches while complying with agency and state policies.

## **CHAPTER VII**

### **CONSOLIDATED CONCLUSIONS AND LIMITATIONS**

Geotechnical risk presents a significant challenge in any construction project.

Preliminary subsurface exploration will always have a degree of uncertainty as estimations are made based on sampling and laboratory analysis along with engineering criteria. Thus, the potential for actual conditions differing from those estimated will always exist until subsurface work is completed. By exploring innovative scheduling and planning tools as well as the state of the practice in DB construction procurement, this dissertation presented alternative approaches that seek to mitigate the risk by accounting for and integrating the geotechnical risk in efforts performed in the early stages of project delivery.

As demonstrated using case study analysis, the applications of the LSM proposed in this dissertation provide instruments to increase the understanding and communication of the geotechnical risk and its effects, and potentially allow for a better and more effective decision making from non-technical key project stakeholders. Although LSM can be applied to virtually any type of construction project, one of its key benefits in the application of this research is the usage of the horizontal axis to display supporting information and the communication benefits derived from that configuration. Therefore, the optimal use for the LSM tools presented in this dissertation is for projects that follow a linear path, e.g. roads, bridges, dams and pipelines. The application of this tool in other types of projects that do not follow an alignment would create complexity in the communication effort.

The analysis from all the case studies for contractual practices presented in this dissertation resulted in one primary conclusion: the best way to manage the geotechnical risk is to involve contractors in design and begin subsurface work as early as practical to uncover and resolve any differing site conditions. The proposed tools like implementing ATCs, Multiple NTPs, Scope Validation Period, or Progressive DB all seek to incorporate contractors' know-how and experience at the early stages of project delivery, which shows that collaboration and risk sharing is the direction that owners are taking towards increasing the effectiveness in managing the geotechnical risk. All the contracting practices presented in this dissertation are based on transportation projects, as the resources for performing all case studies and surveys come from funded research projects in that industry. Even though the concepts can be applied to other industries in construction, it is important to note that the contracting culture or attitude towards risk can vary, making some concepts such as encouraging early contractor involvement, inviable.

This dissertation does not intend to provide a complete integrated framework to cover all aspects of geotechnical risk management. Further research is required to bring these concepts to a more technically-detailed analysis of specific geotechnical risks that may require special attention and management strategies.

## **CHAPTER VIII**

### **CONTRIBUTIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH**

#### **Contributions**

As discussed in Chapter 1 of this dissertation, the geotechnical risk is a major concern in most construction projects because the uncertainty associated with underground conditions has the potential to significantly impact project objectives in terms of scope, time and cost. This is particularly important when using the DB project delivery method since the contractor is required to submit a proposal and commit to a price before the design is completed. The lack of a complete design, and its corresponding final geotechnical studies, increases the uncertainty associated with the underground conditions at the time the contract is awarded. Thus, the potential impact of the geotechnical risk on the project objectives is exacerbated under the DB project delivery method.

The tools presented in this dissertation contribute to the body of knowledge by providing solutions that increase the effectiveness of the risk management effort by allowing the owner to better plan, communicate, allocate, and manage the geotechnical risk as demonstrated in the case studies. This is achieved by taking advantage of the visual nature of LSM to use it not only for scheduling purposes but also for data visualization in applications of the tool that currently do not exist in the literature. Additionally, combining stochastic LSM with DB project delivery and a set of emerging contractual tools that increase early collaboration between owners and contractors, the proposed framework can be used to mitigate the effects of the geotechnical risk during

the procurement process. The specific contributions explained in the body of this dissertation can be summarized as follows:

- *Forensic LSM*: The model explained in Chapter III proposes a new application of the LSM format to analyze the events that occurred in a construction project using location and time information for each activity in a construction project. Using the LSM format for data visualization provides a powerful tool to accurately and objectively represent information about the project performance in a simple chart. This also allows complex problems and situations to be graphically communicated to non-technical stakeholders using data that is typically collected in construction projects, such as daily production reports and quality assurance nonconformance reports.
- *Geotechnical Risk management using LSM*: Chapter V of this dissertation proposes the use of the LSM to analyze the geotechnical risk by visually representing the variations in activity durations due to the uncertainty associated with the subsurface conditions. The proposed method facilitates the interpretation of the geotechnical risk using the location dimension (horizontal axis) to display subsurface conditions. Integrating this information with the expected variations in activity durations allows for more effective decision making in project planning by visually accounting for the geotechnical conditions in the risk analysis effort.
- *ATCs for mitigating geotechnical risks*: The case study analysis presented in Chapter IV demonstrates how seeking early contractor involvement by incorporating contractual provisions for ATCs is an effective tool for



managing the geotechnical risk that can be applied in the DBB, DB and CM/GC project delivery methods. Incorporating contractors' know-how and experience by allowing them to propose alternative design or construction solutions before committing to a price has the potential to mitigate the geotechnical risk premium when difficult conditions are expected, by encouraging both innovation and collaboration.

- *DB Contracting Tools for managing geotechnical risks:* As discussed in Chapter VI, DB project delivery is often used as a way to transfer all risks to the contractor along with the responsibility for designing the project. However, previous research found that the risk of DSC is not unequivocally transferred to the design-builder. This dissertation contributes to the body of knowledge by providing a study of various DB contracting practices and provisions from 11 DOTs across the US resulting in 12 proposed contracting tools to better allocate and/or share the geotechnical risk, reducing the uncertainty associated with subsurface conditions during DB project procurement and contract execution.

### **Recommendations for Future Research**

The wide range of situations where the geotechnical risk can materialize in different contexts create the opportunity for more technically oriented and localized studies aimed to analyze how different geotechnical design parameters are subject to high variation and impact due to the site conditions. Combining, for instance, a state-specific study with the general practices proposed in this dissertation would potentially further reduce the uncertainty and improve the effectiveness of the effort.

The innovative applications presented in this dissertation expanded the usefulness and benefits that the LSM format provides in simple and practical solutions to aid in solving the problem statement. The tool, however, is flexible enough to potentially provide more innovative applications beyond those presented in this dissertation. As discussed in the literature review, previous studies have explored the opportunity for automating the creation of linear schedules (Harmelink, 1995; Duffy et al. 2011). Integrating automation with innovative applications would increase the practicability of more complex analyses. For example, the risk modeling LSM approach presented in this dissertation is currently limited due to the number of activities required to perform an analysis of the combined effect of risks in the entire schedule. This limitation is due to the lack of an automated process to model the risks in the LSM, as the number of activities and scenarios would be too high for common software applications. An optimized algorithm would potentially solve that problem while remaining practical for its application in actual construction projects.

On the procurement and project delivery aspect presented in this dissertation, future research opportunities exist to analyze the performance of some highly innovative tools proposed, such as Progressive DB. As found in the case studies, increasing collaboration between contractors and owners is an emerging trend. Thus, as such tools become more popular and a larger number of projects implement them, their effects on other project risks and challenges can be assessed in a holistic approach that encompasses all aspects of project management, as well as their robustness for mitigating the geotechnical risks.

## APPENDIX

### CONTRACTUAL EXTRACTS FROM CASE STUDIES – EMERGING TOOLS

- 1. Multiple Notices to Proceed:** Texas Department of Transportation – Horseshoe Project Design Build Agreement – Dallas Texas.

*“SECTION 4. TIME; PROJECT SCHEDULE AND PROGRESS*

*4.1 Time of Essence; Notices to Proceed.*

...

*4.1.3 TxDOT anticipates issuing NTP1 concurrently with execution and delivery of this Agreement. Issuance of NTP1 authorizes DB Contractor to perform (or, continue performance of) the portion of the Work necessary to obtain TxDOT’s approval of the component parts, plans and documentation of the Project Management Plan that are labeled “A” in the column titled “Required By” in Attachment 2-1 to the Technical Provisions. It also authorizes DB Contractor to enter Project Right of Way owned by TxDOT for the purpose of conducting surveys and site investigations, including geotechnical, Hazardous Materials and Utilities investigations. Refer to Sections 12.1.4 and 15.9 regarding a Price adjustment to be made in certain circumstances if the effective date of the NTP1 is later than 180 days after the Proposal Due Date, and regarding DB Contractor’s remedies for certain delays in issuance of NTP1 beyond 365 days after the Effective Date.*

