

ENHANCING PRODUCTIVITY BY USING BUILDING INFORMATION
MODELING APPLICATIONS IN PIPELINE
CONSTRUCTION PROJECTS

by

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April 21, 2016

Abstract

ENHANCING PRODUCTIVITY BY USING BUILDING INFORMATION MODELING APPLICATIONS IN PIPELINE CONSTRUCTION PROJECTS

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Building Information Modeling (BIM) is a technology and associated set of processes to produce, communicate, and analyze building models. BIM is a new concept within the construction industry. The objective of this thesis is to utilize BIM in pipeline construction projects as one of the pioneering steps to reduce rework and delays due to unforeseen conditions. This thesis presents evaluation and recommendations to help pipeline construction industry's transition from traditional two-dimensional drawings to a BIM management process aiding owners and contractors to develop and implement a basic form of BIM technique to manage their projects. This thesis uses two pipeline construction projects in the Cities of

Dallas and Fort Worth, Texas, as case studies. These case studies are used to assess and evaluate the effects of applying a supplemental 4-D modeling techniques to enhance the pipeline project's coordination and productivity by minimizing rework and delays due to unforeseen conditions. Some companies may initially consider the costs associated with BIM software licensing and personnel training to be high. However, this thesis concludes that development of a supplemental four-dimensional model as simpler and more manageable alternatives in implementing a fully integrated BIM program is practical and cost effective.

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Chapter 1

Introduction

1.1 Background

The use of pipelines as modes of transporting fluids and gases started in early 1800s. A pipeline construction project looks much like a moving assembly line. A large project typically is broken into manageable lengths called “spreads,” and utilizes highly specialized and qualified workgroups. Each spread is composed of various crews, each with its own responsibilities. As one crew completes its work, the next crew moves into position to complete its task. Typically, the tasks involved in a pipeline construction are pre-construction survey, clearing and grading, trenching, pipe stringing alongside of the trench, bedding, lowering pipe inside the trench, welding and coating pipe joints, embedding and backfilling, testing, commissioning and restoration of ground (The Williams Companies, Inc., 2016).

Pipeline contractors have used an assembly of two-dimensional (2-D) documents consisting of plans, sections, elevations, and specifications as a guide in executing individual projects. As projects become increasingly more complex, and owners demand quicker delivery and greater cost efficiency, contractors must incorporate new practices to

effectively manage project constraints. Also with the increase of project constraints, downfalls in the projects' productivity have been experienced. Especially, underground infrastructure projects often experience delays and rework due to variable ground conditions. This thesis uses two pipeline construction projects as case studies. These case studies are used to assess and evaluate the effects of applying both 2-D and 3-D modeling techniques to enhance the project's coordination and productivity by minimizing rework and delays due to unforeseen events during project execution.

1.2 Importance of the Problem

Construction Industry is one of the major contributors to the United States GDP. In 2013, U.S. Bureau of Economic Analysis has reported that Construction Industry made up approximately 3.6% of the 2013 US Gross Domestic Product with sells of \$584.8 billion (U.S. Bureau of Economic Analysis 2013). Construction Industry Institute have conducted a research and estimated the direct costs caused by rework in the construction industry average five percent of the total construction costs of a project (Hwang, et al. 2009). This in turn constitutes \$29.24 billion in 2013 alone.

The impact caused by the rework not only affects the economy of the project but also affects the morale of all the stakeholders associated

with it. “Despite the fact that numerous studies have been conducted on rework, there is still no standard for measuring and classifying rework. However there are three major factors with which rework is weighted i.e. time, cost, morale and rework often have significant impacts on these three factors” (Villafana, 2011). Removal and reinstating the non-compliant work, affects project economy and often results in schedule delays, which in turn affects the morale of the project team and may have potential decrease in the level of productivity. In the view of project owner, the productivity loss will increase project’s time and cost and it also demotes contractor capabilities to perform work. Fayek et al. (2003) identified the components of rework as depicted in Figure 1-1.

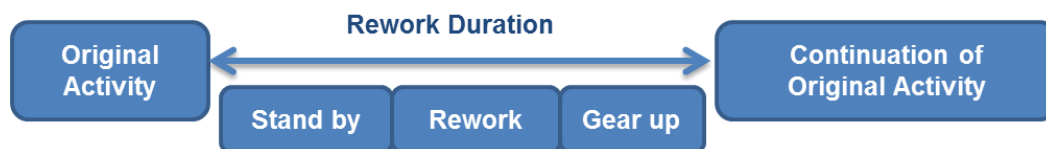


Figure 1-1 Effects of Rework on Time

(Source: Villafana, 2011)

According to Figure 1-1, rework components have been identified as stand by, rework and gear up the pace of construction. During the stand by duration, non-compliant work will be identified and reinstating measures will be addressed. These reinstating measures will be applied to non-complaint work during rework duration and will gear up the pace of

the project to catch up with the schedule. The three factors associated with rework - loss of money, loss of time and lowered morale, have detrimental impacts on project coordination and productivity. It is sensible to assume minimizing rework not only increases the contractor's profit margin, but also owner will get benefited by the faster delivery. This thesis will address these issues by applying both 2-D and 3-D modeling techniques to enhance a pipeline project's coordination and productivity by minimizing rework and delays due to unforeseen conditions.

1.3 Current Project Management Standards

The construction industry in the United States has adapted a fragmented approach when it comes to project procurement. "Paper-based modes of communication has been a common practice among the construction industry for so long that incorporation of technology to supplement the current delivery process will not only require team members to learn a new skill set, but also require changing an industry mindset. However, the construction industry have not completely ignored the incorporation of technology into the project delivery process; many of the activities associated with the delivery process are now performed and delivered faster via the use of software and web-based technologies. For example, estimating and scheduling activities can now be performed

faster via the use of digitizers, digital drawings, and estimating and scheduling software” (Villafana, 2011).

1.4 Introduction to Building Information Modeling (BIM)

BIM is one of the most promising of developments to emerge over the past decade. It is slowly gaining acceptance and its use has increased among many construction companies in the United States (Azhar, 2011). BIM is an innovative or extended approach to object-oriented Computer Aided Drafting (CAD), which extends the capability of traditional CAD approach by defining and applying intelligent relationships between the elements in the building model. With BIM technology, an accurate virtual model of a project is constructed digitally. When completed, the computer-generated model includes both geometric and non-geometric data. The geometric data includes information needed to support construction, fabrication, and procurement activities. The non-geometric data includes information such as object attributes and specifications.

