

THESIS

IMPACTS AND BENEFITS OF IMPLEMENTING BIM ON BRIDGE AND  
INFRASTRUCTURE PROJECTS

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Blaine Fanning

Department of Construction Management

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Master's Committee:

Advisor: Caroline Clevenger

CO-Advisor: Mehmet Ozbek

Hussam Mahmoud

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## ABSTRACT

### IMPACTS AND BENEFITS OF IMPLEMENTING BIM ON BRIDGE AND INFRASTRUCTURE PROJECTS

To date, BIM (Building Information Modeling) is not widely utilized in infrastructure asset management. Benefits achieved through implementation in vertical construction, however, suggests that BIM represents significant opportunity for gains in process, material and economic efficiency throughout infrastructure project lifecycles. 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 construction projects, one that uses BIM and one that does not. The results are confirmed by the observed reduction in RFIs and CMOs relative to construction area (SF), cost (\$), and average daily traffic, compared to typical construction. Finally, it outlines potential benefits and implications of using BIM for infrastructure asset management by regional transportation authorities and the transportation industry in general. 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 specific contribution of this research is to document and assess the role of BIM implementation on one bridge case study in order to highlight the potential of BIM as a dynamic method to assist throughout the lifecycle of infrastructure assets.

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## INTRODUCTION

Research suggests BIM (Building Information Modeling) is a vital asset for building construction throughout the lifecycle of the projects, 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 provides the potential that every maintenance action can be recorded with details associated to the maintained component: this can 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 attitude of maintaining these structures throughout their lifecycle. 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, by doing this it will prolong the assets service life (Cagle, 2003). Implementing BIM can be beneficial due to the cost and time savings that can result from taking the decisions out of the field and exploring them in the office first. Urban transit systems and state departments of transportation (DOTs) are, potentially, well positioned to benefit from such advancements. These transportation authorities typically hold millions if not billions of dollars in assets that could benefit from efficiencies gained through BIM implementation. Transportation organizations responsible for bridge construction are the target audience for the lessons learned from the case study. However, the infrastructure industry in general can benefit from research findings.

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 in 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 their 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 lifecycle proposition for horizontal construction is weighted heavily towards operation 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.

## RESEARCH PURPOSE

BIM for infrastructure is a potentially under-utilized tool in horizontal construction. This research seeks to document potential impact of the intervention of using BIM on horizontal construction by comparing its implementation on one of two similar bridge projects. Specifically, the research seeks to assess the impact of BIM implementation on bridge construction using the metrics of cost, schedule, request for information (RFIs), change orders, normalized across design approach, construction type and transfer method.

### Importance of Research

Identifying the impacts and potential benefits of utilizing BIM on transportation infrastructure construction will begin to inform DOT's and urban transportation districts about potential opportunities related to BIM adoption during construction. Additional and possibly significantly greater benefits may be available throughout 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.

## LITERATURE REVIEW

Building information Modeling was first introduced to the Architecture, Engineering, and Construction (AEC) world nearly half a century ago 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 definition Building Information Modeling, (to incorporate 3-dimensional (3D) graphics along with data sets (spread sheets) 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 3-dimensional (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). By allowing these experienced professionals access at the beginning of these projects it allows for more design development and less time drafting.

Infrastructure 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. For example, a \$100,000,000 new highway construction project with interchanges and bridges typically includes 7-8 percent cost in design development. With BIM, it is possible to reduce the design time by 15% which reduces costs roughly by \$14,000,000 (Strafaci, 2008). Furthermore, BIM models can continue to result in cost savings over the lifecycle of a project.

#### 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, HVAC plans into a 3D model. By incorporating all the projects information into one or multiple 3D model(s), with multiple data sets benefits can result for multiple stakeholders. For example, owners can use the model for operation and maintenance and the engineers and contractors can use the information in design and building considerations. Various alternatives can be easily

compared in order to achieve optimum lifecycle 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 lifecycle 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 amounts 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 material and systems that may cost more initially but have better payback over the lifecycle of the asset (Schley, 6/17/13). The basic premise of proactive asset management is: 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 to the benefits gained over the lifecycle of the infrastructure asset.

## 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 and time along with investment into hardware capable of handling the memory intensive needs of BIM software. BIM Software is memory intensive and requires hardware that is capable of processing the data retrieval that the software will need 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 in to 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 process, however, there is the potential to increase productivity and significantly reduce project cost by use of the BIM software.

### Value of BIM

Cost is a factor regarding 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 the risk and liability (Bennett, 2012). Finally, addition value may result through the use of BIM by avoiding data dispersion, avoided duplication of efforts, increased efficiency and safety, shortened time for routine data collection and recording, all of which could translate in to 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 lifecycle (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 lifecycle 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). Using 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. By clicking on various aspects of the 3D model, it can produce cost information along with 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 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. By doing this it 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. The benefit in the case of one study relating to management of a subway system was that 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.

