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EDITED BY
Zhen Chen,
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REVIEWED BY
Önder Ökmen,
Delft University of Technology, Netherlands
Fidelis A. Emuze,
Central University of Technology, South Africa

*CORRESPONDENCE
William J. O'Brien,
wjob@mail.utexas.edu

†Present address:
Department of Civil and Environmental Engineering, Rutgers, The State University of New Jersey, Piscataway, NJ, United States

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Influential factors for risk assessment and allocation on complex design-build infrastructure projects; the Texas experience

Vassiliki Demetracopoulou[1†], William J. O'Brien[1*] and Nabeel Khwaja[2]

[1]Department of Civil, Architectural, and Environmental Engineering, The University of Texas at Austin, Austin, TX, United States, [2]Center for Transportation Research, The University of Texas at Austin, Austin, TX, United States

Introduction: The design-build (DB) delivery method is used to deliver increasingly complex transportation infrastructure projects associated with higher uncertainty. As such, allocating risks in the contract between the owner and design-builder becomes challenging and often leads to higher initial bids, increased contingency, or claims. Learnings from implementation worldwide have underlined the need for improving risk allocation in DB contracts. Most existing studies address risk allocation mechanisms to manage contingency at the contract level. Other studies have recognized the need for owners to adapt their processes to better allocate risks in DB contracts. This study explored the influential factors for risk assessment and allocation for complex DB infrastructure projects, addressing the opportunity to improve transportation owners' risk allocation processes before the design-builder is selected and the DB contract is awarded.

Method: The objectives of this work were achieved by utilizing empirical data collected through 20 interviews with Texas Department of Transportation and private sector experts. The interview data were analyzed using inductive and axial coding. Inductive coding allowed themes to emerge without a pre-existing framework, identifying six influential *factors* and six pertinent *risks* on complex DB projects.

Results: These factors include the (i) Quality of DB teams, (ii) Level of up-front investigation, (iii) Limitations on the timing of letting, (iv) Design optimization opportunities, (v) Project-specific requirements, and (vi) Relationships with third parties. Through axial coding, the interaction and frequency between the *factors* and *risks* were also examined. The coded interactions demonstrated how the identified *factors* influence allocation for six pertinent *risks* including right-of-way acquisition, stakeholder approval, site conditions, permits and third-party agreements, railroad interaction, and utility adjustments and coordination. Findings indicate that the evaluation of these interactions can shift the risk allocation from baseline norms established by an agency to correspond to project-specific needs.

Contribution: In contributing to the infrastructure project management, this is the first study to examine the factors that influence risk allocation in complex DB projects and examine interactions with pertinent risks, setting the foundation for optimizing allocation based on project-specific needs. In practice, the findings presented in this study can guide owners in adapting their allocation practices, managing, and developing their strategic plan for delivering complex DB projects. The findings can also assist contractors in pricing risks more efficiently and increase competitive bidding.

KEYWORDS

design-build, risk, risk allocation, transportation infrastructure, complex projects, transportation owners

1 Introduction

Increased experience with design-build (DB) has led to lessons learned around its selection and implementation. In particular, the role of risk has been examined in literature since a delivery method provides a means for allocating risk among contractual parties (Tran and Molenaar, 2015; Liu et al., 2016). Some researchers have discussed risk allocation based on project delivery method (PDM) selection. Gransberg and colleagues (2006), for instance, found that an important advantage of choosing DB is that doing so transfers some of the design liability and disputes risks to the DB contractor (or design-builder). On the other hand, such risks as right-of-way (ROW) acquisition are best mitigated through the selection of design-bid-build (DBB) (Molenaar et al., 2005). However, improper risk allocation on highway projects can result in higher initial bids and less competition (Ghavamifar and Touran, 2009). Therefore, there is a need to both further investigate risk assessment and allocation on infrastructure projects and to examine the nuances related to different project conditions and outside factors.

The process of managing risk entails several steps, including assessment, mitigation, allocation, and management. Each stage, though, comes with its own uncertainties. For DB contracts, where the design is incomplete, the uncertainties are higher than in traditional DBB projects. In addition, as projects become more complex, the risk and uncertainty only increase (Erol et al., 2020). Therefore, for complex DB projects, a design-builder will typically try to account for project risks and their management in a project's lifecycle by assigning high contingencies in the contract.

Complex projects have been characterized in literature as consisting of many varied interrelated parts (Baccarini, 1996), uncertainty in goals and methods (Williams, 1999), and demanding an exceptional level of management beyond the conventional systems for ordinary (non-complex) projects (Morris and Hough, 1987). In the context of this work, complex DB infrastructure projects were characterized based on their scope as the projects discussed by experts were executed in urban corridors with high traffic volumes and constrained environment. Interviewees drew insights from DB projects with a combination of these conditions along with significantly large size with costs ranging from $315.6M to $2.1B. Improper risk assessment and allocation in such projects could result in high contingencies and liquidated damages from delays. As a result, providing insights into

TABLE 1 Common risks in infrastructure projects.

Design risks
Design quality and integrity
Design errors and omissions (e.g., errors in plans/specs/estimates)
Long period of design review required by owner
Owner's requirement for design changes
Right-of-way (ROW) and utility risks
Delays in ROW acquisition
Delays in utility agreements
Unexpected utility encounter
Risks related to third parties
Challenges with railroads
Challenges with environmental permit
Obtaining other agency permits
Obtaining public stakeholders approval
Construction risks
Material, labor, and equipment resourcing
Unforeseen site conditions
Managing traffic during the construction phase
Contract and regulations risks
Conflict in contract documents
Changes in rules and regulations
Issues related to strikes/labor disputes
Inadequate claim administration
Economic risks
Market conditions (e.g., project location, availability of qualified contractors)
High inflation
Price escalation of construction materials
Other
Force majeure
Political environment (e.g., change of government and policies)

how risks are assessed and allocated considering the uncertainties of the DB method is essential.

Recent studies have found that the DB contracting process requires significant procedural and cultural changes for state highway agencies (SHAs) (NCHRP 2020). Furthermore, researchers have investigated the evolution of the risk management process as well as the tools that SHAs employ to manage DB contracts (Papajohn et al., 2019; Papajohn et al., 2020).

However, these approaches aim to improve contract management, and collaboration after the risks have been allocated between the agency and the design-builder. The factors that capture uncertainties and impact the risk assessment and allocation before DB contracts are awarded have yet to be explicitly identified. In trying to fill this gap in the literature, this study investigates the factors that impact risk assessment and allocation for complex DB projects. This work utilizes empirical data from interviews with 20 subject matter experts from the transportation infrastructure private sector (Industry) and the Texas Department of Transportation (TxDOT).

The rest of the paper is organized as follows. The literature review presents risks that may arise in transportation infrastructure projects and their relationship with project complexity and the DB delivery method. The materials and methods section outlines the research questions this study sought to answer, and the methods employed to achieve the goals. The results and discussion present the key factors identified that impact risk assessment and allocation and their relationship with some pertinent risks highlighted by the interviewees. Finally, the conclusions section summarizes the findings and contributions of this work.