BIM can also facilitate the integration of functions involved in the lifecycle model of a pipeline. It helps to identify new construction approaches and changes in the role and relationships within the project team. Furthermore, appropriate implementation of BIM facilitates more

integrated design and construction processes that result in better project quality at lower costs and reduced project durations.

1.5 Scope of Research

To improve project productivity, project management tools have to be developed and utilized. BIM (Building Information Modeling) is a modeling technology and associated set of processes to produce, communicate, and analyze building models (Eastman et al., 2008).

In implementing BIM practices, construction firms will have to take on a more collaborative role during the design phase and in facilitating transition into the operation and maintenance of the project. Moreover, making the transition from 2-D based practices to a BIM based process will require investment in software, hardware, and staff training, as well as restructuring the firm's business such that the BIM process is tracked, modified as necessary, and is implemented successfully. This provides a scope of developing supplemental models as simpler and more manageable alternative in implementing a fully integrated BIM program by smaller firms and addresses these elements by enhancing project communication by incorporating another level of project communication, to minimize or eliminate rework and delays through enhance productivity.

1.6 Objectives

Following are the objectives of this thesis:

- Identify a strategy to implement BIM concepts in pipeline construction industry.
- By using BIM, reduce rework and delays due to unforeseen conditions.
- Implement BIM concepts on two distinct pipeline construction projects to assess applicability.
- Investigate the applicability and effectiveness of BIM in improving productivity and cost savings.

1.7 Expected Outcomes

The expected outcomes of this research are:

- Develop a 4-D model to aid pipeline construction companies adopt BIM practices.
- Demonstrate the use of BIM concepts to:
 - Improve project coordination and management.
 - Improve productivity.
 - Improve profit margin.

- Reduce rework and delays due to unforeseen conditions.

1.8 Chapter Summary

Building Information Modeling (BIM) has been evaluated by the Architecture, Engineering and Construction (AEC) Industry for residential and commercial projects. It is slowly gaining acceptance in the AEC industry. Furthermore, attempts have been made to incorporate it into highway and industrial projects. It currently has minimal presence in the pipeline construction industry. The increasingly complex and linear nature of pipeline projects, and demands by owners for quicker delivery and greater cost efficiency, has provided contractors with an opportunity to incorporate new practices to effectively manage project constraints. Hence, evaluating the productivity by using BIM applications for pipeline projects is important and can be a valuable tool to improve productivity.

Chapter 2

Literature Review

2.1 Introduction

Chapter 1 presented a basic outline about the needs and goals of expending the efforts and time to investigate and evaluate the building information modeling (BIM) applicability in the pipeline industry. Chapter 2 presents setting up the current state of pipeline industry and an introduction of BIM concept.

2.2 Current State of Pipeline Industry

In the United States, construction industry has traditionally assimilated a fragmented approach in case of project procurement. The paper-based modes of information exchange are very common in the pipeline industry for very long time. The process of incorporating new technologies in this industry requires the team members to undergo a lot of training exercises and also the mindset of the industry shall be changed.

The pipeline industry have not completely ignored the incorporation of technology into the project delivery process, many of the activities associated with the delivery processes are now performed and delivered faster via the use of software and web-based technologies.

Estimating and scheduling activities for example can now be performed faster via the use of digitizers, digital drawings, and estimating and scheduling software. Information exchange between the contractor's field office (project site) and head office, architect/engineer office can now occur in real time via email and web-based programs. Arguably the cost implications associated with incorporating technology into the project delivery process among smaller sized firms could be the primary limiting factor. Due to the rapid advancements in technology, computer software and hardware costs become secondary to the costs of training staff to properly implement such technologies (Villafana, 2011).

2.3 Construction Project Delivery Methods

A construction project delivery method is a function by which an owner or an agency use it for organizing and funding to plan, design, construction, operations and maintenance of a facility by undergoing a contract or agreements legally with one or more entities.

Common project delivery methods include;

- i. Design-Bid-Build (DBB) or Design-Award-Build (DAB)
- ii. Construction Management
- iii. Design-Build (DB) or Design-Construct
- iv. Design-Build-Operate-Maintain (DBOM)

- v. Build-Operate-Transfer (BOT)
- vi. Integrated Project Delivery (IPD)

2.3.1 The Preferred Pipeline Project Delivery Method

Design-bid-build and design-build delivery methods are most widely used project delivery systems in the pipeline industry for very long time (Hasan, 2010). Figure 2-1 illustrates percentages for different project delivery methods.

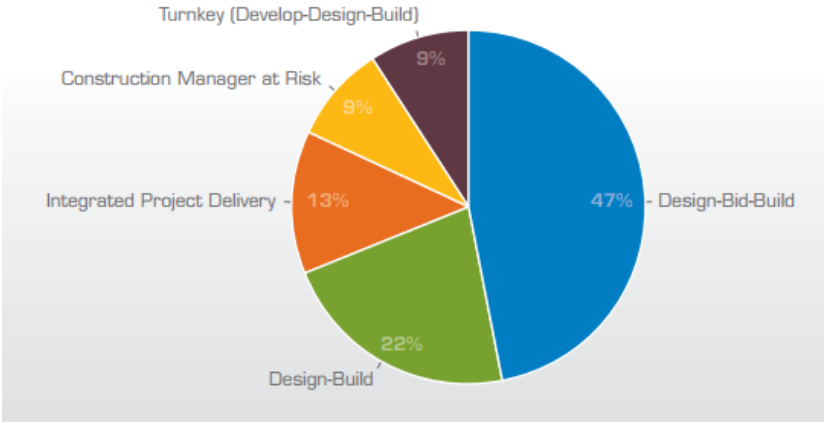


Figure 2-1 Most Preferred Project Delivery Method Perceived Owner Preference Among All Participants (Design-Build Institute of America, 2014)

Design-build and design-bid-build are the most chosen project delivery method in United States, than construction management at risk over the years (from 2005 - 2013) and this can be derived from Figure 2-2.