#### Potential Challenges in BIM Adoption

With all of 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 Geographical Information Systems (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.

## 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) develop 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 interview of project representatives. The case study involved two (2) roadway bridges constructed for the owner, Colorado Department of Transportation (CDOT) utilizing the CM/GC delivery method and Accelerated Bridge Construction (ABC). Metrics used to analyze the data included superstructure cost, project schedule, and utilization of BIM. Due to the limited availability of projects being constructed using these delivery methods, data was normalized to make project comparisons.



## 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 owner of the case study projects, CDOT. These organizations were peers in that they were all of comparable size and utilized Light Rail Train (LRT) infrastructure.

### Denver Regional Transportation District

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. A portion of this research involved documenting how other peer organizations were managing their information that was created for their infrastructure projects.

### 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 have purchased and are 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 state that there have been benefits to using BIM process, but that they have no official data to quantify these benefits.

#### 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 are only able to assume that positive benefits are being gained by implementing BIM. However the organizations 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. This alone they feel is a great benefit and well worth the investment in BIM processes.

#### 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.

## Sound Transit

According to Sound Transits own Justin Lopez, Sr. CAD Drafter, East Link CAD Lead Design, Engineering & Construction Management, Sound Transit has implemented the Autodesk platform across the board on their LRT project. This project covers 14 miles of track, ten (10) stations, three (3) underground tunnels, five (5) parking garages, and a mix of elevated guide ways totaling 2.8 billion dollars. 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 LOD involved. They feel it has been beneficial through public involvement, due to the ability to provide a realistic representation of the projects outcome. From this benefit alone they feel that it is a great investment and moving forward they will use BIM on all new projects.

Table 1.1: 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 that 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 you should partially implement 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. By doing this they could take it on slowly yet exploring the opportunity for maximum gain on a few pilot projects. The interviews with peer organizations reaffirm and are consistent with Figure 1 by stating that there was a steep learning curve, what they anticipated coincided with point #5 (optimal) but that actual outcome was similar to point #4 (actual).



Figure 1.1: BIM Implementation Learning Curve

[http://www.aecbvtes.com/viewpoint/2012/issue\\_65.html](http://www.aecbvtes.com/viewpoint/2012/issue_65.html)

Review of peer organization “state of BIM implementation” suggests and confirms that significant research need exists 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.

## CASE STUDY

### Research Question

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

### Characteristics and Metrics

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:

- Design/Delivery Approach
- Construction Type
- Method of Transfer (for putting bridge in place using Accelerated Bridge Construction)
- BIM Implementation
- Average Daily Traffic
- Design life-span
- Construction era (were the projects constructed in similar timeframes)

While no commonly accepted metrics exist either according to industry or research we propose the following metrics as meaningful in assessing the impact of BIM implementation during construction:

- Cost (\$)
- Duration (mo.)
- Requests for Information ( / \$)
- Requests for Information ( / 100 SQ Ft)
- Requests for Information ( / Day)
- Change Modification Orders ( / \$)
- Change Modification Orders ( / 100 SQ Ft)
- Change Modification Orders ( / Day)

Potential additional metrics include ones that focus on differences in structural complexity.

The two projects selected in our Case Study are intentional of similar structural complexity. It is important to note that the following structural characteristics may be important when comparing or assessing future research. Examples include:

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

Next we present the present day Case Study: two projects which share many project characteristics and apply the proposed metrics on the two relatively similar projects to assess the impact of BIM implementation on bridge construction.

## Project Characteristics

### Comparison of Pecos Street Bridge Replacement & Rocky Ford Sliding Bridge Projects

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 St 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 Method. The 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. In addition to the use of BIM, the projects differed, somewhat, in terms of size and complexity of design and construction. The Pecos over I-70 Bridge complexity was due to being in a highly urban area with the need to address 48<sup>th</sup> Ave. and 4 on / off ramps in a limited amount of space, and it was the first time that the owner (CDOT) utilized BIM during project delivery. The Fort Lyon Canal Bridge was significantly less complicated, and was located in a rural area. Initial findings suggest that the implementation of BIM on the complex Pecos St over I-70 Bridge Replacement project was beneficial and saved the project time and money.

Both projects implemented Accelerated Bridge Construction in order to 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). In addition, they shared the same characteristics across the following variables:

- Design/Delivery Approach: Construction Manager / General Contractor (CM/GC)
- Construction type: Single span-post tensioned concrete
- Method of transfer: Rolled

#### Pecos Street over I-70 Bridge Project

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 was 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.