2 Literature review

According to the Project Management Body of Knowledge (PMBOK) Guide (PMI, 2017), risk is "an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives." The uncertainty associated with risk relates both to the probability of occurrence and the possible impact on the project. Multiple studies have identified risks in infrastructure projects (Wang and Chou, 2003; Vassallo, 2006; Zaye d et al., 2008; Zou et al., 2007; Creedy et al., 2010; Alarcon et al., 2011; Chan et al., 2011; Marques and Berg, 2011; Tran and Molenaar, 2014; El-Sayegh and Mansour, 2015). A synthesis of common risks in transportation infrastructure projects (as captured through a review of the literature) is presented in Table 1.

As the complexity of an infrastructure project rises, so do its risks (Erol et al., 2020; Yang et al., 2021). Vidal and Marle (2008) defined project complexity as "the property of a project, which makes it difficult to understand, foresee, and keep under control its overall behavior, even when given reasonably complete information about the project system." Baccarini (1996) was one of the first to conceptualize project complexity in terms of organizational and technical dimensions. In 2011, Bosch-Rekveldt et al. (2011) developed the technical-organizational-environmental (TOE) framework. Various studies have since used the TOE framework to assess complexity in large engineering projects. In the project management literature, researchers see uncertainty as either a driver (Geraldi et al., 2011) or a consequence (Floricel et al., 2016) of project complexity. Both approaches have merit and support the further examination of risk in complex projects. Demetracopoulou et al. (2022) explored complexity and innovation specifically for DB projects. They found that complexity stems from inherent project characteristics while innovation relates to the exogenous innovation opportunities that the contractor may apply. Complexity may be primarily contributed to the following elements: traffic challenges, design elements, and project constraints. In response, innovation opportunities were categorized into traffic handling and control plans, developer's resource and schedule optimization, and design and construction methods.

In addition to deepening our understanding of the complexity of DB infrastructure projects, researchers have advanced the understanding of DB risk assessment and allocation. When DB was first implemented, it was often seen as a vehicle to transfer all risk to the design-builder. Seng and Yusof (2006) found that DB was a method that transferred more risk to the contractor than any other construction contract. However, improper risk allocation can impact project success and increase costs. Ghavamifar and Touran (2009) found that choosing DB to transfer risk to the contractor could result in higher initial bids and less competition. Lam and colleagues (2007) stated that the cost of improper risk allocation is evident in contractors' responses, such as adding a high contingency (premium) to the bid price or delivering low-quality work.

Hence, one needs to examine project conditions and outside factors to ensure efficient and risk-specific allocation. Early studies in the area suggest that some risks in DB projects are logically assigned to the owner, while some are generally assigned to the design-builder (Molenaar et al., 2000). In a DB contract, according to the Federal Highway Administration (2006), the design errors and omissions risk is transferred to the design-builder. Similarly, Khwaja et al. (2018) and the *Recommended AASHTO Design-Build Procurement Guide* (Molenaar et al., 2005) found that in a DB contract utility adjustments and relocations are best allocated to the contractor. In addition, Tran and Molenaar (2014) argued that in a DB contract ROW acquisition represented a risk that should be assigned to the owner.

A vital step to structuring a DB contract is, of course, allocating risk. However, ensuring each risk is allocated to the party best equipped to manage it is not uniform for every project and organization. For most types of risk, the allocation depends on the project conditions, often presenting opportunities for risk-sharing. SHAs and DB contractors across US states can vary regarding their organizational characteristics and experience with DB. Furthermore, some states have legal limitations attached to the DB delivery method. For example, the Washington State DOT (WSDOT) is legislatively pre-approved and strongly encouraged to use DB as a PDM for projects costing $2 million and over (WSDOT, 2015). TxDOT, in contrast, can employ the DB method only for projects costing $150 million and over (Texas Transportation Code, 2011). In addition, according to the US DOT (USDOT, 2017), agencies differ in their approaches to allowing time extensions and price increases for changes; changes in the project schedule, budget, and public impacts are tied to complex infrastructure projects and strongly influence the decision-making process.

Those differences underline the importance of exploring the factors that impact risk assessment and allocation on DB contracts, as uniform allocation for specific risks would be inefficient. To the authors' knowledge, studies have yet to explore such factors in the context of complex DB projects. However, literature in other areas can

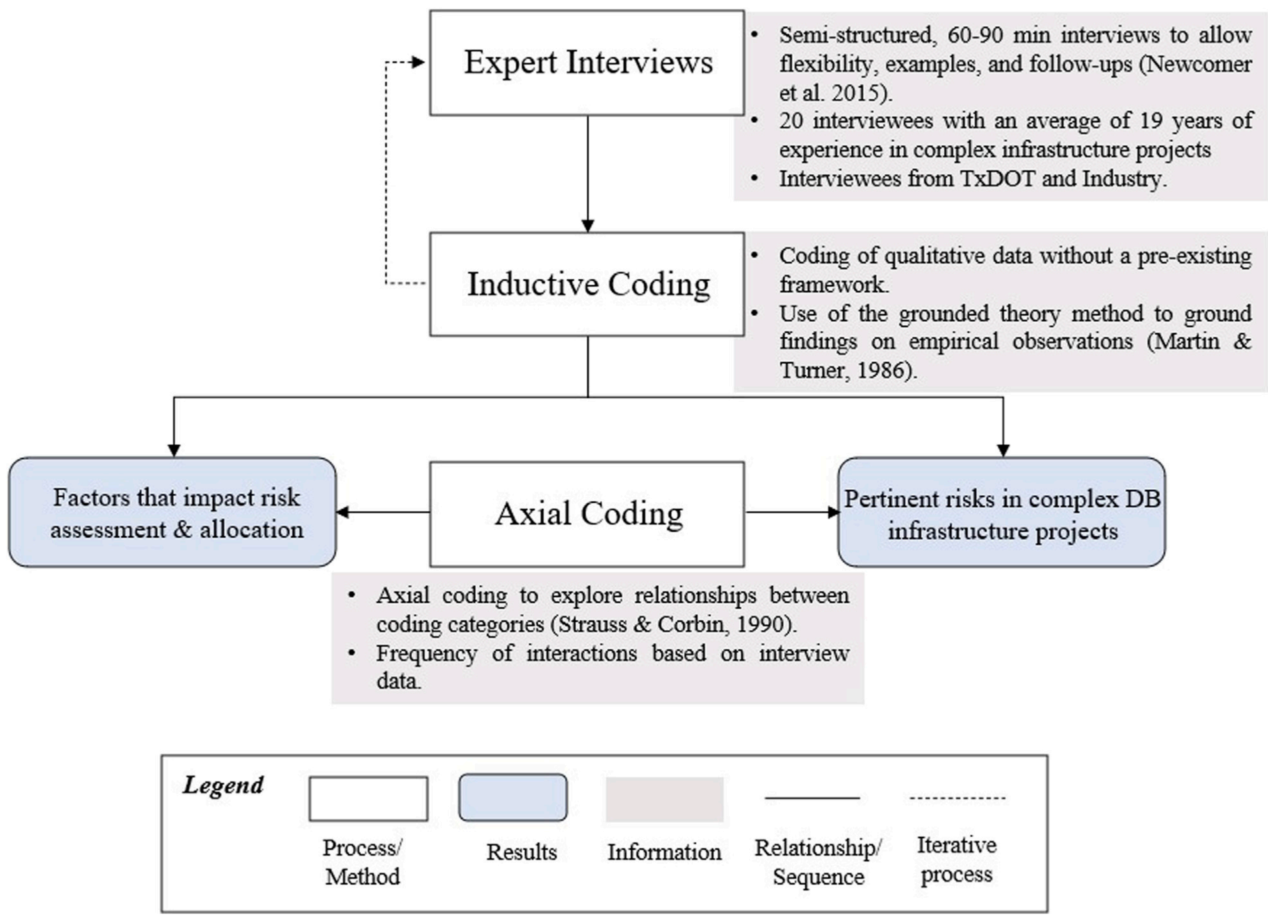

FIGURE 1
Research methodology.