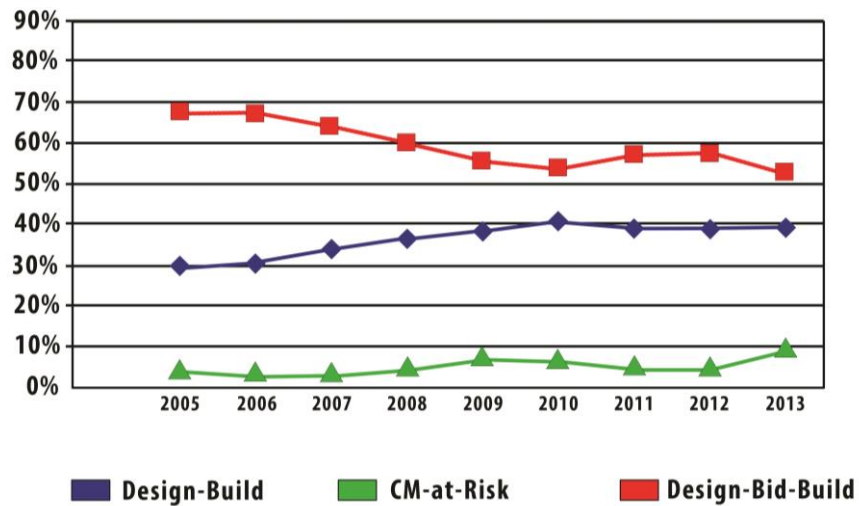


Figure 2-2 Project Delivery Method per Percentage of Contracts in the United States

(Design-Build Institute of America, 2014)

2.4 Pipeline Construction

Pipeline construction is divided into three phases, each with its own activities: pre-construction, construction and post-construction (Source: Pipeline Construction, CEPA, 2015).

2.4.1 Pre-Construction

2.4.1.1 Surveying and Staking:

Once the pipeline route is finalized, crews survey and stake the right-of-way and temporary workspace. Not only will the right-of-way contain the pipeline, it is also where all construction activities occur.

2.4.1.2 Preparing the Right-of-Way:

The clearly marked right of way is cleared of trees and brush and the top soil is removed and stockpiled for future reclamation. The right-of-way is then leveled and graded to provide access for construction equipment.

2.4.1.3 Digging the Trench:

Once the right-of-way is prepared, a trench is dug and the center line of the trench is surveyed and re-staked. The equipment used to dig the trench varies depending on the type of soil.

2.4.1.4 Stringing the Pipe:

Individual lengths of pipe are brought in from stockpile sites and laid out end-to-end along the right-of-way.

2.4.2 Construction

2.4.2.1 Bending and Joining the Pipe:

Individual joints of pipe are bent to fit the terrain using a hydraulic bending machine. Welders join the pipes together using either manual or automated welding technologies. Welding shacks are placed over the joint

to prevent the wind from affecting the weld. The welds are then inspected and certified by X-ray or ultrasonic methods.

2.4.2.2 Coating the Pipeline:

Coating both inside and outside the pipeline are necessary to prevent it from corroding either from groundwater or the product carried in the pipeline. The composition of the internal coating varies with the nature of the product to be transported. The pipes arrive at the construction site pre-coated, however the welded joints must be coated at the site.

2.4.2.3 Positioning the Pipeline:

The welded pipeline is lowered into the trench using special cranes with side booms.

2.4.2.4 Installing Valves and Fittings:

Valves and other fittings are installed after the pipeline is in the trench. The valves are used once the line is operational to shut off or isolate part of the pipeline.

2.4.2.5 Backfilling the Trench:

Once the pipeline is in place in the trench the topsoil is replaced in the sequence in which it was removed and the land is re-contoured and re-seeded for restoration.

2.4.3 Post Construction

2.4.3.1 Pressure Testing:

The pipeline is pressure tested for a minimum of eight hours using nitrogen, air, water or a mixture of water and methanol (Pipeline Construction, CEPA, 2015).

2.4.3.2 Final Clean-Up:

The final step is to reclaim the pipeline right-of-way and remove any temporary facilities.

2.5 Building Information Modeling

2.5.1 BIM's Return on Investment

There is no accurate evaluation to quantify the return on investment (ROI) to implement BIM related strategies and procedures. “Tangible metrics such as productivity are easier to measure as opposed to the benefits associated with profits gained from increased project quality,

repeat business, improved communication, and the interoperability of information. Within the construction industry, even productivity measures can be misleading due to the distinctive nature of each individual project. Unlike the controlled environment within a manufacturing industry, even in projects where the exact construction documents are used to assemble an array of building, each building's site conditions are different. Similarly, other factors such as weather, economic conditions, and labor conditions and morale can have a considerable effect on the production rates at each project location.

Consequently, companies looking to implement BIM related strategies and procedures should not do so solely on the results of an analysis such as ROI, but do so more with the intent of promoting an integrated project delivery atmosphere to enhance a project's performance. In evaluating a ROI for a new system, consideration must be given to the loss of productivity during the training and transitional stage of the system's implementation. Productivity gains, therefore, are not typically experienced until after users are familiarized and confident with the new system's capabilities" (Villafana, 2011).

Figure 2-3 illustrates a graphical representation of the productivity loss and gain in implementing new software (Autodesk, Inc., 2007).

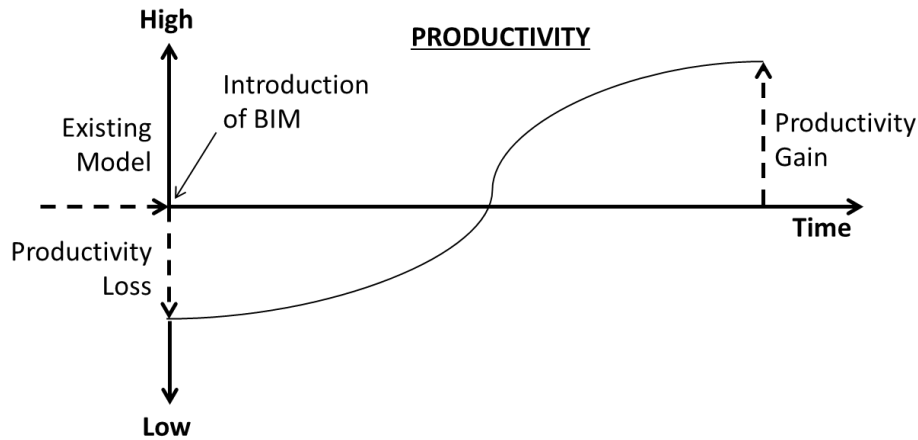


Figure 2-3 Productivity Trend in Implementing BIM

(Source: Autodesk, Inc., 2007)

Figure 2-3 illustrates a downfall in productivity as soon as a firm introduces building information modeling by disturbing the traditional construction practices. The loss in productivity may be due to the investment of time in training the employees and building up the morale in accepting these organizational changes. It is in the hands of business leaders to encourage and motivate their organization to accept and adapt these changes. Once these changes have been accommodated and adapted, the downfall in productivity matches the existing productivity before the loss with time. As the organization gains experience and showcase high involvement in BIM implementation with respect to time, they then experience a gradual gain in productivity and continue. In order

to execute these procedures, the organization shall accept the downfall in productivity to experience a gain in productivity.

