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Impacts and Benefits of Implementing BIM on Bridge Infrastructure Projects

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IMPACTS AND BENEFITS OF IMPLEMENTING BIM ON BRIDGE INFRASTRUCTURE PROJECTS

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Disclaimer

EXECUTIVE SUMMARY

To date, BIM (Building Information Modeling) is not widely utilized in infrastructure asset management. Benefits achieved through implementation in vertical construction, however, suggest that BIM represents significant opportunity for gains in process, material, and economic efficiency throughout infrastructure life cycles. This research documents the current state of BIM implementation across four (4) regional transportation authorities in the United States. Next, it provides a detailed case study analyzing and comparing two current (2013) bridge projects, one that uses BIM and one that does not. The advantages of BIM are confirmed through observed reduction in requests for information (RFIs) and change orders (COs) relative to construction area (SF), cost ($), and average daily traffic, compared with typical construction. Finally, the report outlines potential benefits and implications of using BIM for infrastructure asset management by regional transportation authorities and the transportation industry overall. Numerous stakeholders involved with horizontal construction and operation currently seek information regarding the potentially significant benefits of integrating BIM into infrastructure asset management. This research is important because it serves to assess and inform such an imminent transition. The contribution of this research is to document and assess the role of BIM implementation and potential impacts in order to use it in assisting throughout the life cycle of infrastructure assets.

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1. INTRODUCTION

1.1 Background

Research suggests BIM (Building Information Modeling) is a vital asset for building construction from preconstruction through operation to end of life. Only recently, however, have the benefits of BIM for infrastructure construction begun to be recognized and realized. In addition, benefits of using BIM for infrastructure management include the opportunity to record and detail every maintenance action. Such documentation could provide a record for each component regarding cost and history of maintenance (Marzouk & Abdel Aty, 2012). Using this form of integrated design, construction and management for infrastructure provides the framework for an accurate and proactive approach to maintaining these structures. The basic premise of proactive infrastructure asset management includes the assumption that during the normal life cycle of an asset or system of assets, there is the need to intervene at strategic points, and by doing so, the asset's service life may be prolonged (Cagle, 2003). In addition, implementing BIM can provide cost and time savings to organizations by reducing the number of decisions made in the field. State departments of transportation (DOTs) are well positioned to benefit from such advancements. These transportation authorities typically hold millions, if not billions, of dollars in assets for long periods of time. Transportation organizations responsible for bridge construction are the target audience for the lessons learned from the case study.

BIM for infrastructure provides the opportunity for construction managers, owners, and facility managers to have a dynamic, reliable, organized way of maintaining their assets. Research has demonstrated the extent to which the use of BIM has been beneficial to vertical construction (i.e., buildings) (McGraw Hill, 2012). Horizontal construction (i.e., infrastructure), however, currently remains years behind in realizing the true value of incorporating this tool in the construction and management of projects. Productivity is a major project benefit, which is expected to increase in importance over the next few years (Bernstein & Stephen, 2012). A potential obstacle opposing the adoption of BIM in horizontal construction is that infrastructure projects are typically built to last multiple decades. As a result, and in contrast to the perspective of many decision makers in vertical construction, the life cycle proposition for horizontal construction is weighted heavily toward operations and maintenance rather than first costs. Significant need exists for additional research addressing the impact of BIM implementation across all phases of infrastructure asset management.

1.2 Research Purpose

BIM for infrastructure is an under-utilized tool in horizontal construction. This research seeks to assess the impact of BIM implementation on two similar bridge construction projects using the metrics of cost, schedule, request for information (RFIs), and change orders (COs) for bridges with similar design approach, construction type, and transfer method.

Identifying the impacts and potential benefits of utilizing BIM on real-world transportation infrastructure construction will begin to inform DOTs and urban transportation districts about potential opportunities related to BIM adoption during construction. Additional and possibly significantly greater benefits may be available throughout the operation and maintenance of such infrastructure. This study provides a valuable first step in motivating the implementation of BIM within and throughout infrastructure asset management.

1.3 Building Information Modeling (BIM)

BIM was first introduced to the architecture, engineering, and construction (AEC) world in 1957 by Dr. Patrick J. Hanratty, the developer of Computer Aided Manufacturing (CAM). There are numerous definitions of BIM used throughout literature, but for the purpose of this study we will use the following definition: Building Information Modeling, to incorporate 3-dimensional (3D) graphics along with data sets (spreadsheets) to specify specific aspects of the built environment. BIM's incorporation into construction processes has been emerging into the mainstream primarily for the past 10 years. Technical benefits of BIM include, "making reliable digital representation of the building or infrastructure available for design and decision making, high-quality construction document production, planning, predictions, and cost estimates. Having the ability to keep information up-to-date and accessible in an integrated digital environment gives architects, engineers, builders, and owners a clear overall vision of all their projects, this allows all interested parties the ability to make informed decisions" (http://www.solibri.com/). BIM has become an invaluable tool to many in the AEC industry by providing living 3D models, data sets, and 2-dimensional (2D) graphics incorporated in one source. Incorporating integrated design tools like BIM has allowed organizations to employ experienced project managers and project architects at the beginning of an infrastructure development process (Mihindu & Aryici, 2009). Giving these experienced professionals access at the beginning of these projects allows for more design development and less time drafting.

Infrastructure's use of BIM has not seen the same growth that vertical construction has experienced (McGraw Hill, 2012). Water infrastructure has begun to recognize potential benefits of BIM processes. For example, these assets could be managed in a manner where investment can be optimized to produce a reduction in capital budgets and operating expenditures. Currently, operation and maintenance needs are frequently overlooked. BIM provides the potential for a multidisciplinary approach to water infrastructure management at a corporate level to guide investments and resource allocation (waterfinancerf.org, 2012). Highway infrastructure has also begun to see the benefits of BIM. Because design and construction documentation are dynamically linked, the time needed to evaluate more alternatives, execute design changes, and produce construction documentation is reduced significantly (Strafaci, 2008). A major benefit is that BIM facilitates roadway optimization by including visualization, simulation, and analysis as part of the design process (Strafaci, 2008). Opportunities also exist to save on construction costs while producing a superior final product with less waste and potentially improving the built environment. Furthermore, BIM models can continue to result in cost savings over the rest of the life cycle of a project.