shed light on factors impacting risk. For instance, Howard and Serpell (2012) found that in construction projects, the key factors impacting risk management are organizational culture, process structure, application of the risk management process, and development and experience in risk management. Further, drawing from experiences with public-private partnership (P3) projects, Jin (2010) found that the main determinants for efficient risk allocation are (1) partners' risk management routine, (2) partners' risk management mechanism, (3) partners' cooperation history, (4) risk management environmental uncertainty, and (5) partners' risk management commitment. Miller and Lessard (2008) echoed the need for iterative and pragmatic risk assessment in mega-projects, outlining strategies to minimize the impacts of risks such as information search, network building and co-optation, structures of incentives and contracts, project/design configuration, and influence and bold actions.

In summary, for DB projects, the literature has explored risk from various standpoints, including the following: impact on method selection (Tran and Molenaar, 2014), impact on project performance (Liu et al., 2017), risk management (Molenaar et al., 2005; Papajohn et al., 2019), and allocation (Ghavamifar and Touran, 2009; Bypaneni and Tran, 2018). As a result, a good understanding exists regarding many aspects of risk in infrastructure projects. In the context of complex DB projects, the literature reflects the evolution of risk allocation from delivery method-based (Seng and Yusof, 2006) to project-based by outlining important risks and providing recommendations (Bypaneni and Tran, 2018). In addition, recent literature has captured the need to better manage risks on DB contracts, and the cultural changes SHAs need to make to achieve it (Papajohn et al., 2020). Therefore, as public and private agencies refine their understanding of risk allocation based on different project conditions, an essential addition to DB literature is an investigation of influential factors that, on complex DB projects, impact allocation and their interactions with common risks.

3 Materials and methods

Taking into consideration the environment of additional uncertainty, this study explored the factors that impact risk allocation in the context of complex DB infrastructure projects. Further, this study aims to provide a contemporary understanding of the risk assessment and allocation processes between agencies and contractors based on empirical data. As a result, this study sought to answer these research questions:

- What are pertinent risks in complex DB projects that include significant uncertainty?

- What are the influential factors for risk assessment and allocation on complex DB projects? How do they manifest on pertinent risks?

Figure 1 summarizes the methodology employed in this study.

3.1 Data collection

For the principal data collection method, the authors chose to employ semi-structured interviews. The flexibility of such an approach allows each interviewee to draw on their experience, supports the broad exploration of topics, and provides an opportunity for follow-up questions (Newcomer et al., 2015). The primary screening criterion for selecting these subject matter experts was their experience with complex DB projects. The research team interviewed 20 people, including agency experts from TxDOT and industry professionals. Interviewees had an average of 19 years of experience with complex infrastructure projects. Of the 20 interviewees, 16 were from TxDOT, and four experts represented the industry with both design and construction backgrounds. Interviewees' positions included Director of Project Planning and Development, District Engineer, Director of Construction Division, Director of Strategic Contract Management, and Senior Manager of Alternative Delivery. The experts provided verbal consent to participate in this study, which follows the Institutional Review Board (IRB) protocol (STUDY00000905) and has been approved by The University of Texas at Austin IRB (UT IRB).

Interviewees were called to provide examples specific to their experience in complex DB projects. An interview guide was developed, piloted, and amended after interviews with three agency experts. The interview data obtained before finalizing the guide were excluded from the analysis. Each interview lasted 60–90 min, and the interview guide included the following topics:

- Interviewee's background and experience with DB and DBB projects
- Most problematic/pertinent risks on complex DB projects
- Examples of successful risk allocation in DB projects
- Recommendations for risk allocation practices for the pertinent risks
- Influential factors for risk allocation
- How risk allocation practices change based on influential factors

3.2 Data analysis and validation

All interviews were transcribed and coded using the qualitative coding software Dedoose (Lieber et al., 2011). The methodology used to elicit the codes and findings from the qualitative data was grounded theory (Glaser and Strauss, 1967). The basic principle of the method is inductive reasoning that enables the researcher to "develop a theoretical account of the general features of the topic while simultaneously grounding the account in empirical observations of data" (Martin and Turner, 1986, p. 141). As such, inductive coding leverages inductive reasoning to draw inferences based on raw data that are coded without a pre-existing framework. In this study, responses were coded using the "*in vivo*" scheme that captured the respondent's views rather than any research-imposed framework (Saldaña, 2009). The initial stage of inductive coding is also referred to as open coding, meaning "the analytic process which concepts are identified and their properties and dimensions are discovered in data" (Strauss and Corbin, 1998, p. 101).

The interactions between the risks and the factors that impact risk assessment and allocation were captured through axial coding. According to Strauss and Corbin (1990), axial coding is used to investigate the relationships between concepts and categories that have been developed in the inductive coding process. Axial coding has been used to explore interactions in qualitative construction research (Bakchan et al., 2021). To study the factors that impact risk allocation it is essential to identify the most pertinent risks in complex project environments. Based on the experts' input, six risks were identified as pertinent, along with six factors containing uncertainty that may shift allocation. An interaction was coded between these two categories (risks, factors) on the condition that if the factor assessment varies, it impacts the allocation of a specific risk. For instance, the level of upfront investigation (e.g., low vs. high) impacts the risk allocation in part or in whole for public utilities (e.g., retained by the agency vs. assigned to the DB contractor).

The code validation was an iterative process. According to Glaser (1965), coding consistency and validation in inductive coding involve joint coding with multiple investigators to produce more systematic theory development. As a result, the research team discussed the coded excerpts and corresponding codes to ensure agreement and consistency throughout the data analysis process. There is agreement in the literature (Bernard, 2017; Spearing et al., 2022) that rather than using intercoder reliability statistics, validity in constant comparative analysis and grounded theory is driven by establishing trustworthiness. Trust is supported through criteria such as coding consistency across multiple researchers that could help reduce subjective bias. Furthermore, theoretical saturation was reached (i.e., no new core categories and relationships among them emerged (Charmaz, 2006)) at interview #11. As a result, the analysis can be used to extend or develop theory, and the additional data were used to validate the emerging codes and provide further practical examples.

4 Results and discussion

4.1 Influential factors for risk allocation

Six influential factors for risk assessment and allocation were identified through the qualitative insights provided by the interviewees. These factors influence the assessment and allocation of risks in a DB contract and capture how efficient allocation may change in response to project characteristics and organizational requirements. Some factors reflect the inherent characteristics and conditions that may restrict DB flexibility, while others relate to outside factors and market conditions. Identifying these factors promotes the recommendation of case-by-case analysis on risk allocation decisions. Table 2 summarizes the factors that were extracted from the inductive coding.