2.5.2 Role of BIM: Current and Future Trends

McGraw-Hill Construction (2012) published a comprehensive market report of BIM's use in 2012 and projections for future based on the findings of a questionnaire survey completed by architects, engineers, contractors, and owners in the United States.

2.5.2.1 BIM Adoption:

Overall BIM users have increased significantly from 2007 to 2012. Some of the users are engaging deeply and experiencing greater benefits. While some of them have already experienced these benefits and are planning for their future investments. "Industry-wide adoption of BIM surged from 28% in 2007 to 71% in 2012. Contractors (74%) have surpassed architects (70%) and engineers (67%) are close to parity with the two other groups. Regional differences also narrowed, and though the Western U.S. still leads at 77%, the formerly lagging Northeastern U.S. jumped from 38% in 2009 to 66% in 2012. Other U.S. regions and Canada remain close to the growing national average. Size matters in BIM adoption: About 90% of large and medium-to-large organizations are engaged with BIM, compared to less than half (49%) of small ones.

Although there are fewer non-users, more of them are hardening their resistance, especially among non-using architects where 38% say they will not use BIM. Major benefits include” (McGraw-Hill Construction, 2012);

- Increase in profits is one of the BIM benefits, associated with high level of engagement.
- Maintaining repeat business with past clients, which requires completed projects, outpaced marketing new business to new clients, a benefit that can be done right after adopting.
- The most engaged users enjoyed far larger increases in BIM benefits. Refer to Figure 2-4 for levels of BIM adaptation.

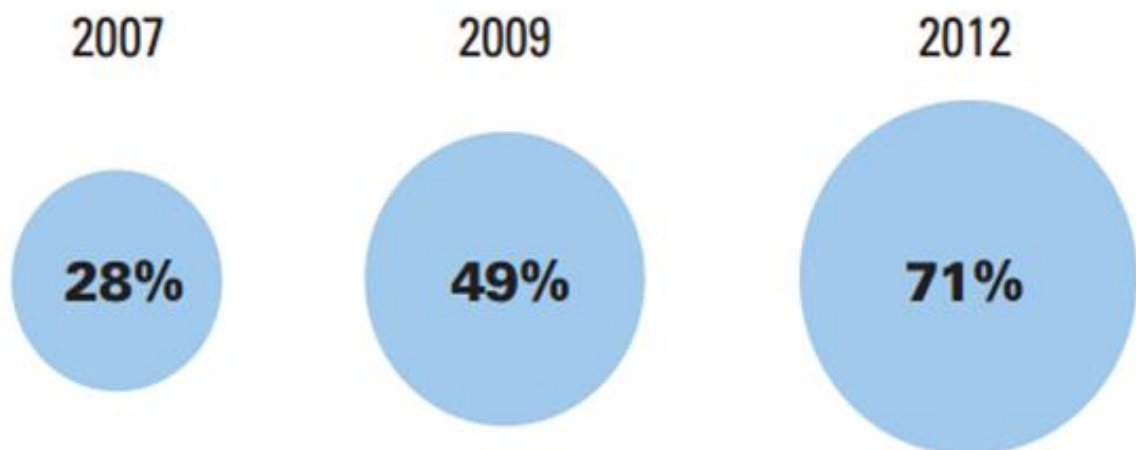


Figure 2-4 Levels of BIM Adoption in North America
(Source: McGraw-Hill Construction, 2012)

2.5.2.2 Return on Investment on Implementing BIM:

“Almost two thirds (62%) of all BIM users’ perceive positive ROI, although not evenly across firm types or BIM engagement levels. 74% of the contractors report a positive ROI compared to only 37% of engineers. ROI correlates strongly with BIM engagement level, rewarding companies with higher skill, experience and implementation levels” (McGraw-Hill Construction, 2012). Figure 2-5 illustrates BIM return on investment for users by the level of engagement.

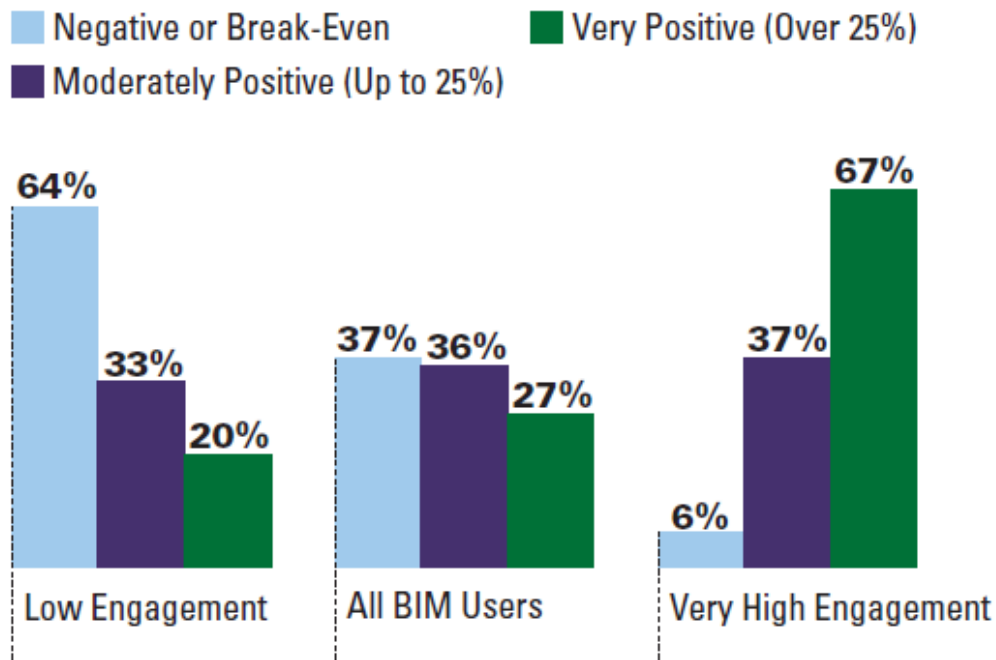


Figure 2-5 BIM ROI for Users by Level of Engagement

(Source: McGraw-Hill Construction, 2012)

2.5.2.3 BIM Implementation Levels:

“In 2009, the highest concentrations were at the two extreme levels. The largest group (35%) was light users, experimenting with BIM to determine if they could generate meaningful value from it. The next largest group (27%) was the very heavy users, already convinced of its value and committing to BIM use.

In 2012, the two extremes are still the most populated tiers, but their positions are reversed. Very heavy users are now by far the largest group (39%), demonstrating the growing commitment to BIM by firms that have adopted it. Light users are the next largest (24%), representing the large number of firms that adopted BIM between 2009 and 2012, many of whom are still in the early stages of implementation.