*4.1.4 TxDOT anticipates issuing NTP2 concurrently with TxDOT's approval of all the foregoing component parts, plans and documentation of the Project Management Plan and the Project Schedule. Issuance of NTP2 authorizes DB Contractor to perform all other Work and activities pertaining to the Project.*

*...”*

**2. Monetary Allowances for DSC/Hazardous Materials:** Ohio Department of Transportation – Columbus Crossroad Project 1 Request for Proposals – Columbus, Ohio

*“104. 02.B Differing Site Conditions.*

*Notify the Engineer as specified in C&MS 104. 05 upon discovery of any of the following conditions:*

- 1) Subsurface or latent physical conditions at the site differing materially from those indicated in the Contract Documents and are not discoverable from an investigation and analysis of the site by the DBT meeting the standard of care for such an investigation and analysis.*
- 2) Unknown physical conditions of an unusual nature differing materially from those ordinarily encountered and generally recognized as inherent in the Work provided for in the Contract Documents, are encountered at the site.*

*Provide required notification before disturbing any differing site condition. Irrespective of the previous paragraph, the following will not be considered Differing Site Conditions for purposes of this section:*

*Work involving utility relocations or utility coordination. This work will be addressed in accordance with the Project Scope. Section 6.*

*Upon notification from the DBT, the Engineer will investigate potential differing site conditions. The Engineer will determine if differing site conditions have been encountered and notify the DBT of the Department's determination.*

*If the Department determines that conditions materially differ and cause an increase or decrease in the cost or time required for the performance of any Work under the Contract, the Department will make an adjustment and modify the Contract as specified in CMS 109.05 and as follows:*

- 1) The first \$250,000 of direct costs and associated impact will be the responsibility of the DBT.*
- 2) All costs which exceed the amount identified in item #1 above will be computed and paid to the DBT without any markup.*

*The Department acknowledged differing site condition Work is excusable, compensable, as defined by CMS 108.06 D except as noted in this section.”*

- 3. Progressive Design-Build:** Maryland Department of Transportation - IS-270 Innovative Congestion Management Project Request for Proposals - Montgomery and Frederick Counties, Maryland

“I. INTRODUCTION

...

A. *Progressive Design-Build Concept*

*This Progressive Design-Build (PDB) contract is a two-phase, fixed value contract. Phase one of the contract will be for the selected Design-Builder to provide design and preconstruction services to SHA to develop the project to the level necessary to submit a price for construction for work packages proposed by the Design-Builder.*

*Once the design has been completed to the necessary level for any work package to submit a price, the SHA will attempt to reconcile a Construction Agreed Price (CAP) for the construction of that work package. As multiple packages are allowed and anticipated, multiple CAPs may be agreed upon as long as the overall sum of all CAPs does not exceed the contract's fixed value. If the SHA agrees to a CAP, then notice to proceed for phase two construction services would be issued for that package. The SHA reserves the right to not proceed with phase two of the contract and bid a package competitively if a CAP cannot be reached. If SHA chooses to deliver the project by other means, the selected Design-Builder will not be permitted to submit a proposal or bid.*

*The intent is to form a partnership with the owner (SHA) and the Design-Builder. The goals of this partnership are to mitigate risk, streamline the design process, improve the decision making process with better information,*

*and develop a project that meets the project goals while adhering to the budget. We anticipate the involvement of the Design- Builder will help reduce errors in design, maximize the achievement of project goals, improve the overall constructability of the project and support the Practical Design process.*

*The fixed value of the contract is an aggregate of the Design-Builder's Design and Preconstruction services fee, the Design-Builder's Construction Management Fee, and the Construction services costs. Construction Services will include all CAPs, costs for any necessary right-of-way acquisition, and costs for any utility relocations required due to the construction of the contract. The fixed value of the contract will be \$100,000,000.*