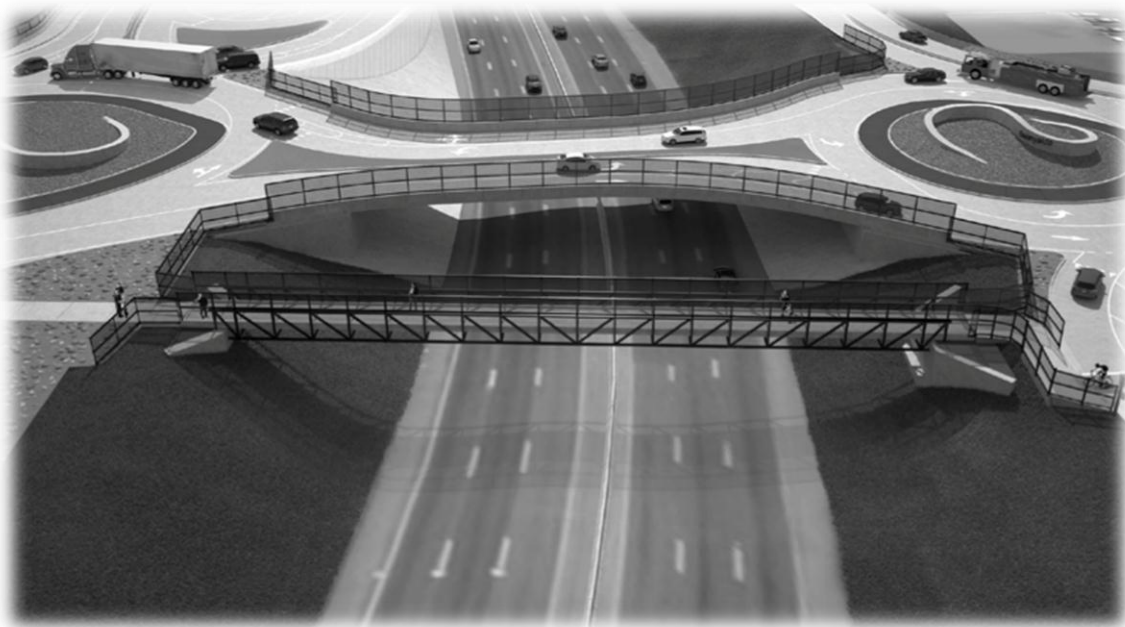


Figure 1.2: BIM Model of Pecos Street over I-70 Bridge and Pedestrian Overpass

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 1.3: BIM Model showing all 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 (4) 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 were able to determine that if they went greater than a .25 inch there was an extreme chance of 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 that they had to utilize in order 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 was able to provide 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 on to the freeway they didn't exceed the maximum grade. Other factors that contributed to its high level of complexity were 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 12050 SQ FT and currently carries 19,000 trips per day (TPD). The Pecos Street Bridge over I-70 has a projected life span of 75 years and a total project award amount of \$18,600,000 of this cost \$3,850,272 was to build the superstructure.

#### Rocky Ford Bridge Project: Fort Lyon Canal Bridge

The following bridge is part of the Rocky Ford Bridge Project, located in CDOT's southeastern Region 2.

## Fort Lyon Canal Bridge



Figure 1.4: Fort Lyon Canal Bridge

The original State Highway 266 Fort Lyon Canal Bridge was built in 1954, and spanned 90'. 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 Accelerated Bridge Construction (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' bridge has a projected lifecycle of 75 years; the Fort Lyon Bridge Deck has a total of 3510 SQ FT 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. The total award amount for the Rocky Ford Bridge Project was \$4,299,627.00 of this \$813,647 was

specifically for the superstructure of the Fort Lyon Canal Bridge. Table 1.2 summarizes project characteristics, and includes cost and duration for reference.

Table 1.2: Project Characteristics plus Cost and Duration

	Rocky Ford Bridge Project	
<b>Project Characteristic</b>	Fort Lyon Canal Bridge	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 SPMTV
BIM Implemented	No	Yes
Average Daily Traffic	809	19000
Life-span	75 Years	75 Years
Deck Area (Super Structure)	3510	12,050
Cost (Super Structure)	\$813,647	\$3,850,272
Duration	170 Days	365 Days
Weather Delays	2 Days	7 days
Completion Date	2013	2013

It is important to state that no two (2) projects are identical, but the comparison being made between the two structures were as alike as possible given the delivery method, material and method of transfer. This was done so the structures could be reasonable compared.

## CM/GC Delivery vs. Typical Project 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. Colorado Department of Transportation 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 methods 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 improving quality (Colorado Department of Transportation). The use of CM/GC is relatively new to CDOT. To date CDOT has used CM/GC on 8 projects starting in 2009, these projects include the Eagle Interchange, Grand Avenue Bridge, Eisenhower Johnson Memorial Tunnel, Dotsero Bridge, Pecos 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).