1.4 BIM for Transportation Infrastructure

BIM for transportation infrastructure asset management processes can benefit from integrating scope, schedule, and budget along with 2D CAD plans, maintenance records, project specifications, warranty information, purchase requests, existing service documents, and HVAC plans into a 3D model. By incorporating all of a project's information into one or multiple 3D models, with multiple data sets, benefits can result for multiple stakeholders. For example, owners can use the model for operation and maintenance and engineers and contractors can use the information in design and building considerations. Various alternatives can be easily compared in order to achieve optimum life cycle cost. A key benefit is the accurate geometrical representation of the parts of building infrastructure in an integrated data environment (Marzouk & Abdel Aty, 2012). Project stakeholders can acquire a greater level of detail at early stages of the project to better inform decisions before they are implemented in the field. In addition, operation and maintenance histories can be well documented. Transportation infrastructure typically has a life cycle of decades and, generally, the maintenance is driven by financial considerations (Davis & Goldberg, 2013). It is typical to have multiple construction crews and engineers producing documents regarding the same infrastructure asset over extended periods of time. BIM provides value in managing relevant data about current conditions and facilitates the analysis of alternatives by being able to embed data on life expectancy and replacement costs in BIM models. Such documentation can help the owner understand the benefits of investing in materials and systems that may cost more initially but have better payback over the life of the asset (Schley, 6/17/13). The basic premise of proactive asset management is that during the normal life cycle of an asset or system of assets, there is the need to intervene at strategic points to extend the expected service life (Cagle, 2003). BIM enables this to be done more cost effectively by providing the potential for up-to-date, accurate, and geometric representations of the assets and their sub assets. Overall, the initial cost of constructing and maintaining a BIM model can be minimal in comparison with the benefits gained over the life of the infrastructure asset.

1.5 BIM Integration

Using BIM efficiently requires planning and effective execution. Implementing BIM technology necessitates re-engineering the design, construction, and maintenance processes (Mihindu & Arayici, 2009). The change process is a journey through adapting principles of integrated processes, interoperability for BIM information management, collaborative working practices, and finally development of BIM-based services organizations operating in the field of the built environment (Makelainen, Hyvarinen & Peura, 2012). One of the biggest challenges associated with BIM is effectively using and fully leveraging the process during construction. It can take multiple implementations and countless hours for BIM usage to become a normal integral part of project construction culture. Furthermore, using BIM includes a process of unlearning the previous systems that were once in place to help in the decision making process (Makelainen, Hyvarinen, & Peura, 2012). Initially companies need to invest time and money into training individuals on chosen software. Training individuals to operate BIM software can require a sizable investment in money, time, and hardware. BIM software is memory intensive and requires hardware that is capable of processing the data retrieval that it needs to access in order to perform the functions that are asked of it. In general, there are many options in the development of constructing a BIM model, and when implementing this software into a company's culture, some of these options are chosen by chance due to inexperience (Makelainen, Hyvarinen, & Peura, 2012). These issues are all challenges that can take place when incorporating new technology into an otherwise tried and trusted system. As individuals learn new, effective processes, however, there is the potential to increase productivity and significantly reduce project cost by use of the BIM software.

1.6 Value of BIM

Cost is a factor in all aspects of construction. Fundamentally, an owner wants the highest quality product for the least amount of money. BIM potentially allows the needs of multiple project stakeholders to be realized more effectively and efficiently, thereby adding value. For example, life-cycle project costs can be impacted by factors such as the state of disrepair of the asset, what has previously been repaired, and how the repairs were performed or how the asset was originally constructed (Stratford, Stevens, Hamilton, and Dray 111-122). BIM potentially allows for such considerations to be assessed and addressed through collaboration using a 3D model. Stakeholders can provide design alternatives in a digital format to address problem areas and apply degradation models to determine the most cost effective and appropriate means of addressing design and construction issues. The use of BIM can help stakeholders move important decisions from the field to the computer where changes are easier and more cost effective. Additionally, stakeholders can develop a shared understanding of the project through cross disciplinary collaboration that helps reduce design errors and miscommunication, which in turn reduces risk and liability (Bennett, 2012). Finally, additional value may result through the use of BIM by avoiding data dispersions, and duplication of efforts, increasing efficiency and safety, and reducing time for routine data collection and recording, all of which could translate into cost savings to the owner and increased structural safety of the assets (Lwin, 2006).

BIM can help decision makers schedule regular maintenance on infrastructure assets. Research suggests BIM implementation can have noticeable cost savings; overall cost diminishes as unplanned maintenance is replaced by planned maintenance. Excessive levels of planned maintenance can also drive the overall cost back up (Cagle, 2003). Infrastructure owners and engineering firms seek integrated and cost-effective solutions that span the entire project life cycle (Jones, 2012). In a recent study by McGraw Hill, it was determined that 67% of the users of BIM associated with infrastructure were seeing a positive return on investment (ROI), and those users that identified themselves as experts with BIM were seeing as much as a 50% ROI.

Information management is a key feature when implementing BIM for infrastructure asset management. Keeping the data current throughout the life cycle of the infrastructure, however, requires proper information flow. Incorporating and integrating large amounts of data using BIM can potentially save significant time and cost for facility managers. For example, facility managers might spend some time searching for manufacturer's contacts in order to replace or maintain a part. However, with BIM, a single click on any part could show all information (Marzouk & Abdel Aty, 2012). With BIM software, it is possible to define different attributes and components of a building and categorize them into major categories: structural, architectural, mechanical, and electrical (Marzouk & Abdel Aty, 2012). Cost can also be incorporated in the model to allow for model-based estimating. Clicking on various aspects of the 3D model can produce cost information and data regarding repair, replacement, manufacturer, fabricator, where it was built, and if it has recently been serviced. Having such information in one place potentially reduces time and costs associated with typical repairs. With BIM, it is possible to leverage knowledge of location, characteristics, maintenance history, and condition of the asset, combined with a systematic approach to inspections and maintenance to allow responsible authorities to effectively manage the condition and capacity of the asset and therefore, indirectly, the capacity/capability of the assets network (Hosseen & Stanilewicz, 1990).