4.1.1 Quality of DB teams

An influential factor identified by both agency experts and contractors is the importance of the DB team both from the agency's and the contractor's sides. This work identified the quality of DB teams can be primarily described as a function of

TABLE 2 Description of influential factors for risk allocation.

Code (factor) name	Code (factor) description
Quality of DB teams	Risk allocation is significantly affected by the teams involved, both from the agency and the contractor. When considering risk allocation, components that are essential include the agency's team's ability to make decisions in a timely manner, as well as the contractor's ability to accurately price risks
Level of up-front investigation	The level of up-front investigation performed by the agency on risks, such as utilities, dictates the availability of information and helps quantify the risk's impact on the project
Limitations on the timing of letting	The timing of letting is a critical component when allocating risks in a DB contract. The flexibility to allocate risks, or part of risks, to the contractor, can be a critical element in the DB method selection
Design optimization opportunities	An important element when allocating risks are the opportunities to optimize design, particularly on utilities and railroads. So, a critical consideration when allocating those risks is the opportunity for the contractor to optimize the design to work around utilities or minimize the costs related to interaction with railroads
Project-specific requirements	Project-specific requirements relate to a project's idiosyncratic characteristics (e.g., aesthetic issues) that may require the agency's complete control over the design and construction processes
Relationships with third parties	The agency and the DB contractors have different relationships with third parties (e.g., railroad, utility companies, and local governments). These relationships should be examined during the risk allocation process to ensure each risk is allocated to the party best equipped to handle it

(i) the ability to make decisions in a timely manner and (ii) the ability to price risks accurately. The findings presented here align with and extend current literature. For instance, Liang et al. (2020) found that efficient project teams can impact a DB project's cost and schedule performance. Kim and colleagues (2017) identified one strategy for responding to the changing environment of transportation construction and effectively prepare for the future—SHAs lead workshop training seminars.

Experts underlined the importance of the team's experience and effective integration, particularly for complex projects where the level of risk and capacity for changes are greater. In this study, contractors indicated that one of the most important aspects of the agency's team is the ability to make decisions in a timely manner. In a DB project, where the design and construction phases overlap, owners have a very short window to approve changes in design and make complex decisions. Design reviews are also part of the DBB process; however, the sequential nature of design and construction allows owners to review documents at various development stages before the project is bid out. One of the benefits of DB is the design-builder's ability to react quickly to changes or problems, especially for complex issues like traffic control or utility relocation. As a result, the agency needs to do all of the following: provide constant input and timely approvals, cooperate with the contractor, and work alongside the contractor for the duration of the project to resolve issues quickly and achieve the desired goals. To ensure the highest quality while staying within the project's cost and schedule goals, both sides (the agency and contractor) must assemble an efficient team that is both qualified and experienced.

Interviewees agreed that the experience of a DB contractor directly correlates with their ability to price risks accurately. That characteristic significantly impacts risk allocation; a contractor that overestimates risks will hesitate to take on some that a more experienced contractor would assume and price accurately. On the other hand, underestimating risks may result in lower initial bids, but disputes may arise between the agency and the contractor, compromising the project's performance. Contractors found that the agency is more eager to allocate risks to design-builders with sophisticated risk-pricing mechanisms in place.

4.1.2 Level of up-front investigation

Another factor impacting risk allocation is the level of up-front investigation performed by the agency. As their experience with DB projects increased, agency experts found that the level of up-front investigation regarding the requirements for ROW, utilities, interaction with railroads, and any other third-party issue in the project, significantly impacted the initial bids and the contingency that contractors assigned to their bids. As the level of up-front investigation and coordination done by the agency increases, contractors can price risks more accurately and clearly define the risk level they are willing to take on. Experts argued that the level of upfront investigation done by the agency includes two aspects: (i) availability of information on utility interactions and other third parties and (ii) early coordination with third parties. The extent of an agency's up-front investigation can indicate the maturity of the agency's DB program, or it can reflect the availability (or lack thereof) of assigned resources for a specific project. As a result, this factor should be assessed on both the program and project levels. The literature has yet to examine this factor, despite its potential to contribute significantly to reducing uncertainties and assessing and allocating risks more efficiently.

4.1.3 Limitations on the timing of letting

Agency experts agreed that one of the critical factors that can impact risk allocation is the timing of letting. The agency can transfer additional risks to the contractor to meet a firm letting date. The most representative example is the ROW acquisition. As many agency experts stated, they can transfer some of the ROW acquisition responsibility to the contractor to meet a letting date constraint. However, identifying all necessary parcels and acquiring the critical ones to start construction are actions that the agency will take, in any case, during the project's up-front coordination. In ROW acquisition, the transfer is associated with clear cost and schedule provisions, and the agency bears the risk of any changes. Legislative constraints across SHAs often impose limitations on the timing of letting. For example, TxDOT can procure up to 6 DB projects per biennium while the Kentucky Transportation Cabinet is authorized to use DB on up to five projects per year (DBIA, 2017).

Furthermore, according to agency experts, restrictions regarding the timing of letting may also be imposed by strategic decisions or budgetary constraints.

4.1.4 Design optimization opportunities

Both owners and contractors found that one of the most decisive factors in allocating many project risks is the opportunity to apply innovation by optimizing design. In many cases, for example, the agency is willing to assign the utility coordination risk to the contractor to optimize the design to work around utilities, avoiding the need for utility relocation. Design optimization can influence risks related to third parties (e.g., railroads), as it motivates the design-builders to minimize interactions with those parties during construction. Agency and contractor interviewees agreed that innovative solutions could result in schedule benefits. A critical step toward efficient risk assessment and allocation is assessing opportunities to optimize design on project risks, particularly around utility relocations and railroad interaction.

This factor is particularly important for complex projects where many stakeholders are involved. In addition, complex projects usually have high costs and a lengthy schedule. Therefore, the potential savings through design optimization can represent a significant impact. Existing literature has explored design optimization opportunities mostly from a cost and value-added perspective. Alternative technical concepts (ATCs) are often used to propose innovative solutions that will add value to the project. NCHRP Report 937 (2020) underlined the benefits of the ATC process and created a tool to assist SHAs in implementing ATCs and leverage insights provided by the industry in their future procurement, design, and construction processes.

Experts agreed that this factor is most influential in the risk allocation for DB projects with high traffic volumes, where being on or ahead of schedule during construction is critical. On the other hand, this factor plays a minor role in risk allocation for projects with no existing traffic and minimal interactions with third parties.

4.1.5 Project-specific requirements

While optimization opportunities can increase DB's value, interviewees agree that the factor that most limits DB's flexibility is project-specific prescriptive requirements. SHAs can be prescriptive in some elements across all their projects (DB and DBB) to ensure the desired level of quality and safety (e.g., pavement design). Project-specific prescriptive requirements include limitations beyond the standards and are usually imposed by aesthetics (e.g., a landmark bridge). In projects entailing points of historical importance or bearing significant public impact, the prescriptive requirements often significantly limit the design-builder's innovation. Project-specific limitations may include approvals of design and construction decisions from local stakeholders, resulting in schedule delays and impacting the DB project's performance. Factors that limit DB flexibility can generally discourage a contractor from entering a DB contract, let alone assuming the risk for that part of the project. Therefore, these project-level factors should be assessed during the PDM decision and the risk-allocation phase.