## Project Metrics

The following section documents the data used for comparison of the three project case studies including Contract Modification Orders, Requests for Information, Schedule, and Costs.

Cost and construction duration data was previously provided in Table 1.2.

Table 1.3: Number of Contract Modification Orders and Requests for Information, and Amount of Rework by Project

	<b>Rocky Ford Bridge Project</b>	
	<b>Fort Lyon Canal Bridge</b>	<b>Pecos Street over I-70</b>
<b>Contract Modification Orders</b>	3	8
<b>Requests for Information</b>	2	6
<b>Rework</b>	2	0



Table 1.4: Contract Modification Orders for Pecos Street over I-70 Bridge super structure

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	UNITY PRICE CNAGE	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	QUANTITY 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	4437	MKFT	\$76.75	\$340523	\$10916

Table 1.5: Contract Modification Orders for Fort Lyon Canal Bridge super structure

<b>CHANGE ORDER # / ITEM #</b>	<b>ITEM DESCRIPTION</b>	<b>BID QTY</b>	<b>UNIT</b>	<b>U/C</b>	<b>TOTAL COST</b>	<b>ADJUSTMENT TYPE / ITEM #</b>	<b>REV QTY</b>	<b>UNIT</b>	<b>U/C</b>	<b>TOTAL COST</b>	<b>TOTAL CHANGE</b>
6 / 700-70034	Relocation of utilities	20000	F.A.	\$1.00	\$20000	ADD					\$20000 / \$0
7 / 403-34741	Hot Mix Asphalt (HMA)	325	TON	\$115	\$37375	SUBSTITUTION / 403 - 34751	325	TON	\$130	\$42250	\$4875 / \$0
7 / 403-34751	Hot Mix Asphalt (HMA)	252	TON	\$115	\$29980	SUBSTITUTION / 403 -34751	252	TON	\$130	\$32760	\$2780 / \$0
8 / 506-01020	Stabilize Existing Sub grade	600	SY	\$8	\$4800	ADD					\$4800 / \$0

Table 1.6: RFI's for Pecos Street over I-70 Bridge super structure

<b>RFI #</b>	<b>Discipline</b>	<b>Location</b>	<b>Subject</b>
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
R0063	Superstructure	Abutment 1 End Diaphragm	NCR-Voids on abutment 1 end diaphragm

RFI's for the Fort Lyon Canal Bridge project.

Table 1.7: RFI's for the Fort Lyon Canal Bridge super structure

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

## Metric Analysis

The following section provides a comparative analysis of the two projects. Data is normalized in an effort to highlight the role of utilizing BIM in the Pecos Street over I-70 Bridge Project, compared to the Fort Lyon Canal Bridge project where it was not used. As described in Table 8, the rolling of the super structures and the difference in cost in the specialty concrete required by the Pecos Street over I-70 Bridge was removed to provide an accurate analysis of the impacts and benefits of BIM.

Table 1.8: Cost of construction methods / materials on the 2 projects that were normalized

<b>Discipline / Material</b>	<b>Fort Lyon Canal Project</b>	<b>Pecos over I-70 Bridge Project</b>
Bridge Roll	\$230,000	\$1,077,144
Concrete Mix	\$0.00	\$47,783*
Total \$ subtracted from Construction Cost for normalization of projects	\$230,000	\$1,124,927
Total Normalized Value	\$583,647	\$2,725,345

\* If Class D Con. (\$900/SY) was used instead of required, high strength SY S-40 Con. (\$944.99/SY) (\$44.99/SY \* 1062 SY)

Contract Modification Orders (CMO)

Table 1.9: Comparison of Contract Modification Orders normalized by project

	<b>Rocky Ford Bridge Project</b>		<b>Impact of BIM Implementation</b>
	<b>Fort Lyon Canal Bridge</b>	<b>Pecos Street over I-70</b>	<b>% Change</b>
<b>CMO / 100 SF</b>	(3/3510)/100 =.0000085	(8/12050)/100 =.0000066	22% Decrease
<b>CMO / dollar</b>	(3 / \$583,647) =.0000051	(8 / \$2,725,345) =.0000029	43% Decrease
<b>CMO/day</b>	(3/170) =.017	(8/365) =.021	24% Increase
<b>CMO / Average daily traffic (ADT)</b>	(3/809) =.00371	(8/19000) =.00042	88% Decrease

Pecos Street over I-70 required a total of 16 change orders during the construction of the project. Of these 16 CMO's, eight specifically dealt with the super structure of the bridge. This average comes out to .0000066 Contract Modification Orders / 100 SQ FT. The CMO's were specific to concrete, steel reinforcement, pre-stressing, and expansion devices. The Fort Lyon Canal Bridge required three Contract Modification Orders for the super structure of the bridge. This is an average of .0000085 Contract Modification Orders / 100 SQ FT, the remaining addressed adding Tensar Triaxial Geogrid to stabilize the existing sub grade.