*When right-of-way acquisition is required, the Administration will establish the right-of-way costs based on the needs established by the Design-Builder. All costs for right-of-way acquisition will be subtracted from the established cost for Construction services. Right-of-way acquisition services are expected to be completed by the Administration; however, the Administration will consider placing acquisition services on the Design-Builder if agreed upon in the development of a CAP.*

*When utility relocations are required, the Administration will establish relocation costs for utilities to be relocated by parties other than the Design-Builder. Any costs for utility relocations to be performed by the Design-*

*Builder will be included in any CAP. All costs for utility relocations will be subtracted from the established cost for Construction services.*

*Early procurement or Construction work may be considered for acquisition of long lead items or to complete early Construction tasks that can be completed and turned over to another Design-Builder or Contractor, should a CAP for final Construction not be agreed upon. Early right-of-way acquisition, utility work or Construction work may be considered with the understanding that early phases are not a guarantee of agreement of a CAP for final Construction. Early phases must be independent and severable from the final Construction package, with well-defined end point. Construction will not begin until a CAP has been accepted for a Plans, Specifications & Estimates (PS&E) package.”*

- 4. Scope Validation Period:** Maryland Department of Transportation - IS-270  
Innovative Congestion Management Project Request for Proposals - Montgomery and Frederick Counties, Maryland

“F. Scope of Services / Description of Work

...

*Scope Validation and Identification of Scope Issues*

*A Scope Validation Period of 120 days from the date of the Notice to Proceed for Design and Preconstruction Services will be provided on this contract. During the Scope Validation Period, the Design-Builder shall*



*thoroughly verify and validate that the Design-Builder's understanding of the scope of work and its ability to complete it within the Design and Preconstruction Services Fee. Any Scope Issues determined during this period shall not be deemed to include items that the Design-Builder should have reasonably discovered prior to submission of its Technical Proposal.*

*If the Design-Builder intends to seek an adjustment to the Design and Preconstruction Fee due to a Scope Issue, it shall promptly, but in no event later than the expiration of the Scope Validation Period, provide the Administration in writing with a notice of the existence of such Scope Issue and basis for such Scope Issue. Within 30 days of the notice, the Design-Builder shall provide documentation that specifically explains its support for the Scope Issue, which shall include among other things: (a) the assumptions the Design-Builder made during the preparation of its Proposal that form the basis of its allegation, along with documentation verifying it made such assumptions in developing its Proposal; (b) explanation of the Scope Issue that the Design-Builder could not have reasonably identified prior to submission of the Technical Proposal; (c) specific impact on the Design and Preconstruction Services. For the avoidance of doubt: (1) The Design-Builder shall not be entitled to raise any Scope Issues that were not previously addressed with a notice; and (2) Design-Builder shall have no right to seek any relief for any Scope Issues not identified in a notice provided to the Administration during the Scope Validation Period.*

*Within a reasonable time after the Administration's receipt of the documentation, the parties shall meet and confer to discuss the resolution of such Scope Issues. If the Administration agrees that the Design-Builder has identified a valid Scope Issue, a change order will be executed to increase the value of the Design and Preconstruction Fee; however, the Construction Services will be adjusted to retain the overall fixed value of the contract. Notwithstanding anything to the contrary in the Contract Documents or a matter of law, the Design-Builder shall have the burden of proving that the alleged Scope Issue could not have reasonably been identified prior to the submission of the Technical Proposal and such Scope Issue materially impacts its Design and Preconstruction Services Fee.*

*The parties acknowledge that the purpose of the Scope Validation Period is to enable the Design-Builder to identify those Scope Issues that could not have reasonably been identified prior to the submission of the Technical Proposal. By submission of the Technical Proposal, the Design-Builder acknowledges that the Scope Validation Period is a reasonable time to enable the Design-Builder to identify Scope Issues that materially impacts its Design and Preconstruction Fee. The Design-Builder will assume and accept all risks to complete the Design and Preconstruction Services at the conclusion of the Scope Validation Period without any change in the fee absent any change to the Contract requirements after the completion of the Scope Validation Period.”*