4.1.6 Relationships with third parties

Finally, the relationships that the agency and the contractors have in place with third parties must be examined during the risk-allocation process to ensure risks are allocated based on each entity's ability to manage them. The DB contractor's experience and efficiency can sometimes be reflected in the contractor's relationship with third parties, such as utility and railroad companies. When the contractor has developed relationships with third parties involved in a project (e.g., a specific utility company), they might be willing to take on the risk associated with that third party since they are more equipped to handle it than the agency. Public sector (TxDOT) interviewees stated that DB contractors might also use a relationship with a third party as a selling point to win a project; the contractor is confident that they can handle that risk effectively in terms of both time and cost. In exchange, the agency benefits by transferring an important risk that would require time and resources. A key aspect of the relationship between the contractors and third parties is the possibility of private party agreements outside the DB contracts, which can benefit both the contractor and the third party. For instance, the contractor may agree to perform betterments for a private utility company in exchange for immediate cooperation.

4.2 Pertinent risks and interactions with influential factors

This study also identified the most pertinent risks for complex DB projects to investigate their interactions with the factors that impact risk allocation. For these risks, the assessment and allocation are greatly dependent on the factors outlined above. Drawing from their experiences, the interviewees outlined the most important risks during the management and allocation phase, filtering down a broader list compiled through the literature review (Table 1). For complex DB projects, the most pertinent risks were identified as the following: (1) ROW acquisition, (2) stakeholder input and approval, (3) site conditions, (4) permits and third-party agreements, (5) railroad interaction, and (6) utilities adjustment and coordination. Interviewees recognized the relevance of examining a broad range of risks during early planning (as seen on Table 1); however, these six risks were deemed most critical for assessment and allocation in the project examples discussed. The identified pertinent risks largely align with existing DB literature (Tran and Molenaar, 2014; Bypaneni and Tran, 2018). Some risks, such as the political environment risks, were not discussed by the interviewees. While political support is important to all infrastructure projects, this risk may be more relevant in different contexts and project locations.

For each of the pertinent risks, the experts provided recommendations for mitigation and allocation practices, i.e., which party is more equipped to handle a particular risk and under what circumstances. The interactions between the influential factors and pertinent risks are presented in Figure 2 and discussed below. According to the interview data, Figure 2 illustrates which factors impact which risks. The relationships presented in the table are not exhaustive. While the absence of interaction implies that the interview data did not directly support it, future research may uncover additional interactions between the factors and risks. In addition, the % values in Figure 2 represent the frequency of interaction as discussed in the interview data. Therefore, the % relates to observed frequency and not the strength of

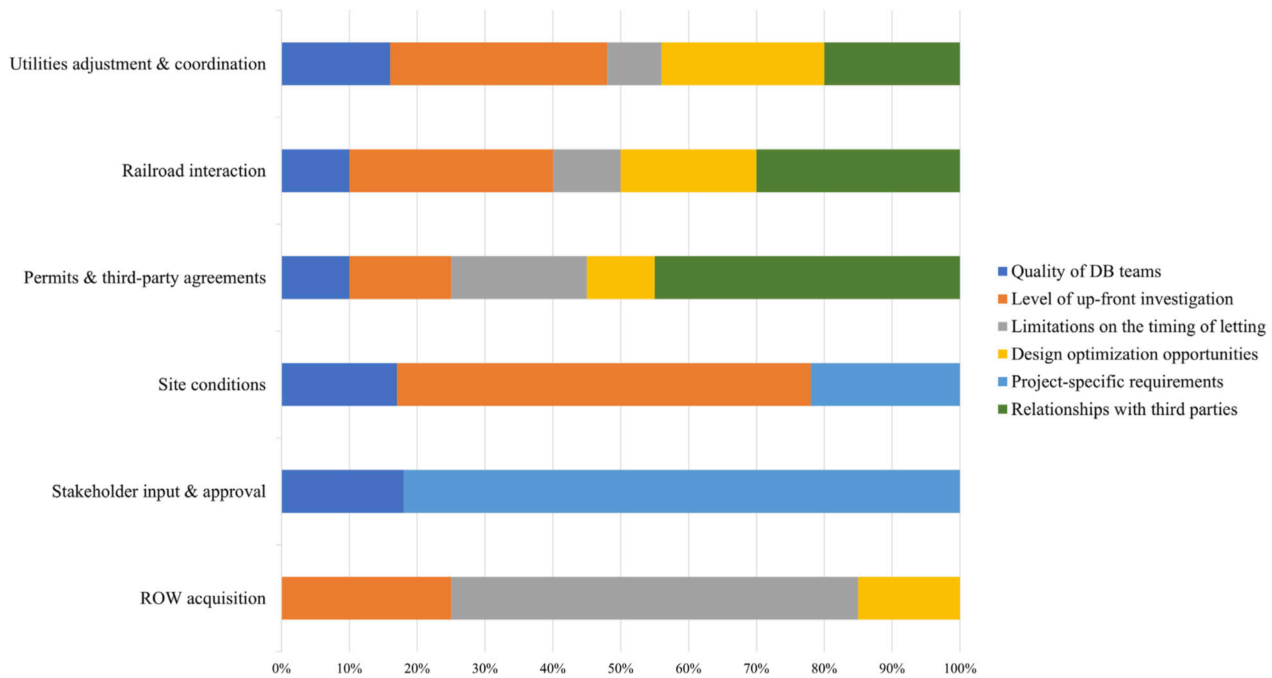

FIGURE 2
Frequency of coded interactions between pertinent risks and influential factors for risk allocation.

relationship. Indirectly, frequency (through counts) may relate to the strength of relationships, however, in this study qualitative descriptions of interactions (e.g., strong) would not impact the counts presented in Figure 2. The identified interactions and project examples are discussed below.

4.2.1 ROW acquisition

ROW acquisition is a complex process that involves multiple uncertainties (Anderson et al., 2009). Studies have found that government agencies have more power and control over the ROW acquisition process (Molenaar et al., 2005). Therefore, SHAs should, in most cases, purchase the ROW (Tran and Molenaar, 2014). However, factors such as limitations on the timing of letting and design optimization opportunities may influence the ROW risk allocation. Verbatim excerpts from the interviews that capture the expert input on this risk are presented below.

> "If there is outstanding ROW, the agency might feel more comfortable with DB due to timing; even if the contractor acquires the ROW, there is not much risk transfer—it's more of a responsibility transfer."

> "It's a good idea to transfer some risk to the contractor with the prospect that he can eliminate some of it through innovative, alternative design."

> "Expediting ROW is a resource issue. The agency and contractor will bring the same people for the process."