Comparing these averages suggests that BIM played a role in reducing Contract Modification Orders for the Pecos Street over I-70 project. The number of CMO's suggests that even though the Fort Lyon Canal Bridge was less complex than the Pecos Street over I-70 Bridge, it was still difficult to determine possible conflicts that could arise on the project. It is possible that using BIM technology could have helped the project team prepare for these unexpected issues, and may possibly avoided them.

Request for Information (RFI)

Table 1.10: Comparison of RFIs normalized by project

	<b>Rocky Ford Bridge Project</b>		<b>Impact of BIM Implementation</b>
	<b>Fort Lyon Canal Bridge</b>	<b>Pecos Street over I-70</b>	<b>% Change</b>
<b>RFI / 100 SF</b>	{(2/3510)/100} =.0000057	{(6/12050)/100} =.0000050	12% Decrease
<b>RFI / dollar</b>	(2 / \$583,647) =.0000034	(6 / \$2,725,345) =.0000022	35% Decrease
<b>RFI/day</b>	(2/ 170) =.011765	(6 / 365) =.016438	39% Increase
<b>RFI / Average daily traffic</b>	(2 / 809 ) =.002472	(6 / 19000) =.000316	87% Decrease

The Pecos Street Bridge construction required a total of 98 RFI's, of the 98, 42 RFI's were for the structure and superstructure of the bridge. Of the 42, 36 were for the structure of the bridge and six were for the superstructure. According to CDOT these RFI's were necessary due to the complexity of the bridge structure, specifically having to incorporate the partial roundabouts and the amount of post-tensioning involved with the deck. Other contributing factors that increased the RFI's were the moving of the bridge on the SPMTV from where it was constructed to where it would be put in place. Taking this into account when comparing the Fort Lyon Canal Bridge, which was rolled into place, and constructed next to the structure it was replacing. The Fort Lyon Bridge required three RFI's for the bridge deck. This structure was considerable smaller and less complicated than the Pecos Street Bridge due to not having the tensioning requirements, length of move, and the sustained traffic load for the Pecos Street Bridge over I-70. The Pecos Street Bridge over I-70 had .0000050 RFI / 100 SQ FT, the Fort Lyon Canal Bridge had .0000057 RFI / 100 SQ FT. These numbers show a difference between the BIM

Project (Pecos Street Bridge) and the non-BIM project (Fort Lyon Canal Bridge). The Pecos Street Bridge over I-70 was an extremely complicated project and dealt with more complex factors. This suggests that BIM may have helped the project team reduce the RFI's greatly in comparison of not utilizing BIM.

Schedule and Cost

Table 1.11: Comparison of Average costs of construction for the (2) projects

	<b>Fort Lyon Canal Bridge</b>	<b>Pecos Street over I-70</b>
Total Cost	\$559,987	\$2,725,345
SQ FT Cost	\$160	\$226
Average Daily Spending	\$3,294	\$7,467

Pecos Street Bridge over I-70 super structure was finished in 365 days at a normalized cost of \$2,725,345, with a total SQ FT cost of \$226. The average per day spending on this project was \$7,467. The Fort Lyon Canal Bridge was finished in 170 days at a cost of \$583,647 with a Total SQ FT cost of \$166. The average per day cost was \$3433.