## REFERENCES

- Arditi, D., and M. Z. Albulak. "Line of Balance Scheduling in Pavement Construction." *Journal of Construction Engineering and Management*, Vol. 112, No. 3, 1986, pp. 411–424.
- Beard, L.J., C.M. Loulakis, and C.E. Wundram, *Design- Build: Planning Through Development, 1st ed.*, McGraw–Hill Professional, New York, N.Y., 2001, p. 10.
- Bernstein, H.M., Russo, M. A., and Laquidara-Carr, D., *Mitigation of Risk in Construction*, Smart Market Report, McGraw Hill Construction, 2011, 56pp.
- Callahan, M.T., D.G. Quackenbush, and J.E. Rowings. *Construction Project Scheduling*, New York: McGraw-Hill, 1992, pp. 86-112, 200-210.
- Carr, R. I., and Meyer, W. L. "Planning construction of repetitive building units." *Journal of the Construction Division*, ASCE, 100(3), 1974, pp.403-412.
- Castro-Nova, I, G.M. Gad and D.D. Gransberg, "An Assessment of State Agency Practices in Managing Geotechnical Risks," *Transportation Research Record, Journal of the Transportation Research Board*, National Academies, Paper 17-03399, 2017.
- Castro-Nova, I., B. Cetin, and D.D. Gransberg, "Identification of Potential Geotechnical Risk Factors in Design-Build Transportation Projects" *Journal of Management in Engineering*, ASCE, 2017. (in press).

- Cetin, K. S. “Characterizing large residential appliance peak load reduction potential utilizing a probabilistic approach,” *Science and Technology for the Built Environment*, Vol. 22, No. 6, 2016, pp. 720–732.
- Christensen M.R. and Meeker, L.E. “Design/Build Projects – Lessons Learned from the Contractor’s Perspective,” *Proceedings, American Railway Engineering and Maintenance-of-Way Association*, Lanham, Maryland, 2002, p.14
- Clark, G.T. and Borst A. “Addressing Risk in Seattle’s Underground,” *PB Network*, January, 2002, pp. 34-38.
- Clayton, C. R. “Managing geotechnical risk: Improving productivity in UK building and construction.” London: Thomas Telford, 2001.
- Craigie, E., D.D. Gransberg, and H.D. Jeong. “Cost and Scope Breakdown Structure for Functional Level Estimating of Consultant Fees.” *Transportation Research Record: Journal of the Transportation Research Board*, No. 2573, National Academies, 2016, pp. 78-89.
- Gransberg, D.D., “Case Studies of Early Contractor Design Involvement to Expedite the Delivery of Emergency Highway Projects,” *Transportation Research Record No. 2347, Journal of the Transportation Research Board*, National Academies, 2013, pp. 19-26.
- Department of Education (DOE). “Designing Structured Interviews for Educational Research.” *ERIC/AE Digest*. ERIC Clearinghouse on Assessment and Evaluation Washington DC, 1997.

Design-Build Institute of America (DBIA), *Design-Build Manual of Practice*, DBIA, Washington, D.C., 2009, pp. 6–35.

Design-Build Institute of America (DBIA), State Statute Report, 2015. [online]

Available at:

[https://www.dbia.org/advocacy/state/Documents/state\\_statute\\_report151029.pdf](https://www.dbia.org/advocacy/state/Documents/state_statute_report151029.pdf)

[March 6, 2017]

Duffy, G. A., G. D. Oberlender, and D. H. Seok Jeong. "Linear Scheduling Model with Varying Production Rates." *Journal of Construction Engineering and Management*, Vol. 137, No. 8, 2011, pp. 574–582.

Eisenhardt, K. M. "Better Stories and Better Constructs: The Case for Rigor and Comparative Logic." *Academy of Management Review*, 16(3), 1991, 620-627.

Eisenhardt, K. M. "Building Theories from Case Study Research." *The Academy of Management review*, 14(4), 1989, 532-550.

El-Sayegh, S.M. "Linear construction planning model (LCPM): A new model for planning and scheduling linear construction projects." *Ph.D. thesis, Texas A&M Univ.*, College Station, TX, 1998.