Experts from the agency and industry agree that ROW risk is best handled by the agency. Institutionally, ROW acquisition is considered a risk that the agency prefers to keep in-house because it can often significantly impact schedule and cost. However, project-specific conditions, like the timing of letting, can result in transferring part of the ROW responsibility to the contractor. If the agency wants to "push" a project for procurement within a certain time frame and there is an outstanding ROW issue, agency experts agreed they would feel more comfortable with a DB over a DBB contract. With DB, the contractor can acquire any remaining parcels by prioritizing them with the sequence of work and avoiding delays, while with traditional delivery, the agency typically always acquires all necessary ROW before bidding.

Both agency and industry experts agree that, because the agency provides explicit provisions around cost and schedule relief in the DB contract, ROW acquisition is a responsibility transfer. Also factoring into such a case is the level of up-front coordination. Agency experts stated that if the project needs 100 parcels and the agency is working on them for 14 months—even if they have not acquired all of them—they will provide a list of all the acquired information to the contractor. This would include the number of parcels acquired, the number of parcels for which they have right-of-entry, and the acquisition stage for all remaining parcels. The information is provided to ensure the contractor can more accurately price the risk, effort, and resources required.

Interviewees highlighted that opportunities to optimize design might also result in transferring part of the ROW risk to the contractor. In some circumstances, allocating part of the responsibility of acquiring ROW to the DB contractor comes with the prospect of eliminating some parcels through design alternatives. Experts agreed that contractor input in the ROW-acquisition process is indispensable; the relationship between ROW, utilities, and design can optimize the amount of ROW acquired. Also, experienced contractors can prioritize the parcels acquired with their construction sequencing. Interviewees stated that to more efficiently manage the ROW risk, an agency might solicit contractors' input pre-contract. In addition, some experts provided the insight that ROW is primarily a resource issue on large projects with significant ROW footprint. Apart from people and time, resources also relate to project-specific conditions. An agency expert provided an example from a large-scale project in the Houston District, where there were, not enough courtrooms to hear the sudden influx of ROW eminent domain cases, rendering the risk management process more complex.

While aligning with other studies on the primary role of the agency in handling the ROW risk, this study extends the current literature by noting the impact on risk allocation of the constraints posed by the timing of letting, the opportunities for eliminating certain parcels through innovative design, and the influence of up-front investigation in the cost and schedule relief provisions of the DB contract.

4.2.2 Stakeholder input and approval

"Stakeholders are people or groups that have or believe they have, legislative claims against the project's substantive aspects" (Winch, 2004). In infrastructure projects, examples of such stakeholders are cities and local governments. Early studies in DB implementation underlined the importance of stakeholder input in DB highway projects (Molenaar et al., 2000). Mobility projects traditionally include numerous stakeholders. However, the risk increases when third parties—principally local stakeholders—have to provide approvals of design and construction decisions. WSDOT stated that third-party approvals may require more time than internal ones and should be reflected in the RFP phase schedule, particularly for ATCs (WSDOT, 2017). For complex projects executed in urban environments, the number of local stakeholders involved can be very high. According to the interviewees, managing this risk relates to the quality of teams as well as project-specific requirements. Below are two expert opinions.

> "The agency may lose context-sensitive design aspects from the design-builders unless they think of it beforehand and put it in the specs."

> "The agency needs to set the expectations and boundaries right for public approval on design."

Agency experts stated that support from local stakeholders has a tremendous impact on every project. However, the risk presented by local stakeholders increases significantly for projects with community value or historical importance and projects that depend on aesthetics and prescriptive requirements. These projects require approval from the local stakeholders in design decisions and ATCs proposed by the DB contractors. Industry experts argue that a schedule can be negatively impacted if it requires local stakeholders to approve construction decisions; the timeframe and project details required to reach a decision are uncertain.

The experts agreed that the cost and schedule risk related to the portion of the projects where local stakeholders require approval is best allocated to the agency. By assigning that risk to the contractor, the agency may lose track of context-sensitive design aspects unless included in the specifications. In many cases the project component requiring approval is small, so the agency will assume the schedule and cost risk for that component through contract provisions; for that portion of the project, for example, the contractor would be entitled to cost and schedule relief for any impact or delay caused by the stakeholder approval process. However, if approvals are necessary for an important component, the agency, wanting to have complete control over the process, may decide to deliver the project with DBB.

To minimize the schedule impact of stakeholder input and approvals risk, experts from the agency and industry sides agreed that the agency needs to set expectations and establish boundaries with local stakeholders. If schedule disruptions during construction are to be avoided, the quality and experience of the DB teams play an important role in addressing the elements of the project that require third-party approvals.

4.2.3 Site conditions

The importance of site conditions and investigation risk have been revealed in the literature. Lopez del Puerto and colleagues (2017) argued that the most significant risk in construction is geotechnical uncertainty. To achieve successful planning, design, construction, and operation, USDOT (2017) underscored the need on every transportation project to thoroughly investigate the site conditions. For DB projects, Kim et al. (2009) argued that responsibility lies with the contractor for all design and construction elements (including risks from the geotechnical investigation). However, the allocation of this risk is not uniform for every project. Interviewees found that efficient allocation can be correlated with the quality of teams, the level of up-front investigation, and the presence of project-specific requirements. Below are some interview excerpts from agency and industry experts.

> "There is a big geotechnical risk on this project (abandoned utilities, old structures), and that could lead towards DBB. However, they will run into that risk regardless of the delivery method."

> "The agency does a more robust site investigation for every project, regardless of project delivery method."

> "DB has cost savings for the agency on unforeseen site conditions: delay costs, re-design, and change orders can be avoided."

Agency experts stated that, regardless of the delivery method, project cost and schedule are vulnerable to unknown site conditions. This risk is directly linked with project-specific conditions and, on complex projects, is highly variant. As a result, the agency has instituted a more robust site-investigation process to prevent that risk on all projects. Agency experts found that projects with significant site-condition risks could be better procured with DBB, where the agency retains control over the project, and the bid is composed of units that allow more granular pricing.

Industry experts also agreed that unknown site conditions could be a significant risk for the contractor at the RFP phase and that the contract clauses in DB offer no relief to the contractor for geotechnical risks. Each DB team that bids on a project may identify locations to obtain additional samples. However, the uncertainty associated with this risk is also tied to the constrained proposal submission timeframe that limits the sampling ratio. The severity of this risk may also be impacted by other unknown factors at the bidding stage, e.g., the depth of the foundation. As a result, insufficient information regarding on-site and geotechnical conditions may result in higher contract prices because the DB contractor allocates a higher contingency for this risk. Thus, the economic impact of that risk depends on the contractor's contingency in the contract and the actual geotechnical conditions presented in the project. A key factor that can impact this risk is the DB team's ability to assess it, particularly for complex projects where the assessment may include high uncertainty. The findings of this study align with NCHRP Report 884 (2018), which argues that in DB projects DOTs often try to shed geotechnical risk, leading industry practitioners to include pricing for contingencies that may not be realized and thus increasing overall project cost.

There is consensus in the literature on how critical that risk is. We argue, however, that geotechnical risk has a negative effect on all PDMs and should be mitigated upfront rather than transferred through a DB contract. Experts agreed that this risk is best mitigated by enhancing the initial site-investigation process and that, for any geotechnical uncertainty, the risk should be shared, providing some cost and schedule relief to the design-builder.