The forecast for 2014 implementation shows growing commitment. By 2014, 58% of firms predict they will be at a very heavy level of BIM implementation, increasing from 39% in 2012 and 27% in 2009. Conversely, the percentage remaining at light usage dwindles to 6%, meaning 94% of current users intend to make a serious commitment to BIM” (McGraw-Hill Construction, 2012). Refer to Figure 2-6 for BIM implementation levels.

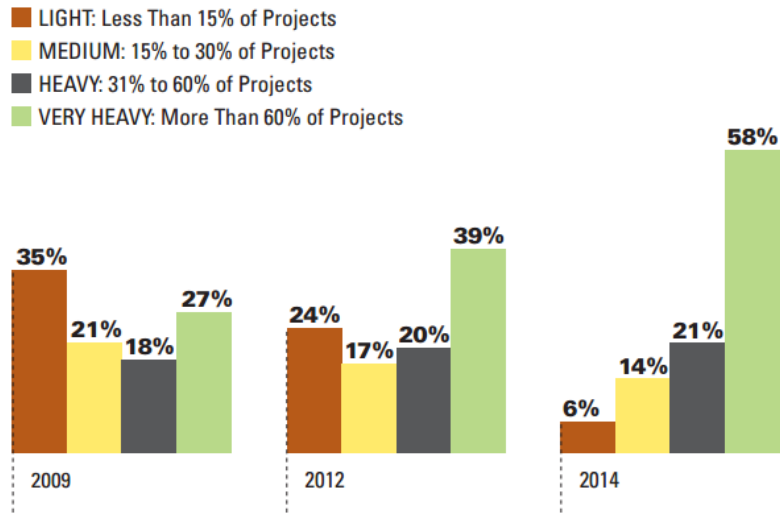


Figure 2-6 BIM Implementation Levels (2009–2014)
 (Source: McGraw-Hill Construction, 2012)

Architects, Engineers, contractors and owners are major players in the industry. Figure 2-7 showcases percentage of players using BIM on more than 60% of their project increased drastically from 2009 to 2012 and projected 2014.

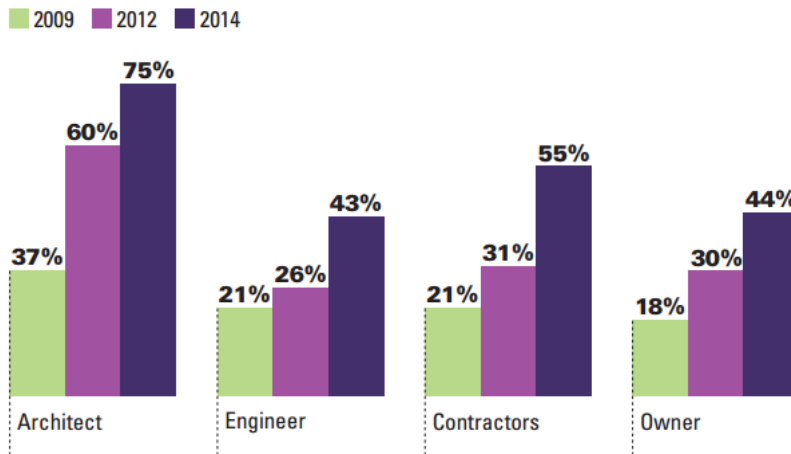


Figure 2-7 Percentages of Players Using BIM on More Than 60% of Their Projects

(Source: McGraw-Hill Construction, 2012)

2.6 Chapter Summary

Chapter two covered a brief overview of the current state of the pipeline industry. The Design-Bid-Build delivery method and Design-Build delivery methods are the most widely used project delivery systems in the pipeline industry for very long time. Brief discussion on the phases involved in pipeline construction. Building information modeling was introduced and statistical data in terms of its initial investment, ROI, and benefits indicating both positive measured and perceived value to implementing BIM.

Chapter 3 Methodology

3.1 Introduction

This chapter presents a brief overview of thesis methodology selected to create a 4-D schedule using BIM applications. In addition to 4-D schedule there are some added features such as, detailed conflict report and detailed progress report. Appendix A presents a sample conflict report and detailed progress report. This chapter also talks about the approach that was adopted to develop the 4-D model with emphasis on methods and procedure used to implement BIM. Finally, it evaluates the created 4-D model by analyzing the productivity, task durations, climatic conditions and sequence of operations that was used to install pipelines.

A pipeline construction project looks much like a moving assembly line. Planning a pipeline installation and identifying sequence of operations are crucial steps. Planning for any pipeline project begins months and even years in advance of actual construction. Initial steps in the planning process include determination of demand, pipeline design, route alternatives and selection, environmental assessments, public consultation, landowner negotiations and government permitting. Once these steps are complete, the construction process begins (Enbridge, 2012).

Contractors should invest in newer technologies and project management tools to enhance their productivity and minimize disruptions and/or delays caused due to unforeseen conditions. Figure 3-1 illustrates the initial steps in pipeline project planning process leading to construction.

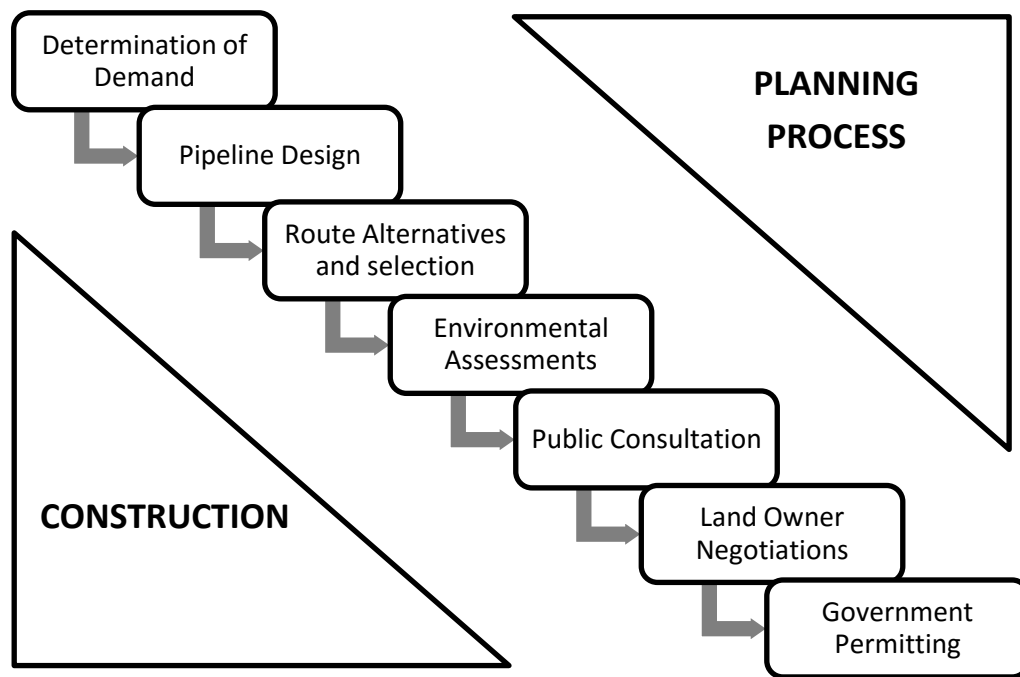


Figure 3-1 Initial steps in the planning pipeline projects (Enbridge, 2012)