On an organizational level, companies and organizations are also beginning to realize the benefits of incorporating BIM into their transportation infrastructure asset management. Doing this allows the owners or facility operators the ability to answer key questions such as, what do we own? By being able to query such questions, they can pursue answering more specific questions such as, when was the last service performed on this component? The incentive of being able to ask and answer questions on an organizational level with the click of the mouse proves invaluable for managing a collection of assets small or large. In addition, BIM may be used to view and organize monitored data across a collection of assets. For example, air quality sensors and moisture sensors can be placed within infrastructure and input data into BIM to provide the ability to monitor and analyze current conditions. In one study, managers of a subway system found they could control the HVAC system through BIM-integrated software if the indoor air quality (IAQ) was poor or moisture levels too high. Off-site access to such information can help management teams monitor safety issues before they happen. Such new technologies and opportunities provide the opportunity for radical improvement from preconstruction through operation and maintenance in the management of transportation infrastructure assets.

1.7 Potential Challenges

With all the potential benefits of BIM implementation, several challenges remain, particularly for large transportation organizations. One major issue involves developing standards that will allow smooth information transfer among software systems, providing access to data for multiple stakeholders over long periods of time. The development of a universal BIM standard is being coordinated by the International Alliance for Interoperability (IAI) through their development of the exchange specification, Industry Foundation Classes (IFC). This general standard is being used as a platform for developing domain-specific views by government agencies and consortia in the AEC industry, such as the National Institute for Building Standards (NIBS), National Building Information Model Standard (NBIMS), the United

States General Services Administration (GSA) BIM Guide, and INSPIRE in Europe and Byggsok in Norway. Today, most developers of tools for modeling building are supporting IFC as an option for open exchange of building information (Lapierre & Cote). Providing a common format for data transfer among BIM software and the incorporation of software such as GIS into BIM is an important part of managing infrastructure assets. Transportation organizations generally need a way to reliably weigh long-term benefits versus implementation costs for BIM.

2. METHODOLOGY

This research implemented a case study methodology. Key tasks were to 1) review the “current state of the infrastructure industry” through interviews/surveys of peer mass transit organizations; 2) adapt and synthesize metrics to assess impact of BIM implementation on bridge construction; 3) collect data from two similar, current bridge construction projects – one implementing BIM, one not; 4) compare and analyze data to assess the impact of BIM implementation on bridge construction; and 5) validate findings through interviews of project representatives.

The case studies analyzed the superstructure of two roadway bridge constructions with similar project characteristics. Both were completed in 2013 for the owner, Colorado Department of Transportation (CDOT), constructed by Kiewit Infrastructure, and utilized construction manager/general contractor (CM/GC) and accelerated bridge construction (ABC) delivery methods. To perform this research, the authors adapted previously established investment metrics (construction cost) as well as return metrics (requests for information [RFI], change orders [CO], and schedule) to assess the impact of BIM (Barlish and Sullivan, 2012, Khanzode et al., 2008.) Analysis of these metrics was limited to project superstructures to minimize the effect of project differences.

2.1 Research Question

What are the impacts and potential benefits and challenges of implementing BIM on bridge construction?

2.2 Project Characteristics

Each transportation infrastructure project, as constructed, is unique, making accurate comparison a challenge. The following two transportation projects were intentionally selected due to their relatively high number of similar characteristics, including owner, delivery method, construction type, and structural design, as well as the method of transfer (into final location). Characteristics compared to establish similarity include:

- Owner
- Contractor
- Design/delivery approach
- Construction type
- Method of transfer
- Average daily traffic
- Design life span
- Construction era

2.3 Research Metrics

While no universally accepted metrics exist, we propose the following metrics as meaningful in assessing the impact of BIM implementation during construction:

- Cost
- Duration
- Requests for information
- Change orders

Potential additional characteristics to be considered in future research may also include ones that focus on differences in structural complexity. The two projects selected in our case study are intentionally of similar structural complexity, and therefore these project characteristics were not considered.

- Continuous span – distance between expansion joints
- Type of super-structure – i.e., pre-stressed concrete girders
- Number of expansion joints – used to absorb heat-induced expansion, vibration, or settlement of the earth

3. REVIEW OF PEER ORGANIZATIONS

The following findings regarding the current “state of practice” of BIM implementation by transportation organizations were generated by interviewing peer organizations to the owners of the case study projects, CDOT.

3.1 Denver Regional Transportation District

A portion of this research involved documenting how other peer organizations were managing their information that was created for their infrastructure projects. Currently, the Denver Regional Transportation District (RTD) manages its transportation infrastructure assets from construction through operations and maintenance (O & M) by using the Microsoft folder structure. When projects are turned over, there is no defined organizational structure that is required other than providing all the documents necessary for future rehabilitation or construction. Many of the projects’ construction and O & M documents are placed on a hard drive or via a hard copy and turned over in this fashion.

3.2 New York Transit Authority

New York Transit Authority (NYMTA) adopted BIM across the board with use of Bentley Products. They are currently using BIM for preconstruction through construction; it is their goal to use their BIM information for O & M once the projects are completed. Projectwise (Bentley, n.d.) has been implemented as the main source of BIM information. By request of the senior vice president, NYMTA has purchased and is testing Autodesk Suite for a comparative analysis as to which design platform is better suited to meet their needs. To date, BIM has been used on 18 projects with two of these projects currently (2013) in construction. NYMTA stated there have been benefits to using BIM process, but they have no official data to quantify these benefits.