Federal Highway Administration (FHWA), *Design-Build Effectiveness Study – As Required by TEA-21 Section 1307(f): Final Report*, USDOT Federal Highway Administration, Washington, D.C., January 2006, 215pp. [Online]. Available: <http://www.fhwa.dot.gov/reports/designbuild/designbuild0.htm> [March 20, 2011].

Flyvbjerg, B. "Five Misunderstandings About Case-Study Research," 12(2), 2006, 219-245

French, B., "Three Risk Management Approaches," Unpublished interview with author, Virginia Beach, Virginia, 2006.

Gransberg D.D. and Loulakis, M.C., *Geotechnical Information Practices in Design-Build Projects*, Synthesis 429, Transportation Research Board, National Academies, Washington, D.C. 2011, 124pp.

Gransberg D.D., M.C. Loulakis, and G.M. Gad, *Alternative Technical Concepts for Contract Delivery Methods*, NCHRP Synthesis 455, Transportation Research Board, National Academies, Washington, D.C. 2014, 119pp.

Gransberg, D.D. and G.M. Gad, "Geotechnical Requirements in the Design-Build Selection Process," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2408, National Academies, 2014, pp. 26-33

Gransberg, D.D., "Case Studies of Early Contractor Design Involvement to Expedite the Delivery of Emergency Highway Projects," *Transportation Research Record No. 2347, Journal of the Transportation Research Board*, National Academies, 2013, pp. 19-26.

Harmelink, D. J., and J. E. Rowings. "Linear scheduling model: Development of controlling activity path." *Journal of Construction Engineering and Management*, Vol. 124, No. 4, 1998, pp. 263–268.

Harmelink, D.J. "Linear scheduling model: The development of a linear scheduling model with micro computer applications for highway construction project control", PhD Dissertation, Iowa State University, Ames, Iowa, 1995, 221pp.

Harris, R. B., and P. G. Ioannou. "Scheduling Projects with Repeating Activities." *Journal of Construction Engineering and Management*, Vol 124, No. 4, 1998, pp. 269.

Hatem, D.J., "Risk Allocation for Subsurface Conditions and Defective Design," *Design-Build Subsurface Projects*. Edited by Brierley, G.S. Corkum D.H. and Hatem, D. J. Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 2011, 228pp.

Higbee, J.B., "Geotechnical Issues with Large Design-Build Highway Projects." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1868, National Academies, 2004, pp.147-153.

Hitt, R., "Alternative Technical Concepts and Design-Bid-Build," Unpublished presentation, FHWA Every Day Counts Summit, Kansas City, Missouri, October 2012, 22pp.

Jergeas, G. and J. Van der Put, "Benefits of Constructability on Construction Projects," *Journal of Construction Engineering and Management*, Vol. 127, (4), 2001, p 281.

Johnson, D. W. "Linear Scheduling Method for Highway Construction." *Journal of the Construction Division*, Vol. 107, No. 2, 1981, pp. 247-261.

- Jones, C., (2005). "Linear Scheduling. Presentation Slides" Unpublished Lecture given at Norman, Oklahoma, (April 4, 2005), Peter Kiewit and Sons, Inc., Dallas, Texas.
- Ke, H., and B. Liu. "Project scheduling problem with stochastic activity duration times." *Applied Mathematics and Computation*, Vol. 168, No. 1, 2005, pp. 342–353.
- Khedr, M. K. "Project Risk Management Using Monte Carlo Simulation." *AACE International Transactions*, 2006, pp. 1–10.
- Kim, K.J., C.A. Kreider, and M.D. Valiquette. "North Carolina Department of Transportation's Practice and Experience with Design–Build Contracts Geotechnical Perspective," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2116, National Academies, 2009, pp. 47–52.
- Lee, J.S. "Delay analysis using linear schedule in construction," *AACE 403 International Transactions*, Annual Meeting, Vol. 404, 2007, pp. 1-6.
- Lee, J.-S., and J. E. Diekmann. "Delay analysis considering production rate." *Canadian Journal of Civil Engineering*, Vol. 38, No. 4, 2011, pp. 361–372.
- Lopez del Puerto, C., and D.D. Gransberg. "Fundamentals of Linear Scheduling for Cost Engineers," *Transactions, AACE, International, Toronto, Ontario, Canada*, 2008, PS.05.01-PS.05.08