Implementing a BIM program by a pipeline construction company requires a financial burden but more importantly a substantial cultural change. When it comes to BIM, it must be understood that it is more than

software; Building Information Modeling is an information management process. Contractors and/or Business leaders have a tendency to evaluate incorporation of technologies into their business model on the basis of acquisition cost rather than on its full implementation cost and full revenue generating potential (Smith and Tardif, 2009). In general, contractors will encourage their organization in software owning, licensing and training. They should shift their focus on managing technology such that, they can divert the indirect costs incurred to educate their organization in developing a new business culture. Developing a new business culture, incorporation of new technologies and managing them will improve their business and also improve productivity of the personnel associated with them.

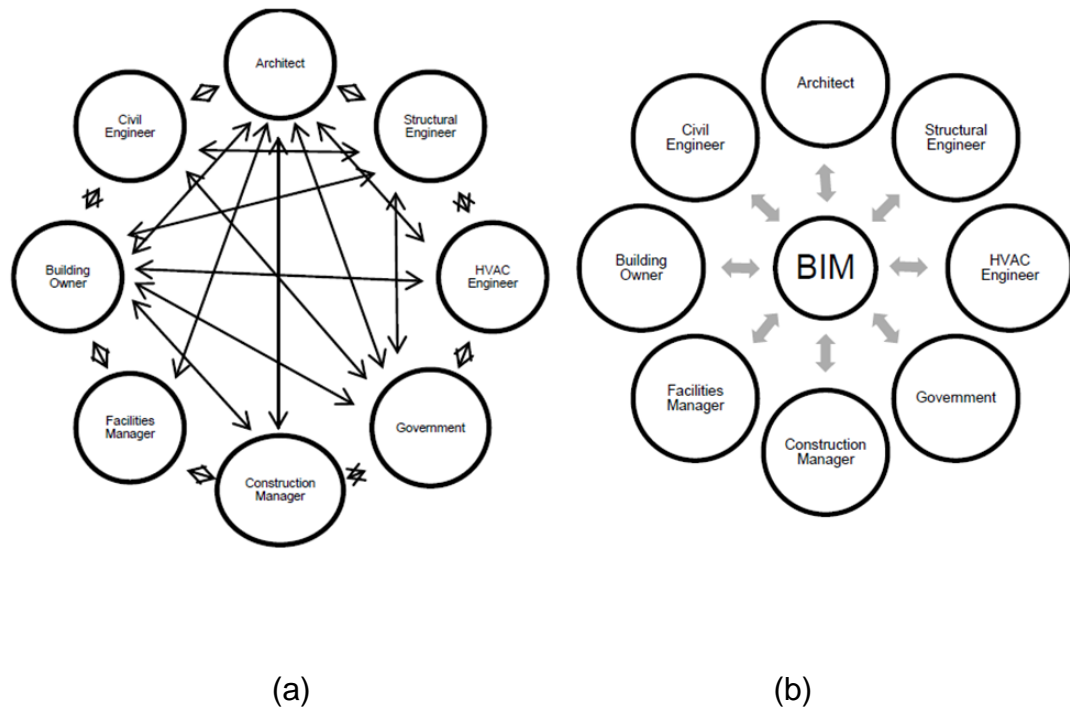


Figure 3-2 Information Exchange Matrices (a) Current AEC Information Exchange (b) BIM Information Exchange (Villafana, 2011)

As can be observed from Figure 3-2, the complexity of the construction environment makes it both difficult and cost intensive to implement a collaborative approach such as Building Information Modeling. Larger construction companies are more likely to have the capital, both financial and personnel, to allocate towards the development of implementation strategies to incorporate BIM programs into their business practice. Furthermore, larger well established construction firms are more likely to foster an apparent sense of security in project owners

and investors in regards to incorporating BIM to the project scope in comparison to smaller construction companies (Villafana, 2011).

Incorporating BIM in a business organization is very expensive and consumes a lot of man-hours for training. In order to change the mindset of the industry and as a starting step, introduce a simple, economic project management tool which will have three main functions a 4-D schedule, detailed conflict report and detailed progress report.

3.2 Tools and Techniques Used

As BIM does not propose any means and methods beyond current practices in the construction industry. Main focus is on the financial part of this project management tool. As BIM is very expensive, a contractor will not show interest in investing if he is in need of project coordination tool. First and foremost goal of this research is to identify tools and platforms to develop a project coordination tool inexpensively. Second goal of this research is to build a schedule template in reference with Microsoft Project and Primavera, but with ease in use. Final goal is to minimize the indirect costs incurred by a business organization in training their personnel to use any new technologies.

The outcomes of this thesis will focus on cost effective nature and accuracy of the said coordination tool, effects of incorporating

supplemental information, additional 2-D and 3-D models, to aid in managing a project.

- Developing the survey data into a 2-dimensional plans, elevations and sections provided by the field superintendent using a CAD based system in addition to the project documents.
- To incorporate certain details such as conflict reports and progress reports that will aid the owner, contractor and subcontractors in minimizing discrepancies pertaining to as-build drawings and actual site conditions.
- Developing 4-D schedule that will aid in coordinating the construction activities with utmost perfection.
- Applying the said project management tool and analyzing it in terms of cost and time savings.

Construction companies, their project managers and project teams currently spending a substantial amount of time “documenting their own actions as a bulwark against possible future legal action – a no-value task, as far as the project is concerned (Smith and Tardif, 2009).”

Ultimately the contractors should adapt an integrated approach and be prepared to accept a cultural change in their organization.

3.2.1 Methodology Flow Chart

Figure 3-3 illustrates a flowchart, which explains this thesis methodology.