3.3 Edmonton Transit System

Edmonton has implemented a variety of BIM platforms in order to utilize a variety of aspects of the BIM process. Autodesk and Bentley platforms are currently being utilized for preconstruction through construction. Currently there are no completed projects that have utilized the BIM process. Edmonton Transit System feels there are benefits to using BIM, such as preconstruction/design development and clash detection, but without having real numbers they can only assume that positive benefits are being gained by implementing BIM. However, the organization’s integration manager feels that using BIM has greatly enhanced public engagement by being able to provide animations and realistic representations of how projects might look. They feel this alone is a great benefit and well worth the investment in BIM processes.

3.4 Southeastern Pennsylvania Transportation Authority

Southeastern Pennsylvania Transportation Authority (SEPTA) has not implemented BIM on any projects to date. The organization’s chief engineer stated that there was no budget or funding for projects like that within SEPTA and there has been no talk of utilizing any technology similar to BIM.

3.5 Sound Transit

According to Oregon Sound Transit's Justin Lopez, senior CAD Drafter, East Link CAD lead design, Engineering & Construction Management, Sound Transit has implemented the Autodesk platform across the board on its LRT project. This project covers 14 miles of track, 10 stations, three underground tunnels, five parking garages, and a mix of elevated guide ways totaling $2.8 billion. They report that they have seen RFI's decrease since this implementation but have no quantifiable data. They also report some drawbacks to having implemented BIM. One of the most noticeable is reworking models to accommodate major design changes when they get past the 60% completion point due to the level of detail involved. They feel it has been beneficial to public involvement, due to the ability to provide a realistic representation of the project's outcome. They feel this benefit alone is a great investment, and moving forward they will use BIM on all new projects.

3.6 Peer Organization Review Discussion

Table 3.1 highlights the current state of practice of BIM implementation by transportation organizations.

Table 3.1 BIM implementation in peer mass transportation organizations

	Organizational Full Implementation	Partial / Minimal Implementation	No Implementation
Denver Regional Transportation District			X
New York Transit Authority	X		
Edmonton Transit System	X		
Southeastern Pennsylvania Transportation Authority			X
Sound Transit	X		

As noted by NYTA, ETS, and Sound Transit, implementing BIM was not an easy or cheap task, but the benefits and impacts they have seen make it worthwhile. These organizations stated they have not been able to quantify a numerical impact as they are not far enough along in their implementation, but it is something all vested stakeholders have noticed. They also expressed the opinion that BIM was not something that should be partially implemented on a project. Rather, it should be implemented to the full extent on a few hand-picked, pilot projects to determine the overall impact on the organization. Taking it slowly will allow the opportunity for maximum gain on a few pilot projects. The interviews with peer organizations reaffirm and are consistent with Figure 3.1 by stating there was a steep learning curve; what they anticipated coincided with point #5 (optimal) but the actual outcome was similar to point #4 (actual).

Figure 3.1 Theoretical BIM Implementation learning curve

(Source: http://www.aecbytes.com/viewpoint/2012/issue_65.html)

Review of peer organization “state of BIM implementation” suggests and confirms that significant research is needed to investigate initial implementations of BIM on transportation infrastructure projects. The following case study documents the potential benefits and challenges of implementing BIM during bridge construction.

4. CASE STUDY

The following case study provides a comparative analysis of the impacts, benefits, and challenges associated with utilizing Building Information Modeling (BIM) on recent bridge construction in the Denver Metro area, utilizing a CM/GC delivery method for the Colorado Department of Transportation (CDOT). The two bridge structures analyzed are the Pecos Street over I-70 Bridge replacement (delivered using BIM) and the Fort Lyon Canal Bridge (delivered not using BIM). As previously noted, the two projects share many similarities. They are both constructed using the CM/GC delivery method and were constructed utilizing the Accelerated Bridge Construction (ABC). Benefits of using ABC include the abilities to improve safety, quality, durability, social costs, and environmental impacts. In general, ABC techniques provide the opportunity to improve site constructability, decrease total project delivery time, and increase work zone safety while reducing traffic impacts, onsite construction time, and weather related time delays (CDOT, 2013). Construction of the two bridges was performed off-site with the structures rolled into place after they were constructed. Both projects were completed in 2013.

The projects differ in terms of size and complexity of their design and construction. The Pecos Street over I-70 Bridge project complexity was high as a result of being located in a dense urban area with the need to address on/off ramps, while supporting high traffic volume. The Fort Lyon Canal Bridge had lower project complexity as it was located in a rural area with greater access, less space constraints, and reduced traffic demand. Despite these differences, the projects shared significant similarities, particularly in regard to their structural design. Table 1 provides a summary of major similarities providing a strong basis for comparison. Of note, the Pecos Street over I-70 Bridge represented the first time the owner (CDOT) utilized BIM during project delivery.

Table 4.1 provides a comparison of the two bridge construction projects.

Table 4.1 Project characteristics comparison

	Project Name	
Project Characteristic	Fort Lyon Canal Bridge (part of Rocky Ford Bridge Project)	Pecos Street over I-70
Design / Delivery Approach	CM/GC	CM/GC
Project Contractor	Kiewit Infrastructure	Kiewit Infrastructure
Construction Type	Pre-stressed concrete box girders with a reinforced concrete deck	Post-tensioned cast-in-place concrete box girder using high strength concrete
Transfer Method	Rolled via Steel Rollers	Rolled via Self Propelled Modular Transport Vehicles (SPMTV)
BIM Implemented	No	Yes*
Average Daily Traffic	809	19000
Life-span	75 Years	75 Years
Superstructure Area	3,510 sf	12,050 sf
Cost (Superstructure)	$747,292	$3,816,520
Duration**	150 Days	365 Days
Weather Delays	2 Days	7 days
Year Completed	2013	2013

*First time implementation

**Duration calculated as "Onsite construction time" per time metric defined for Accelerated Bridge Construction in Culmo (2011).

The following sections provide more detailed descriptions of the two projects used for the case study.

4.1 Rocky Ford Bridge Project: Fort Lyon Canal Bridge

The Fort Lyon Canal Bridge is part of the Rocky Ford Bridge project, located in CDOT's southeastern Region 2.