- Loulakis, M.C. and O. J. Shean, "Risk Transference in Design-Build Contracting," *Construction Briefings, 2<sup>nd</sup> series*, Federal Publications, Washington, DC, 1996, 12pp.
- Loulakis, M.C., B.P. Wagner, and H.C. Splan, "Differing Site Conditions," Chapter 11, *Construction Claims Deskbook*, R.S. Brams and C. Lerner, Eds., Aspen Law and Business, New York, N.Y., 1995, pp. 131–166.
- Loulakis, M.C., N.C. Smith, D.L. Brady, R.E. Rayl, and D.D. Gransberg, *Liability of Design-Builders for Design, Construction, and Acquisition Claims*, NCHRP Legal Synthesis 20-02, Transportation Research Board, National Academies, Washington, D.C. 2015, 258pp.
- Maine Department of Transportation, *Request for Proposals, I-295 Commercial Street Connector*, FHWA Project No. IMD-7589(300); Maine DOT Project No. 7589.30, Maine Department of Transportation, Augusta, 2003.
- Marchman, D.A. "*Construction Scheduling with Primavera Project Planner*®". Delmar Publishers, Albany, NY, 1998, pp. 97-118.
- McLain, K., D.D. Gransberg, and M.C. Loulakis. "Managing geotechnical risk on US design-build transport projects." *Australasian Journal of Construction Economics and Building* 14, no. 12 (2014): 1, 2014.
- Miller, J.B., Garvin, M.J. Ibbs, C.W. and Mahoney, S.E. "Toward a new paradigm: simultaneous use of multiple project delivery methods." *Journal of Management in Engineering*, 16(3), 2000, pp. 58-67.

- Minnesota Department of Transportation *Design-Build Manual*, MnDOT, St Paul, Minnesota, 2012, [http://www.dot.state.mn.us/designbuild/documents/online/DBv12.htm#\\_Toc305159425](http://www.dot.state.mn.us/designbuild/documents/online/DBv12.htm#_Toc305159425) [May 19, 2015].
- Missouri DOT (MoDOT). Hurricane Deck Bridge Replacement Project. Presented at the 20 ATC Meeting, February 10, 2011. 21  
[http://www.modot.org/central/major\\_projects/camden.htm](http://www.modot.org/central/major_projects/camden.htm).
- Mulholland, B., and J. Christian. "Risk Assessment in Construction Schedules." *Journal of Construction Engineering and Management*, Vol. 125, No. 1, 1999, pp. 8–15.
- Nasir, D., B. McCabe, and L. Hartono. "Evaluating Risk in Construction–Schedule Model (ERIC–S): Construction Schedule Risk Model." *Journal of Construction Engineering and Management*, Vol. 129, No. 5, 2003, pp. 518–527.
- Papernik, B.G. and Farkas, D.J., "Using Alternative Technical Concepts to Improve Design-Build and PPP Procurements," Nossaman E-Alerts, (2005) [Online]. Available: <http://www.nossaman.com/using-alternative-technical-concepts-improve-designbuild-ppp>, [May 26, 2016].
- Pittenger, D.M., D.D. Gransberg, M. Zaman, and C. Riemer. "Stochastic Life Cycle Cost Analysis for Pavement Preservation Treatments," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2292, National Academies, 2012, pp. 45-51.
- Rueda-Benavides, J.A. and D.D. Gransberg, "Indefinite Delivery/Indefinite Quantity Contracting: A Case Study Analysis," *Transportation Research Record*, No.

2408, *Journal of the Transportation Research Board*, National Academies, 2014, pp. 17-25.

Schaefer, V.R., Douglas, S.C. and Berg, R.R., "SHRP2 R02 Geotechnical Solutions for Transportation Infrastructure: Guidance and Selection System," *TRB 2011 Annual Meeting*, Washington, D.C. January 2011.

Scheepbouwer, E. and Humphries, A.B., "Transition in Adopting Project Delivery Method with Early Contractor Involvement," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2228, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 44–50.