Table 1.12: Comparison of Contract Items for the (2) projects

<b>Pecos Street over I70 Bridge</b>			<b>Fort Lyons Bridge</b>		
Contract Item No	Contract Item	Total Cost	Contract Item No	Contract Item	Total Cost
206-00100	Structure Backfill (Class 1)	\$0	206-00100	Structure Backfill (Class 1)	\$23,595
206-00200	Structure Backfill (Class 2)	\$60,765	206-00200	Structure Backfill (Class 2)	\$3,430
206-00360	Mechanical Reinforcement of Soil	\$0	206-00360	Mechanical Reinforcement of Soil	\$18,150
502-11489	Steel Piling (HP 14X89) (Install Only)	\$0	502-11489	Steel Piling (HP 14X89) (Install Only)	\$28,864
506-01020	Geogrid Reinforcement	\$13,919	506-01020	Geogrid Reinforcement	\$0
512-00101	Bearing Device (Type I)	\$28,052	512-00101	Bearing Device (Type I)	\$0
513-00690	Bridge Drain (Special)	\$7,807	513-00690	Bridge Drain (Special)	\$0
515-00120	Waterproofing (Membrane)	\$0	515-00120	Waterproofing (Membrane)	\$6,720
518-01004	Bridge Expansion Device (0-4 inch)	\$45,644	518-01004	Bridge Expansion Device (0-4 inch)	\$0
519-03000	Thin Bonded Epoxy Overlay	\$41,952	519-03000	Thin Bonded Epoxy Overlay	\$0
601-03040	Concrete Class D (Bridge)	\$643,657	601-03040	Concrete Class D (Bridge)	\$277,200
601-05045	Concrete Class s40	\$1,003,583	601-05045	Concrete Class s40	\$0
602-00000	Reinforcing Steel	\$118,771	602-00000	Reinforcing Steel	\$0
602-00020	Reinforcing Steel (Epoxy Coated)	\$299,196	602-00020	Reinforcing Steel (Epoxy Coated)	\$55,695
606-11032	Bridge Rail Type 10M (special)	\$84,173	606-11030	Bridge Rail Type 10M	\$27,750
613-00200	2 Inch Electrical Conduit	\$6,226	613-00200	2 Inch Electrical Conduit	\$2,185
613-00300	3 Inch Electrical Conduit	\$2,224	613-00300	3 Inch Electrical Conduit	\$0
618-00000	Prestressing Steel Bar	\$6,410	618-00000	Prestressing Steel Bar	\$0
618-00002	Prestressing Steel Strand	\$329,608	618-00002	Prestressing Steel Strand	\$0
618-01994	Pressed Concrete Box (Depth 32" Through 48") (Install Only) (4032)	\$0	618-01994	Pressed Concrete Box (Depth Less Than 32 Inches) (Install Only) (3096)	\$40,248
631-20020	Move Bridge (Roll)	\$1,077,144	631-20020	Move Bridge (Roll)	\$230,000
	Subtotal	\$3,769,130		Subtotal	\$713,837
	Related Change Orders	\$81,142		Related Change Orders	\$99,810
	<b>Total Sub-structure Costs</b>	<b>\$3,850,272</b>		<b>Total Sub-structure Costs</b>	<b>\$813,647</b>

This representative itemized comparison shows a SQ FT cost of \$231.81 for the Fort Lyon Canal Bridge and a SQ FT cost of \$319.52 for the Pecos over I-70 Bridge project.



## Qualitative Feedback

After the analysis was performed, interviews were conducted with the Colorado Department of Transportation to clarify and validate any cost disparities seen between the Pecos Street over I-70 Bridge and the Fort Lyon Canal Bridge. According to both project contacts these projects were CM/GC delivered, so by definition they would be lump-sum projects. Taking this into account, there was scope growth reported on both projects specifically through change orders which added additional unforeseen costs during construction. On the Pecos Street over I-70 Bridge project scope growth represented a 9% increase in total cost, scope growth on the Fort Lyon canal bridge represented a 14% change in cost. Tamara Hunter Maurer P.E. CDOT Pecos over I-70 Bridge Project, and Dean L. Sandoval, Fort Lyon Canal CDOT Project Manager were asked what might have caused the differences in costs between the two projects including materials, methods of construction, and BIM implementation.

### Pecos Street over I-70

The project Engineer from the Pecos Street over I-70 Bridge project stated that the concrete required for the bridge was extremely expensive and cost roughly \$944 / SQ YD with a total cost of \$1,003,582.99. To add to this, she stated that there were multiple loads that had to be turned away due to not meeting the project specifications and to compound this, it was incredible difficult to work with. The reasoning behind using this specific concrete is that it reduced cracking and therefore was necessary due to the bridges required move, and they were able to justify it as a necessary cost. BIM's portion in the cost was due to this being the first time it had been implemented on a project of this nature. Associated costs came from the actual software purchase (which runs \$8,000 - \$23,000 depending on if your using the basic or full

version), the initial learning curve associated with billed hours, which turned out to not be extremely challenging, and the software (Midas Civil) outputs were not exactly straightforward. It was noted that over the course of the project the understanding of the specific software got better. It was also noted that there was not an exact number in regard to BIM for the cost, but it had a significant impact on the total project cost. Other factors that could be associated to the projects cost is the use of Accelerated Bridge Construction, specifically the actual rolling of the superstructure (\$1,077,144), which she stated a bridge like this could have not been built without it.

#### Fort Lyon Canal Bridge

The project manager of the Rocky Ford Sliding Bridge project stated that costs were accrued on the Fort Lyon Canal Bridge Project due to implementing Accelerated Bridge construction. These costs were expected and they were specific to the use of special rollers, tracks, and the hydraulic system used to roll the bridge superstructure (\$230,000.00). It is known that specialty items might be needed when using the ABC method but overall costs tend to be lower.