4.2.4 Permits and third-party agreements

When it comes to permitting DB projects, USDOT (2017) found that approaches used by SHAs vary. For example, the North Carolina DOT obtains all permits for all projects. At the same time, FDOT performs sufficient preliminary design to verify that a project can be permitted, but the design-builder is responsible for obtaining the permits. The Virginia DOT approaches permitting on a project-by-project basis. For TxDOT, the agency is usually best equipped to acquire DB projects' necessary permits. However, interviews revealed complexities regarding the permits and third-party agreements associated with DB.

> "The agency is often better at handling interactions with third parties, like cities and local governments."

> "If the contractor wants to change something drastically, he assumes the environmental risk that will come with the change. Also, it is almost impossible to go through the NEPA process again; the schedule risk is too much for the contractor to handle."

> "The agency is urging the utilities to come to the table early for coordination. The most important thing is to set the expectation with the utility agencies and get them involved. Each agency has different relationships with different players. That's why master agreements are so important."

Permits may be required from federal, municipal, and local governments, agencies, or other entities, such as the US Army Corps of Engineers, and are often project-specific. Most infrastructure projects necessitate ongoing coordination with third parties like cities and local governments. Agency experts stated that coordination with cities and local governments is generally better handled by the agency. Experts from both agency and industry agreed that cities and local governments might be more willing to work with the agency than with the contractor. This arrangement, however, may be influenced either way by the quality of existing relationships.

Interviewees indicated that it is best to align all stakeholders and establish master agreements that outline roles and responsibilities and bind the parties to commit to the project. Particularly in complex projects, multiple third parties may be involved in the permitting phase. The up-front investigation and quality of DB teams are critical to managing the risks and minimizing impacts to cost and schedule.

Owners and contractors agreed that one of the most significant and time-consuming permits is the environmental clearance obtained through the National Environmental Policy Act (NEPA) process. The agency experts stated that the SHAs should acquire the environmental clearance, according to NEPA regulations, regardless of the delivery method. While important on every project, NEPA compliance is particularly important for complex projects that present opportunities for innovation. Contractors indicated that NEPA regulations could significantly constrain their ability to innovate. One of DB's greatest benefits is flexibility in design. Hence, limiting design innovation can negatively impact the DB value and project performance. In addition, environmental commitments may challenge the DB contractor, as any design alterations may call for the re-issuing some permits. One industry expert argued that the constraints imposed by NEPA on the ability to innovate significantly decreased the potential value gained through the DB method. These constraints associated with the NEPA process highlight the importance of quality teams from the agency side and the level of up-front work performed so that the agency team could complete the NEPA process with minimal restrictions on the project design and the contractor's flexibility.

4.2.5 Railroad interaction

If railroad agencies are uncooperative, the risk associated with railroads can reduce flexibility and negatively impact cost and schedule (Tran and Molenaar, 2014). Aligning with the literature reviewed, the interviewees highlighted the complexity of the risk associated with railroads. However, the allocation of this risk on complex DB projects has not been explored in the literature. The following two comments complement our discussion of the complexities associated with railroad risk management and allocation.

> "Railroads own the ROW, so they have the first say; they can even recall a project clearance once it is scheduled or has started (e.g., having cranes on-site). The project will change plans to accommodate the railroads, not the other way around."

> "The agency needs to start the coordination either way. They need a third party agreement. You could get some cost savings through innovation from the contractor, but not schedule benefits."

Some experts from both agency and industry argued that the agency should assume the risk and do more coordination upfront. In one of the most complex DB projects delivered in Texas, agency personnel met with railroad representatives monthly to manage the agreement and complete the project on time. The agency is moving towards a new paradigm—developing schematics and meeting with railroad representatives regardless of who assumes the contractual risk. The effectiveness of this approach greatly depends on the experience and quality of the DB teams. Efficient early coordination reduces the unknowns related to this risk, quantifies the schedule impact on the project, and facilitates the risk pricing.

Timing constraints can impact the allocation of this risk, similar to ROW acquisition and permitting. Other factors affecting the railroad risk are the opportunities to optimize the design and the contractor's relationship with the railroad company. For the former, the contractor can minimize disruptions from interactions with railroads by designing around them. The value added by innovation can mostly translate to cost benefits. The experts agreed that schedule benefits are difficult to achieve when the DB team cannot design around the railroads. When interfacing, the railroads often have the first say and can dictate the scheduling of activities due to ROW ownership. The contractor's relationship with the railroad company can shift the risk allocation to the contractor in specific cases. Agency experts provided examples where DB teams used their pre-existing relationship with a railroad company as a selling point during procurement.

Contractors and owners agreed that the intensity and allocation of that risk could differ significantly based on project conditions; indeed, the agreements' complexity depends on the design, the site conditions, and the type of railroads involved (public and private). Public commuter railroads often prefer to work with the agency rather than the contractor. In some cases, private railroads might have an existing relationship with a DB contractor. Interviewees agreed that the agency is often the party best equipped to handle railroad risk and establish the third-party agreement (the design-builder is in a contractual relationship with the agency, not the third parties). However, the recommendation for case-by-case analysis to allocate the railroad risk is also supported by opportunities for design optimization, pre-existing relationships, and timing considerations.

4.2.6 Utilities adjustments and coordination

The risk allocation associated with utilities is complex and involves considerations similar to the railroad risk. One challenge in many highway projects is utility relocation and coordination (Ellis and Thomas, 2003). Studies have suggested that in a DB contract, the utility risk is usually allocated to the contractor (Tran and Molenaar, 2014). However, this study found that recommended allocation depends on multiple factors, including the quality of teams, the timing of letting, the level of up-front investigation, opportunities for design optimization, and existing relationships with third parties.

> "The goal is to minimize relocations and cost. The benefit in DB is that the design team can design relocations to minimize the impact on construction, the benefit of integration."

> "DB contractors have developed relationships with utility companies to speed up."

> "They [the agency] realized they pay for the [unnecessary] risks that the agency transfers to the DB contractor. In the past, they transferred all risk on Utilities, ROW, and RRs to the DB contractor without considering time. Now they put much effort into the up-front planning. They ask the Districts to be aggressive in identifying utilities, especially long lead."

DB contracts were often viewed as a vehicle to transfer all risk related to the utility challenges to the contractors. However, agency experts agreed that TxDOT now places more emphasis than it used to on coordination and up-front investigation before award or letting. For utilities, the preliminary investigation concerns data gathering. Unknowns can somewhat constrain the agency in the design since it is the DB contractor's responsibility. However, the agency's teams state that they are more "aggressive" in identifying utilities and devoting effort to up-front planning. As a result, the agency aids the contractor by reducing unknowns and facilitating agreements with utility companies.

Even if the agency implements institutional changes to achieve more efficient handling of the utility risk, interviewees stated that DB contractors continue to assume the majority of cost and schedule risk for utility adjustments. However, a thorough up-front investigation conducted by the agency increases the contractor's ability to price the risk accurately, thus making the risk-management process more effective. An SHA's initial data gathering can prevent excessively high bids created when the design-builder may assign higher contingency in preparation for assuming an unknown extent of utility-related risk. The volume and accuracy of the gathered information can be critical to the project outcome. Particularly with complex projects, more confidence in assessing project risks may result in more competitive bidding—a challenge for large-scale DB projects.