Figure 4.1 Fort Lyon Canal Bridge under construction

The original State Highway 266 Fort Lyon Canal Bridge was built in 1954, and spanned 90 feet. This bridge was selected for replacement due to being declared functionally obsolete and structurally deficient. A replacement Fort Lyon Canal Bridge was built using the CM/GC delivery method and was constructed next to the original structure. The structure utilized ABC techniques to negate issues to the traveling public. The super structure was rolled into place by using a temporary abutment and bridge rolling technology. This structure is located in a rural area with minimal space constraints, which proved beneficial in allowing the structure to be built adjacent to the existing structure. The 90-ft bridge has a projected life cycle of 75 years; the Fort Lyon Bridge deck has a total of 3,510 square feet and average daily traffic of 809 trips. Construction began on November 27, 2012, and was completed in April 26, 2013 (5 months); weather was not a defining factor in duration.

4.2 Pecos Street over I-70 Bridge Project

The Pecos Street over I-70 Bridge project is located in the Denver metro, CDOT Region 1. The original structure was built in 1965, but was recently identified as being in poor condition and selected to be replaced. The replacement project included replacing the old Pecos structure, installing roundabout type intersections, and building a pedestrian bridge. Kiewit Infrastructure constructed the project utilizing the Construction Manager/General Contractor (GM/GC) delivery process. Construction started in November 2012 and was completed in October 2013 (13 months); weather was not a defining factor in project duration.

Figure 4.2 BIM Model of Pecos Street over I-70 Bridge and pedestrian overpass

The new super structure was built utilizing BIM and Accelerated Bridge Construction (ABC) techniques. One goal of the ABC technique is to reduce the impact on the traveling public. Benefits of using ABC include the abilities to improve safety, quality, durability, social costs, and environmental impacts. In general, ABC techniques provide the opportunity to improve site constructability, total project delivery time, and work zone safety while reducing traffic impacts, onsite construction time, and weather related time delays ("Bridges and structures," 14).

Figure 4.3 BIM Model graphic showing converging streets and the need for the roundabouts

BIM was utilized on the project from conceptual design through construction. Specifically, the bridge design consultant Wilson, and Kiewit the contractor, utilized the BIM processes through the software Midas Civil ("Midas Civil integrated," 2013). The project's cost was affected directly due to the purchase and learning curve of this software. Kiewit used this software to model the bridge and associated lifting diaphragms. This was to determine how the specific lifting points might be affected due to the associated stress and pressure. They looked at overall longitudinal design, shear, torsion, and maximum twist and the impact it would have on the differential or deflection. The super structure required four types of post tensioning, including longitudinal internal tendons, longitudinal external tendons, vertical tendons in the diaphragms, and transverse deck tendons ("Pecos Street Bridge"). By modeling this they determined that a tolerance of .25 inch was necessary to reduce the chance of significant structural damage. Modeling also provided a means for them to determine how they would put them on the Self Propelled Modular Transport Vehicles (SPMTV) from the jacks they utilized to lift the structure straight up in order to not damage these points on the bridge. The Pecos Street over I-70 Bridge superstructure was cast on a rat slab (concrete pad) with underground jack vaults put in place to lift it when moving it into place. Another aspect the model provided was how to deal with the elevation change of I-70. They had to determine the most effective way to flatten out the grade for ease of moving the superstructure; this was to minimize bridge deflection and make sure when they were rolling the bridge onto the freeway they didn't exceed the maximum grade. Other factors that contributed to its high level of complexity included the incorporation of partial roundabouts as part of the bridge deck. To add to the project complexity, the bridge location is a highly urban area with a minimal amount of workspace and, when completed, spans a heavily used freeway. This structure was built using a bridge farm technique in close proximity to the original structure. This structure has a total area of 12,050 square feet and currently carries 19,000 trips per day (TPD). The Pecos Street over I-70 Bridge has a projected life span of 75 years.

4.3 Delivery Methods

All bridges constructed within Colorado use the American Association of State Highway and Transportation Officials (AASHTO) specifications and the CDOT Bridge Design Manual. CDOT has typically used Design-Bid-Build, Design Build, and Modified-Design-Build for project delivery on a large portion of its previous projects (Vessley, 2009). The purpose of utilizing the CM/GC contracting method is that it incorporates an integrated team approach applying project management techniques to planning, design, and construction (Vessley, 2009). The CM/GC delivery method is conducive to using BIM in that it helps with the collaboration and communication processes. The reasoning for using a delivery approach on the bridge projects analyzed in the case study is that it involves the contractor in both the design and construction of the project, which allows for collaboration with the engineer and architect. The delivery method has the ability to help reduce cost by the inclusion of the contractor in providing alternative means and methods to address the complicated design and constructability issues. The CM/GC delivery method provides for a shared risk approach that can help with schedule optimization and keeping the project on budget. CM/GC gives the contractor the ability to start construction before the entire design is complete, which allows for an earlier turnover and can benefit a project by improving safety and quality (Colorado Department of Transportation). The use of CM/GC is relatively new to CDOT. To date, CDOT has used CM/GC on eight projects starting in 2009; these include the Eagle Interchange, Grand Avenue Bridge, Eisenhower Johnson Memorial Tunnel, Dotsero Bridge, Pecos Street over I-70 Bridge, Rocky Ford Sliding Bridge project, I-70 East Bound Twin Tunnels, and the I-70 West Bound Twin Tunnels (Vessley, 2009).

4.4 Comparison of Projects' Costs Related to Superstructure

Table 4.2 presents a side-by-side cost breakdown of costs related to the superstructure for both projects.