#### CDOTS Feedback on Cost Differences

According to Nabile Haddad P.E., Innovative Contracting Manager with CDOT some of the cost difference observed between the two projects were directly attributed to project location: due to the urban aspect of the Pecos Street Bridge and the rural aspect of the Fort Lyon Canal

Bridge. Costs are associated with the level of traffic each site has to deal with. Construction Phasing, cost of sliding and the actual labor all need to be accounted for these location differences. He stated that there is software CDOT specifically uses to determine feasibility of using ABC, and associated processes in deciding what delivery method will be most effective, weather that be cost, time or other factors that is slowly becoming part of their SOP.

## Discussion

Determining the impacts and benefits of BIM Implementation requires comparing numerous quantity metrics. To analyze early adoption (first implementation) of the technology it is also important to speak with the individuals involved in the process to understand the qualitative impacts of BIM implementation. The results of this Case Study suggest that using BIM was beneficial for the Pecos Street Bridge over I-70 and resulted in reducing the number of RFI's and CMO's compared to traditional construction methods, as demonstrated in the / SQ FT and the / day comparisons. However, the complexity and size of the Pecos Street Bridge over I-70 resulted in a higher award amount and a greater daily cost. This is evident in the \$18,600,000 total award amount and the Super structures normalized cost of \$2,725,345. However, using BIM on the Pecos over I-70 Bridge allowed CDOT to deliver a bridge that otherwise could not have been built in the space and time constraints required. The ability to provide accurate and realistic views of the finished project provided the owner with a significant benefit. Prior to construction, CDOT showed images of the design to the public using the BIM model. This helped the public to better understand and support the expected outcome. By showing BIM-

enabled 3D images of the project, CDOT was able to educate all of the individuals on how the construction might benefit them in terms of future movement through the area.

In the end, the overall cost impact of BIM implementation on the Pecos over I-70 Bridge was determined to be cost neutral. Moving forward CDOT believes that the next project could see a potential Return on Investment (ROI) versus being cost neutral. Such a result would align with the McGraw Hill study “The Business Value of BIM for Infrastructure” which states “ROI has a powerful correlation with BIM expertise” (Bernstein & Stephen, 2012).

In sum, the impact of BIM was shown to be significant by the Case Study primarily because CDOT was able to provide a project that otherwise could not have been delivered. Specifically, the use of BIM facilitated modeling of the actual structure and the transfer of the structure. Analyzing variables related to the transfer allowed for the minimization of possible damage to the superstructure. This result is confirmed by the observed reduction in RFIs and CMOs relative to construction area (SF), cost (\$), and average daily traffic, compared to typical construction. CMO’s on the Pecos Street over I-70 Bridge accounted for 2% of the total cost of the super structure. CMO’s on the Fort Lyon Canal Bridge accounted for 12% of the superstructures cost. BIM theoretically saved the Pecos Street over I-70 Bridge project 10% over the total projects cost. BIM’s full benefit, however, is not limited to the construction, but will continue once a bridge is in place, since it can then be managed more effectively by the incorporation of the information gained through the construction process. Utilizing BIM for operation and management of transportation infrastructure is still in infancy, but it is the goal of the peer organizations that have implemented it into their construction processes. The opportunities presented allow for an asset that can be maintained efficiently and effectively by incorporating all maintenance and material aspects, accessible in one 3D smart model.

Although the cost to construct the Pecos over I-70 Bridge was higher, this Case Study suggests that BIM's influence on the project provided added value by helping minimize complexities with the unique super structure and its' required move. The Pecos over I-70 Bridge represented the first time BIM was implemented and utilized within the entire CDOT organization, and may have incurred avoidable "learning or first adoption" costs. Even on first implementation, however, using BIM technology allowed for the project team to evaluate potential risks before encountering them in the field. By utilizing a 3D model the construction crew was able to analyze both permanent and temporary loads that would result from the moving of the super structure (Colorado Department of Transportation, 2013). This was critical to avoid loads that might otherwise cause unwanted fractures to the super structure, which in turn, would reduce lifespan. Another benefit was that BIM allowed the project team to obtain a general idea of cost, although in the end the plans were utilized for estimating purposes. The Pecos Bridge avoided rework altogether through the incorporation of BIM technology. This suggests that there were undocumented (under represented) cost savings due to avoiding the potential effects of rework. If a BIM model had been used on the Fort Lyon project the Contract Modification Order's and RFI's could possibly have been reduced, therefore decreasing overall project costs by as much, if not more than \$92,155 (total cost of Change Modification Orders). This comparison Case Study suggests that BIM may be beneficial for many transportation infrastructure projects, complex or simple by affecting associated costs of design development through construction, and O & M. The findings presented here outline why similar organizations would implement BIM due to alleviating possible issues that can be encountered by utilizing a 3 dimensional smart model. The research suggests that not only will you see possible positive ROI after initial implementation, but also the ability to deliver complex projects in limited time

allotments is now feasible. For organizations to really benefit from BIM implementation it is important to take on a select few handpicked projects and implement BIM to the full extent. By approaching implementation in this fashion the organizations are able to take it slow and get it right the first time by realizing any possible mistakes. This allows for the organization to understand the correct processes involved and move forward with implementation throughout the organization with a lessons learned approach.