Contractors and agency experts stated that one of the primary drivers for allocating the utility adjustment risk to the contractor is optimizing the design to minimize the utility interaction. The design-builder can, by innovating, design around utilities. However, what makes the utility risk so critical is that it often cannot be avoided, particularly when located along the entire length of the corridor. In addition, the contractor can better align the utility coordination with the construction sequencing and the available resources.

Another factor that can impact the allocation of risk is the contractor's relationships with utility companies. According to most contractors, they can better cooperate with private utilities than public ones since they have a "business-to-business" understanding. The DB contractor has a financial incentive (a profit-driven motive to coordinate relocations more quickly) and has more flexibility than the agency to allocate resources to the process. DB contractors can often profit from assuming that risk, though cases exist where they incurred losses. If the utility company is unwilling to cooperate with the design-builder, the contractor cannot control the quality of the agreement. However, the DB contract does not provide schedule relief if the agreement fails to outline specific provisions. The contractors argue that in extreme cases they need cost and schedule relief. In a severe case, for example, a contractor may need to install an additional bridge because of an uncooperative utility, a cost they could not have known about to factor into the initial bid.

Finally, interviewees agreed that the utility type also impacts the risk-management process. For example, the agency does extensive up-front investigation and coordination for long-lead utilities, e.g., gas and transmission lines. The agency plans and resolves issues with long-lead items before the environmental clearance. As noted above, the risk allocation may differ for public and private utilities because of the agency and the contractor's relationships with them. Another distinction can be drawn between reimbursable and non-reimbursable utilities. Generally, agreements with reimbursable utilities are more accessible, and experts stated that the agency often assumes the risk for reimbursable utilities. These nuances around utility types and risk-management practices have yet to be explored in the literature.

While many factors impact the risk allocation of utility risk, DB contractors, interviewees agreed, assume most of that risk. However, the agency's up-front investigation and sharing of the acquired information with the DB contractor can result in lower initial bids and more competition.

5 Conclusion

This study utilizes empirical data from 20 subject matter experts with significant experience in complex DB infrastructure projects to extend the understanding of risk assessment and allocation in DB contracts. The primary contributions to the body of knowledge are identifying and defining factors that influence risk assessment and allocation and presenting how they can shift allocation practices on pertinent project risks for complex DB infrastructure projects.

The current study identified six influential factors for risk allocation: (i) the quality of DB teams, (ii) the level of up-front investigation (e.g., the agency's upfront work on utility coordination), (iii) limitations on the timing of letting, (iv) design optimization opportunities, (v) project-specific requirements (e.g., aesthetic concerns), and (vi) relationships with third parties (e.g., railroad and utility companies, local governments). Furthermore, the pertinent risks discussed by interviewees include ROW acquisition, stakeholder approval, site conditions, permits and third-party agreements, railroad interaction, and utility adjustments and coordination. The findings from expert input can help agencies manage the risk associated with complex DB projects, outlining contract provisions, proactively addressing long-lead items (e.g., long-lead utilities), and assigning resources to minimize outstanding risks at the time of letting.

Advancing the knowledge in this area has multiple practical implications. Public-sector entities, such as SHAs, have distinct institutional characteristics that impact how they assign risks. Assessing these factors and their interactions with pertinent risks on a project level promotes efficient risk allocation for SHAs, industry firms, and consortiums charged with carrying out projects. In addition, the dynamic environment and higher uncertainty associated with complex DB projects render risk allocation critical to project success. To maximize the efficiency of risk allocation, decision-makers need to consider the distinctive conditions of each project. To that end, the factors presented here capture aspects that may differ among projects, even within the same organization, and whose assessment dictates the party most equipped to handle risk. Other important insights provided in this work include the association of the quality of DB teams with the ability to make decisions in a timely manner and the impact of the level of upfront investigation on competitive bidding by reducing risk and uncertainty. These aspects are particularly important for complex projects where significant uncertainty may result in higher contingency and, therefore, higher initial prices.

In addition to advances in practice, this work provides valuable insights for researchers in the area of complex DB infrastructure projects. First, the factors that impact risk assessment and allocation presented here add to the literature. Previous studies have discussed risk allocation and exposed some nuances; however, this study presents a concise list of factors that may change the magnitude and the party most equipped to handle risk and should be examined by project stakeholders and included in planning frameworks developed by researchers. The factors and interactions with risks presented herein can inform planning, management, and mitigation decisions through formalized frameworks and tools for complex DB projects. Furthermore, future work can endeavor to assign relative values to the factors and risks to prioritize mitigation strategies. Finally, the list of factors and interactions can be used as a basis that future research may broaden through additional data collection or different project types.

The findings of this work complement and expand existing risk management frameworks examined in literature. For instance, stepwise risk management processes for mega-projects include establishing the context, identifying, analyzing, evaluating and treating risks, along with continuous communication and monitoring feedback loops (Australian/New Zealand Risk Management Standard, 2004; Flyvbjerg et al., 2003). Focusing on the context of a complex DB infrastructure project, the factors presented in this work contribute to improving the assessment and understanding of how risks manifest on projects, rather than the decision-making framework itself. As such, the examination of these factors for DB projects, where the contract is finalized before the design is complete and uncertainties are higher, informs risk assessment and contributes to creating realistic scenarios and corresponding risk management actions. In particular, the presented factors and interactions should be examined when (i) determining the consequences and likelihood of each risk (Australian/New Zealand Risk Management Standard, 2004) and (ii) during the risk allocation in the DB contract to ensure that risks are assigned to the party most equipped to handle it. Similarly, considering the layering process to managing risk presented by Miller and Lessard (2008), the factors and insights presented herein should be primarily assessed at the 'Assess/understand risk' and 'Transfer/hedge' stages.

The principal limitation of this work is that all data were collected through experts based in Texas. However, the authors argue that findings can be generalized to complex DB transportation projects for three reasons. First, Texas presents a unique opportunity for understanding the challenges of complex transportation projects due to its tight urban corridors and high traffic volume as the second most populated state in the US with multiple urban transportation projects. Work zone mobility is critical in Texas since public transportation is underdeveloped and scarcely utilized. Therefore, the volume and complexity of traffic management plans are significant. Considering these factors, experts from Texas—both TxDOT and industry practitioners—were considered good candidates for this study, with experience on projects ranging from $315M to $2B. Second, the experts from the industry have all delivered complex DB projects within and outside of Texas. As a result, they provided examples where the factors that impact risk allocation were relevant for projects across the US that presented complexity and significant risks and uncertainty. Finally, all DB project examples discussed utilized federal financing and are subject to the US regulatory framework. As such, the findings likely reflect the US experience, although extending to other states would help generalize the results. Expanding the research to international contexts would also further understanding. As a practical matter, though, international SHAs can benefit from this study's findings by considering their institutional framework and legislative constraints.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation, after any identifying and privileged information has been removed.

Ethics statement

The studies involving humans were approved by the IRB, The University of Texas at Austin. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their informed consent to participate in this study.

Author contributions

VD: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing–original draft, Writing–review and editing. WO'B: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Writing–review and editing. NK: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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