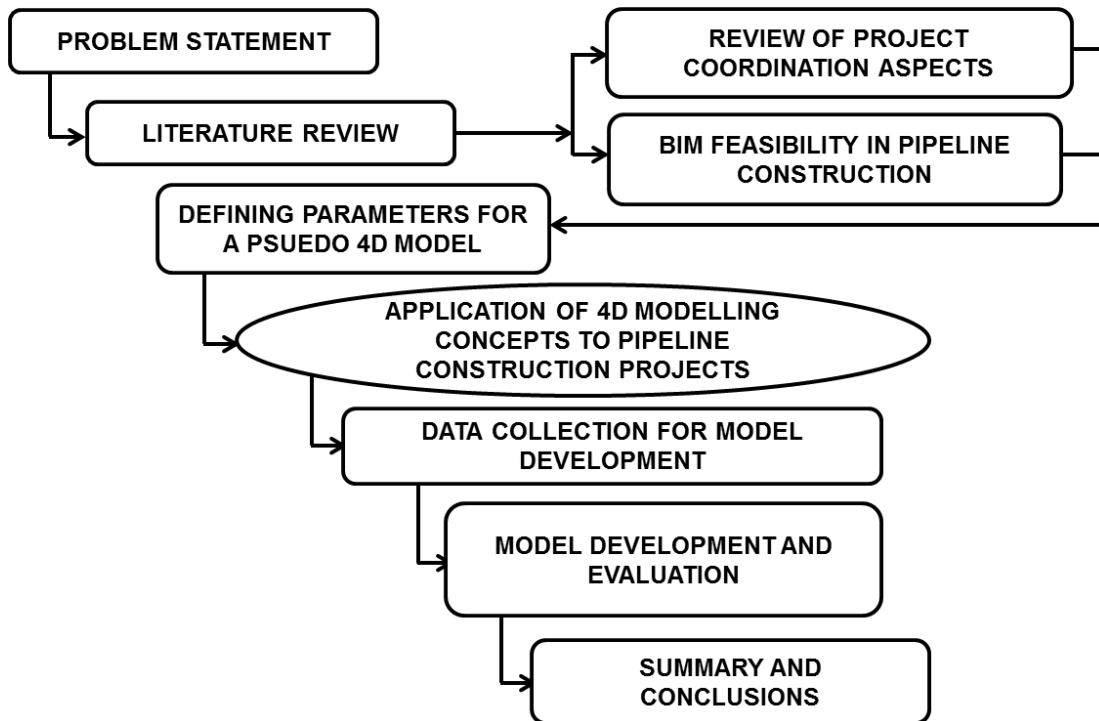


Figure 3-3 Methodology Flow Chart

3.3 Chapter Summary

Implementation of a Building Information Modeling program by a pipeline construction company requires a financial burden but more importantly a substantial cultural change. The main objective of this thesis is to introduce a project management tool to reduce the financial burden and improve project coordination. This will in turn reduce the indirect cost incurred in training for understanding and operating newer technologies.

As the three dimensional modeling become more popular in the industry, contractors should adapt a basic BIM program as an introduction.

Chapter 4 Developing a 4-D Schedule Using BIM Applications

4.1 Introduction

Chapter 3 presented the methodology used in this research; Chapter 4 focuses on developing a 4-D schedule using Building Information Modeling applications. There are many dedicated software programs available to schedule a construction project, some of them are Microsoft Project, Primavera etc. This 4-D schedule uses the primary functions of the said software programs with the incorporation of visual interpretation and project management inputs. There were many discussions and brain storming sessions to select a software platform which is cost effective and has high degree of accuracy. Using Microsoft Excel as a platform for the said 4-D schedule was economic; as MS Excel is available with all construction firms small, medium and large and also considering its ease of use.

4.2 Developing and Testing an MS Excel Bar (Gantt) Chart Schedule

A basic bar chart has been created in MS Excel using a sample construction operation. Collected some of the major tasks involved in remodeling a house in Dallas-TX, from a local contractor. Table 4-1 portraits tasks used in developing a two-dimensional Gantt chart with time as its third dimension.

Table 4-1 Major Tasks Involved in Remodeling a House

TASK	START DATE	DURATION (DAYS)	END DATE
Demolition	8/24	1	8/24
Roofing	8/19	1	8/19
Sub-floor Overlay	8/24	1	8/24
Plumbing - Phase I	8/24	2	8/25
Electrical - Phase I	8/24	2	8/25
Siding/Sheathing/Insulation	8/25	2	8/26
Remove interior doors and window	8/27	1	8/27
Install sheet rock and trim/Prep exterior Window frames and trim	8/28	1	8/28
Tape, bed and texture walls	8/31	4	9/3
Paint walls and trim	9/4	2	9/7
Install Vinyl Planks	9/8	2	9/9
Install Ceramic Tiles in bathroom	9/10	1	9/10
Plumbing - Phase II	9/10	2	9/11
Electrical and HVAC trim out - Phase II	9/14	2	9/15
Final site Clean-up	9/16	1	9/16

JOB TITLE:	15-68 R	JOB LOCATION:	9928 Bowman, Dallas, TX 75220	Note: Input only in "TEXT" & Type in reason column in case of delays.
JOB SUPERVISOR:	Mr. Mark Biggs	JOB DURATION:	28 DAYS	
DATA DATE:	2/13/16	START DATE:	8/19/15	

TASK	START DATE	DURATION (DAYS)	END DATE	DAYS COMPLETE	% COMPLETE	STATUS	REASON
Demolition	8/24	1	8/24	0	0%	As perschedule	
Roofing	8/19	1	8/19	1	100%	As perschedule	
Sub-floor Overlay	8/24	1	8/24	0	0%	As perschedule	
Plumbing - Phase I	8/24	2	8/25	0	0%	As perschedule	
Electrical - Phase I	8/24	2	8/25	0	0%	As perschedule	
Siding/Sheathing/Insulation	8/25	2	8/26	0	0%	As perschedule	
Remove interior doors and window	8/27	1	8/27	0	0%	As perschedule	
Install sheet rock and trim/Prep exterior window frames and trim	8/28	1	8/28	0	0%	As perschedule	
Tape, bed and texture walls	8/31	4	9/3	0	0%	As perschedule	
Paint walls and trim	9/4	2	9/7	0	0%	As perschedule	
Install Vinyl Planks	9/8	2	9/9	0	0%	As perschedule	
Install Ceramic Tiles in bathroom	9/10	1	9/10	0	0%	As perschedule	
Plumbing - Phase II	9/10	2	9/11	0	0%	As perschedule	
Electrical and HVAC trim out - Phase II	9/14	2	9/15	0	0%	As perschedule	
Final site Clean-up	9/16	1	9/16	0	0%	As perschedule	