Table 4.2 Superstructure cost-items breakdown for the Fort Lyon Canal Bridge (baseline) and the Pecos Street over I-70 Bridge (BIM-enabled)

Contract Item No	Contract Item	Total Cost for Fort Lyon Canal Bridge ($)	Total Cost for Pecos Street over I-70 Bridge ($)
206-00100	Structure Backfill (Class 1)	$23,595	$0
206-00200	Structure Backfill (Class 2)	$3,430	$60,765
206-00360	Mechanical Reinforcement of Soil	$18,150	$0
502-11489	Steel Piling (HP 14X89) (Install Only)	$28,864	$0
506-01020	Geogrid Reinforcement	$0	$13,919
512-00101	Bearing Device (Type I)	$0	$28,052
513-00690	Bridge Drain (Special)	$0	$7,807
515-00120	Waterproofing (Membrane)	$6,720	$0
518-01004	Bridge Expansion Device (0-4 inch)	$0	$45,644
519-03000	Thin Bonded Epoxy Overlay	$0	$41,952
601-03040	Concrete Class D (Bridge)	$277,200	$643,657
601-05045	Concrete Class S40	$0	$1,003,583
602-00000	Reinforcing Steel	$0	$118,771
602-00020	Reinforcing Steel (Epoxy Coated)	$55,695	$299,196
606-11030/32	Bridge Rail Type 10M	$27,750	$84,173
613-00200	2 Inch Electrical Conduit	$2,185	$6,226
613-00300	3 Inch Electrical Conduit	$0	$2,224
618-00000	Prestressing Steel Bar	$0	$6,410
618-00002	Prestressing Steel Strand	$0	$329,608
618-01994	Prestressed Concrete Box	$40,248	$0
631-20020	Move Bridge (Roll)	$230,000	$1,077,144
	Subtotal	$713,837	$3,769,130
	Related Change Orders	$33,455	$47,390
	TOTAL	$747,292	$3,816,520

In the cost breakdowns reported in Table 4.2, several cost items are included or excluded from each project as a result of specific project differences. Most notably, the bridge-roll and extra-high strength concrete (Concrete Class S40) required for the more complex Pecos Street over I-70 Bridge project resulted in significantly higher costs that were not incurred in the design of the Fort Lyon Canal Bridge. In addition, the unit costs for the Concrete Class D used in both projects were significantly different; with the unit cost of Concrete Class D for the Fort Lyon Canal Bridge being almost twice as expensive as that of the Pecos Street over I-70 Bridge, mainly due to the remote location of the former. Therefore, an additional location cost adjustment was made for the Fort Lyon Canal Bridge to isolate the effect of significantly higher cost of concrete (resulting from its location). For purposes of this analysis, these construction cost differentials were deemed unrelated to BIM implementation for otherwise relatively similar structural projects. They were, therefore, removed from the cost comparisons. Table 4.3 lists all costs deemed to be construction cost differences not resulting from the implementation of BIM and, thus, deducted from superstructure costs.

Table 4.3 Construction cost differentials unrelated to BIM implementation

Construction Difference	Fort Lyon Canal Bridge **(Baseline)**	Pecos Street over I-70 **(BIM-enabled)**
Cost of Bridge Roll	$230,000	$1,077,144
Design Cost Adjustment for Concrete	$0	$520,210*
Location Cost Adjustment for Concrete	$137,014**	$0
Total Construction Cost Differential	$367,014	$1,597,354

* If Class D Con. ($455.15/CY) were used instead of required, high strength Class S40 Con. ($944.99/CY) for 1062 CY as required by the design of Pecos Street over I-70 Bridge→ ($944.99/CY-455.15/CY) * 1062 CY= $520,210 additional cost on Pecos Street over I-70 Bridge unrelated to BIM implementation.

** If the unit price for Class D Con. used for the Fort Lyon Canal Bridge location were the same as that used for the Pecos Street over I-70 Bridge location (i.e., $455.15/CY instead of $900/CY)→ ($900/CY-$455.15/CY) * 308 CY= $137,014 additional cost on Fort Lyon Canal Bridge unrelated to BIM implementation.

These unrelated (i.e., unrelated to the implementation of BIM) construction cost differentials were removed from the project cost comparisons to provide “standardized costs.” Finally, the cost comparisons were normalized to account for scale differences between the two bridge projects. Table 4.4 presents the final cost comparison for the structurally similar construction projects normalized on a square foot basis.

Table 4.4 Normalized Superstructure cost comparison

Cost Items	Fort Lyon Canal Bridge **(Baseline)**	Pecos Street over I-70 **(BIM)**
Total Project Cost (Superstructure)	$747,292	$3,816,520
Construction Cost Differential unrelated to BIM Implementation	$367,014	$1,597,354
Standardized Superstructure Cost	$380,278	$2,219,166
Standardized Superstructure Cost (Normalized per SF)	$108/SF	$184/SF

For this case study, the standardized comparison of costs related to two structurally similar bridge construction projects, one using BIM and one not, suggests that the first time implementation of BIM contributed to an approximately 70% increase in $/SF costs.

4.5 Comparison of Projects' RFIs related to Superstructure

The following tables summarize the requests for information (RFIs) related to superstructure recorded for the two projects. The RFIs for the Fort Lyon Canal Bridge project are summarized in Table 4.5.

Table 4.5 RFIs for the Fort Lyon Canal Bridge superstructure

RFI #	Discipline	Location	Subject
0007	Bridge Rolling Details	SH 266 Fort Lyon	Bearing stiffener spacing
0009A	Bridge Roll	SH 266 Fort Lyon	1" nominal grout bed

The RFIs recorded for the Pecos Street over I-70 Bridge project related to the superstructure are summarized in Table 4.6.

Table 4.6 RFIs for the Pecos Street over I-70 Bridge superstructure

RFI #	Discipline	Location	Subject
R0038	Superstructure	Bottom Slab	Additional Bottom Slab Thickness adjusted for concrete
R0042	Superstructure	Bridge Move	Superstructure deck cure time prior to lifting
R0043	Superstructure	Bifurcation section of web walls 1A and 4A	Rebar conflict with Post Tension (PT) tendons 2 and 3 at the bifurcation section
R0045	Superstructure	Web Wall 1	Damage to PT duct #1
R0061	Superstructure	End diaphragm on Abutment 2	Rock Pockets on the Abutment 2 End diaphragm wall

Fort Lyon Canal Bridge (baseline project) recorded a total of two RFIs related to the superstructure while the Pecos Street over I-70 Bridge (BIM, first-implementation) recorded a total of six.