## Conclusions

The research documented two similar ABC bridge constructions with relatively similar project characteristics including project delivery, construction type and transfer type. The similarity of projects allowed analysis of the impact of BIM implementation (a first implementation) using the metrics identified. This research found that although costs increased, CMO's and RFI's decreased on the project that utilized BIM compared to the project that did not utilize BIM. Specifically, Table 10 suggests that using BIM has decreased the number of RFIs and CMOs relative to construction area (SF), cost (\$), and average daily traffic, compared to typical construction.

It is important to distinguish between the impact of BIM during its first implementation and overtime. While this research analyzed a project that did not utilize BIM and compared it one where BIM was implemented for the first time, it is possible to make some projections based on research findings. Specifically, costs related to CMO's decrease by 10% when BIM was used (2% CMO related costs for super-structure documented) relative to the non-BIM project (12% CMO related costs for super-structure documented). As a result, it is possible to provide data

which adds a level of precision to the BIM Implementation Learning Curve (see Figure 1.1) in terms of costs related to capabilities. Figure 3.1 graphically represents data related to the impact of BIM adoption for transportation projects as documented in this research.

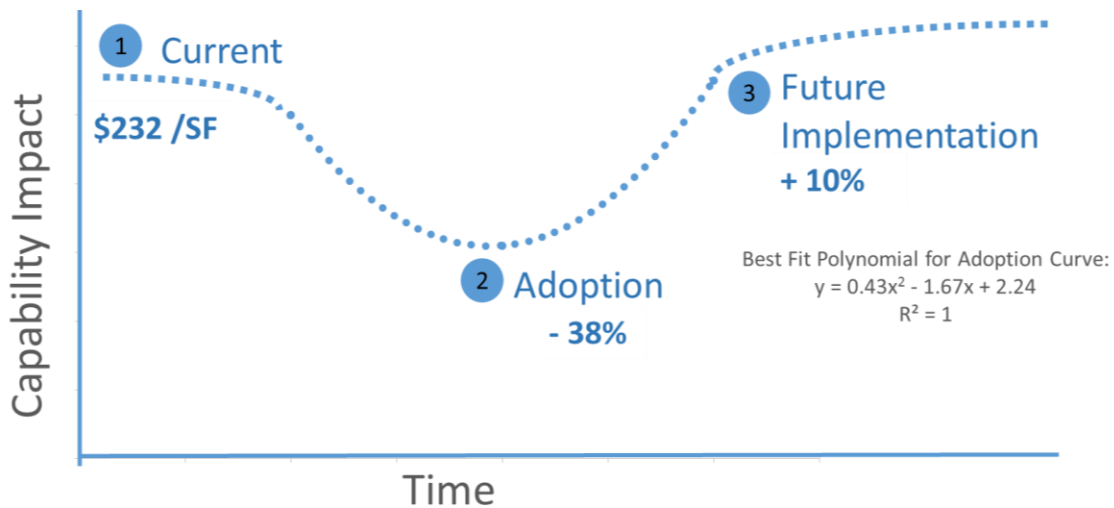


Figure 1.5: BIM Implementation Learning curve (Current to Future Implementation)

The points in Figure 3.1 are derived from the costs presented in Table 4.5: Point (1) represents cost per SQ FT for Fort Lyon Canal Bridge; Point(2) represents the negative impact of a 38% cost increase per SQ FT for Pecos Street over I-70 Bridge and Point (3) is an estimated future impact improvement based on the cost savings from reduced CMOs observed in the two case study projects.

The primary benefit of the research is to suggest that through implementation organizations can move along the BIM implementation learning curve recognizing incremental benefits from implementation (see Figure 3.1). Finally, the underlying contribution of this research is that it increases understanding for transportation organizations about the impacts of implementing BIM during the construction phase of transportation asset management.

## FUTURE RESEARCH

In the future there is a need to populate information about the difference through more case studies. Specifically ones that

- 1) Address more of the metrics in cases where the projects are not as similar across delivery, construction type and transfer. For example, state that difference in structural complexity (# 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.
- 2) Include projects that are not “first implementations” but 2<sup>nd</sup>, 3<sup>rd</sup>, etc. so that you can further plot the curve of BIM implementation over time.



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