Schomburg, K. A., P. D. Collopy, P. J. Compton, and C. C. Krejci. "Systems Engineering and Project Success at NASA," *Proceedings of the 2015 Industrial and Systems Engineering Research Conference*, 2015, pp. 379–388.

Smith, K. "ATCs: Implications and Nuances from both the Owner and the Proposer Perspectives," Paper 12-6803, TRB 2012, 22pp.

Smith, R. "An Evolving View of Geotechnical Engineering – A Focus on Geo-Risk Management Geotechnical Special Publication No. 178, GeoCongress 2008: Geosustainability And Geohazard Mitigation, New Orleans, Louisiana, March 9-12 2008, pp. 231-239.

Songer, A.D. and Molenaar, K.R. (1996). "Selecting design-build: private and public sector owner attitudes," *Journal of Management in Engineering*, ASCE, Vol. 12(6), 1996, pp. 47-53.

- Tapia P. R.M. and Gransberg, D.D., “Forensic Linear Scheduling for Delay Claim Analysis: Panama Canal Borinquen Dam Case Study,” *Compendium*, 2016  
Transportation Research Board Annual Meeting, Paper 16-0557, January 2016.
- Tapia, R.M. Gransberg D.D. and Touran A., “Managing Scheduling Risk Due to Geotechnical Uncertainty Using Linear Scheduling,” *Compendium*, 2017  
Transportation Research Board Annual Meeting, Paper 17-01389, January 2017.
- Tellis, W. M. (1997). “Application of a Case Study Methodology,” *The Qualitative Report*, 3(3), 1-19. Retrieved from <http://nsuworks.nova.edu/tqr/vol3/iss3/1>  
[December 6, 2015]
- Trauner Consulting Services, “Innovative Procurement Practices Alternative Procurement and Contracting Methods,” California Department of Transportation Report No. 53A0104 Sacramento, California, 2007, pp. 10-12
- Trevicos, G. “Tuttle Creek Dam Modification Project,” *Technical Reference Report 2005-09*, The Trevi Group, Charlestown, MA, 2010, pp. 1-2.
- URS Corporation, Basis of Schedule Revision and Schedule Risk Analysis, Under Contract SAA-241959 Engineering Services for Borinquen 1E Dam, Unpublished report for the Panama Canal Authority, Panama, January, 2013.
- U.S. Army Corps of Engineers (USACE), Army Reserve Design/Build RFP Instruction Manual, USACE, Washington, D.C., Sep. 2009, 73 pp.
- United States v. Spearin, (Spearin) 248 U.S. 132, 39 S. Ct. 59, 63 L. Ed. 166 (1918).

- Vermont Agency of Transportation (VTrans) *Request for Qualifications, US Route Bridge Improvement, Bridge No. 24, Town of Richmond Vermont*, VTrans Project No. Richmond STP-RS 0284(11), VTrans, Montpelier, Vermont, 2010b, 46 pp.
- Washington State Department of Transportation (WSDOT). *Guidebook for Design-build Highway Project Development*, Washington State Department of Transportation, Olympia, Washington, 2004, 109 pp.
- Weaver, P. "Brief History of Scheduling – Back to the Future," Proceedings, myPrimavera Conference, Canberra, Australia, 2006.
- Yamín, R. a., and D. J. Harmelink. "Comparison of Linear Scheduling Model (LSM) and Critical Path Method (CPM)." *Journal of Construction Engineering and Management*, Vol. 127, No. 5, 2001, pp. 374–381.
- Yates, J. K. and L.C. Battersby, "Master Builder Project Delivery System and Designer Approach to Transportation Projects *Transportation Research Record: Journal of the Transportation Research Board*, No. 1575, *Journal of the Transportation Research Board*, National Academies, Washington, D.C., 2007, pp.116-121.
- Yin, Robert K. *Case Study Research: Design and Methods*. Sage Publications, New York, 2011.
- Yuksel, I.T. and O'Connor, J.T. *Schedule compression of an urban highway project using the linear scheduling method*, Center for Transportation Research, Austin, Texas, 2000, 99pp.