Table 4.7 provides a comparison of the number of RFIs normalized according to individual project characteristics.

Table 4.7 Comparison of RFIs normalized for projects

Metric	Fort Lyon Canal Bridge	Pecos Street over I-70	% Change
RFI / SF	(2/3,510) =.00057	(6/12,050) =.00050	12% Decrease
RFI / $	(2 / $380,278) =.0000053	(6 / $2,219,166) =.0000027	49% Decrease
RFI/day	(2/ 150) =.01333	(6 / 365) =.016438	23% Increase
RFI / average daily traffic (ADT)	(2 / 809) =.002472	(6 / 19,000) =.000316	87% Decrease

In three of the four comparisons, normalized according to superstructure area, cost, schedule, and daily traffic, the number of relative RFIs decreased (ranging from 12%–87%) for the project where BIM was implemented. The exception was the number of RFIs per day. Arguably, this increase may be the result of an accelerated schedule enabled by the implementation of BIM on the Pecos Street over I-70 Bridge project.

4.6 Comparison of Projects' Change Orders Related to Superstructure

The following tables summarize the change orders (COs) related to superstructure recorded for the two projects. The COs for the Fort Lyon Canal Bridge project are summarized in Table 4.8.

Table 4.8 Change orders for Fort Lyon Canal Bridge superstructure

CHANGE ORDER # / ITEM #	ITEM DESCRIPTION	BID QTY	UNIT	U/C	TOTAL COST	ADJUSTMENT TYPE / ITEM #	REV QTY	UNIT	U/C	TOTAL COST	TOTAL CHANGE
6 / 700-70034	Relocation of utilities	20000	F.A.	$1.00	$20000	ADD					$20000
7 / 403-34751	Hot Mix Asphalt (HMA)	577	TON	$115	$66355	SUBSTITUTION / 403-34751	577	TON	$130	$75010	$8655
8 / 506-01020	Stabilize Existing Subgrade	600	SY	$8	$4800	ADD					$4800

The COs recorded for the Pecos Street over I-70 Bridge project related to the superstructure are summarized in Table 4.9.

Table 4.9 Change orders for Pecos Street over I-70 Bridge superstructure

CHANGE ORDER # / ITEM #	ITEM DESCRIPTION	BID QTY	UNIT	U/C	TOTAL COST	ADJUSTMENT TYPE	REV QTY	UNIT	U/C	TOTAL COST	TOTAL CHANGE
512-00101	Bearing Device (Type 1)	23	EA	$1219.65	$28052	UNIT PRICE CHANGE	23	EA	$1877.78	$43189	$15137
518-01004	Bridge Expansion Device (0-4 inch)	198	LF	$222.65	$44085	QUANTITY CHANGE	205	LF	$222.65	$45644	$1559
601-03040	Concrete Class D (Bridge)	1700	CY	$454.18	$772099	UNIT PRICE CHANGE	1700	CY	$455.15	$773757	$1658
602-00000	Reinforcing Steel	157567	LB	$0.76	$119158	QUANTITY CHANGE	183649	LB	$0.76	$138882	$19724
602-00020	Reinforcing Steel (Epoxy Coated)	406413	LB	$0.89	$363293	QUANTITY CHANGE	387534	LB	$0.89	$346417	($16876)
606-11032	Bridge Rail Type 10M (Special)	432	LF	$192.18	$83021	MATERIAL CHANGE	432	LF	$192.18	$83021	-
618-00000	Pre-stressing Steel Bar	2473	LK	$2.59	$6410	QUANTITY AND UNIT PRICE CHANGE	1979	LB	$10.96	$21682	$15272
618-00002	Pre-stressing Steel Strand	4734	MKFT	$69.63	$329608	QUANTITY AND UNIT PRICE CHANGE	4437	MKFT	$76.75	$340523	$10916

Fort Lyon Canal Bridge (baseline project) recorded a total of three COs related to the superstructure while the Pecos Street over I-70 Bridge (BIM first-implementation project) recorded a total of eight. Table 4.10 provides a comparison of the number of COs normalized according to individual project characteristics.

Table 4.10 Comparison of change orders normalized by project

Metric	Fort Lyon Canal Bridge	Pecos Street over I-70	% Change
CO / SF	(3/3,510) =.00085	(8/12,050) =.00066	22% Decrease
CO / $	(3 / $380,278) =.0000079	(8 / $2,219,166) =.0000029	47% Decrease
CO/day	(3/150) =.02	(8/365) =.022	10% Increase
CO / average daily traffic (ADT)	(3/809) =.00371	(8/19,000) =.00042	89% Decrease

Similar to the RFI analysis for the two projects, for three of the four comparisons normalized according to superstructure area, cost, schedule, and daily traffic, the number of relative COs decreased (ranging from 22%–89%) for the project where BIM was implemented. Again, the exception was the number of COs per day, and, once again, this increase may be the direct result of an accelerated schedule enabled by BIM implementation.

Furthermore, results indicate that COs added additional costs during construction to both projects. Tallying CO costs in both cases suggests that for the Fort Lyon Canal Bridge, costs associated with COs accounted for a 5% cost increase over the original estimate, whereas on the Pecos Street over I-70 Bridge, costs associated with COs accounted for only a 1% cost increase.

4.7 Comparison of Projects' Rework Related to Superstructure

The Fort Lyon Canal Bridge required rework of two items, while no rework was necessary on the Pecos Street over I-70 Bridge. Table 4.11 summarizes the nature of these rework items.

Table 4.11 Rework items on Fort Lyon Canal Bridge

Rework	Description
Item 1	The backwall of Abutment #12 for the structure over Fort Lyon on SH-266 had to be partially removed and repaired. This work took several days to complete.
Item 2	The mechanical reinforcement of soil between the two bridges on SH-266 was not installed correctly and had to be removed and replaced. The work took several days to complete.

On the Fort Lyon Canal Bridge, these rework items were related to contractor error, therefore no compensation was provided and costs were not directly tracked. Nevertheless, the project representative estimated the total cost for both items was approximately $10,000.

5. VALIDATION AND FEEDBACK

The next research task after analysis of project metrics was validation of results. Follow-up interviews were conducted with the CDOT representatives on both projects. After reviewing the results, both project representatives stated that the results appeared accurate. The project representatives also provided the following additional insights regarding the higher costs associated with the Pecos Street over I-70 Bridge project.

- Additional waste on the Pecos Street over I-70 Bridge project resulted from the fact that multiple loads of high strength concrete had to be turned away because they did not meet the project specifications. Additional inefficiencies occurred because the concrete was difficult to work with.
- Additional costs for BIM implementation resulted from software purchases ($8,000–$23,000 depending if it was the basic or full version), and a steep learning curve was associated with the use of Midas Civil for the project team, which was challenging to learn and had confusing outputs associated with its use.
- Finally, while significant costs were associated with the use of ABC and the necessary rolling of the superstructure into place on the Pecos Street over I-70 Bridge project, the project representative noted that without using these advanced techniques, the bridge could not have been built.

6. CONCLUSIONS

The results of the case study suggest that first implementation of BIM incurred significant costs. Specifically, the Pecos Street over I-70 Bridge project, which utilized BIM, had a 70% construction $/SF cost premium (see Table 4) compared with a structurally similar bridge construction project completed concurrently by the same contractor for the same owner. However, increased project complexity (siting and average daily traffic, etc.) may have contributed to the cost increase. Likely, and as suggested by project representatives, the learning curve of first BIM implementation also partially contributed to the higher costs.

Conversely, implementing BIM on the Pecos over I-70 Bridge project may have contributed to the reduction of the number of RFIs and COs and, potentially, a decrease in project schedule and elimination of rework, compared with traditional construction methods. Specifically, RFI and CO metrics, evaluated relative to cost, area, and traffic, decreased in the ranges of 12%–87% and 22%–89% respectively, on the project where BIM was first implemented. In addition, total costs for COs and rework represented a 6% increase over the original estimate for the baseline project versus only a 1% cost increase over estimate for the BIM-enabled project. Such a finding suggests that BIM may have provided approximately 5% cost savings during construction by contributing to reduced COs and rework. Furthermore, when total costs for COs and rework are compared with the standardized project costs of both projects, analysis suggest a 9% cost savings. Such findings are graphically summarized in Figure 6.1.

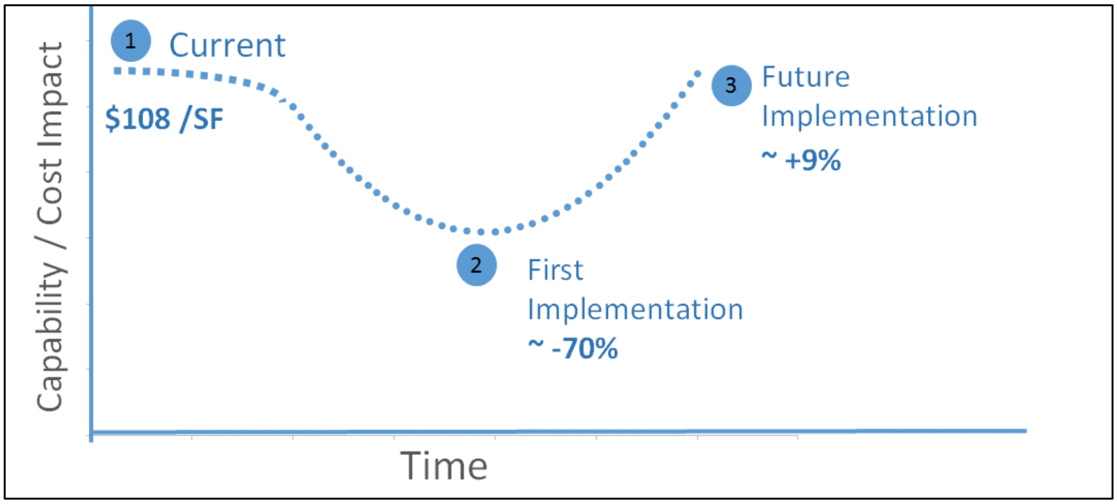

Figure 6.1 Case study BIM implementation learning curve

Finally, according to the owner and contractor, implementing BIM on the Pecos over I-70 Bridge allowed the project team to deliver a bridge that otherwise could not have been built according to the required time and space constraints. Specifically, the ability to provide accurate and realistic visualizations of the project to the public prior to construction enabled the level of public engagement and support necessary for success.

In sum, this case study validates previous research, which suggests BIM has important impacts across several investment and return metrics. In addition, the case study provides data regarding the magnitude of these impacts as related to both first time and follow-on implementation during construction. More research is needed to assess additional, and potentially significant, opportunities during operation and management of these assets.

While findings suggest that BIM has the potential to bring significant value to transportation and infrastructure projects, several potential barriers to BIM implementation exists. One major issue involves developing standards that will allow smooth information transfer among software systems, and will provide access to data for multiple stakeholders over long periods of time. The development of a universal BIM standard is being coordinated by the International Alliance for Interoperability (IAI) through their development of the exchange specification, Industry Foundation Classes (IFC). This standard is being used as a platform to develop domain-specific views by numerous government agencies and consortia; and today, most software developers are supporting IFC as an option for open exchange of building information (Lapierre & Cote). Providing a common format for data transfer among BIM software and the incorporation of software such as Geographical Information Systems (GIS) into BIM will be important steps in managing infrastructure assets in the future.

6.1 Future Research

In the future, there is a need to collect more and more detailed information about the impact of BIM through more case studies. Specifically, future case studies could:

- Address additional metrics when the projects are not similar across delivery, construction type, and transfer. For example, the impact of differences in structural complexity (number of expansion joints, length of continuous span, etc.) may be of particular interest because we theorize that BIM will add more value on the more complex projects.
- Include projects that are not "first implementations" but second, third, etc. so that it is possible to determine the impact of BIM implementation over time (plotting additional points on Figure 6.1).

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