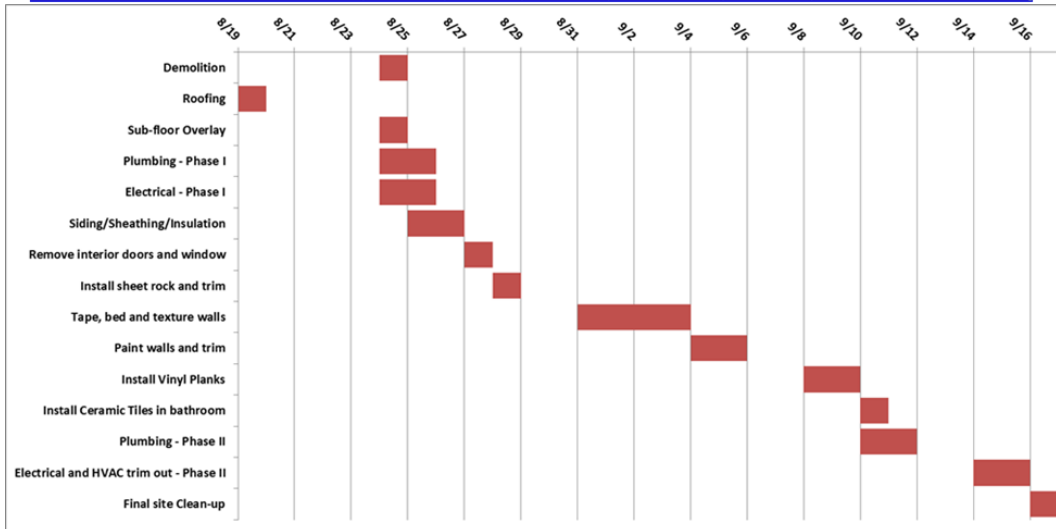


Figure 4-1 Gantt Chart Schedule for the Tasks Involved in Remodeling a Garage House in Bowman, Dallas-TX

Microsoft office support has developed an eighteen step procedure to plot a Gantt chart in MS Excel and the final output is simple and clear Gantt chart as in Figure 4-1.

This schedule has eight columns; they are task, start date, task duration, end date, days complete, percent complete, task completion status and reasons for delay, if any. Tested this Gantt chart schedule with the help of aforementioned general contractor and his subs. It did not consume much time to educate them in using this schedule. The schedule was updated every alternate day. By using this basic coordination tool the project was completed ahead of schedule and under budget, as shown in Table 4-2.

Table 4-2 Savings in terms of Time and Budget after Using a 2-D Schedule

DESCRIPTION	BID VALUES	ACTUAL VALUES	SAVINGS (2015 \$)
Duration	28 Days	24 Days	4 Days
Material	\$ 1,702	\$ 1,702	\$ 0.00
Labor	\$ 11,902	\$ 10,202	\$ 1,700
O&P	\$ 2,040	\$ 1,785	\$ 255
Total Bid	\$ 15,644	\$ 13,689	\$ 1,955

4.3 Developing a 4-D Schedule

In reference with the aforementioned basic Microsoft excel Gantt chart schedule, a four-dimensional schedule shall be developed using same platform. Many features were incorporated using basic excel formulas and macro codes. The developed version has title / project name, contractor details, project manager and scheduler details. It also

has the project start date and the data date. Based on the project start date all the date columns representing the Gantt charts are set to be arranged automatically. A sample layout of the said details representation is provided below in Figure 4-2.

Cultural District / Will Rogers Sanitary Sewer Improvements, Part IV								
SJ Louis Construction of Texas		CUIRE		Data Date: 10/16/2015 Friday				
The University of Texas at Arlington		CUIRE		Prepared by: Mr. Harsha Vardhan				
Project Lead: Mr. Gilberto Nazario		Project Start Date: 6/16/2015 Tuesday		Supervised by: Dr. Najafi				
Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining

Figure 4-2 Sample Layout of the Project Details

Just the details pertaining to the task and duration needs to be printed in the appropriate columns and rest everything will be calculated and displayed automatically by using the pre-assigned formulas. Also the pictorial representation of duration will be displayed in terms of horizontal bars. As the task initiates and precede towards its completion the color of the bars in the chart changes, in-order to aid in tracking the task progress with respect to percentage complete. This gives us a comprehensive two-dimensional schedule with time as its third dimension. The prospective fourth dimension of this model is visual interpretation. Adding a visual perception to a two-dimension schedule is a tedious task and after many

hits and trails, a macros code is identified to place a visual over 2-D plane. Microsoft excel has many developing features and one of them was “Microsoft visual basic for applications.” In an existing visual basic project and Microsoft excel object, a new sheet is created and the identified code is entered and stored. Figure 4-3 illustrates a code for the visual interpretation on a two-dimensional plane.

```
Sub Img_in_Commentbox()
With Application.FileDialog(msoFileDialogFilePicker)
    .AllowMultiSelect = False           'Only one file
    .InitialFileName = CurDir           'directory to open the window
    .Filters.Clear                       'Cancel the filter
    .Filters.Add Description:="Images", Extensions:="*.jpg", Position:=1
    .Title = "Choose image"

    If .Show = -1 Then TheFile = .SelectedItems(1) Else TheFile = 0
End With
'No file selected
If TheFile = 0 Then
MsgBox ("No image selected")
Exit Sub
End If
Range("A1").AddComment
    Range("A1").Comment.Visible = True
[A1].Comment.Shape.Fill.UserPicture TheFile
End Sub
```

Figure 4-3 Code for the Visual Interpretation on a Two-Dimensional Plane
(CCM.NET, June 2014)

Using this code, any two-dimensional construction plans can be attached to the schedule at any milestone across the length and breadth

of the bar chart. But the task precedence shall be color coded manually by measuring the percentage complete in real time and convert it in terms of distance and areas using same scale mentioned in the drawings. Four-dimensional schedule has nine columns, which are task, task lead, start date, end date, duration (including holidays), percentage complete, actual working days (duration minus holidays), days complete and days remaining. Brief descriptions of columns are given at the bottom of schedule, as the main purpose of this model is ease of use. Figure 4-4 showcases notes and descriptions associated with columns in Figure 4-2.

Notes:	
4D Feature	To view the 4D feature of the above schedule place the mouse pointer on the respective milestones
Start Date	Enter the starting date for this task. To associate the start date with the end of another task, enter a formula in the start date that refers to the end date of that task.
End Date	The ending date is calculated by adding the Duration (calendar days) to the Start date minus 1 day, because the task duration is from the beginning of the Start day to the end of the End day.
Duration	Enter the number of calendar days for the given task. Refer to the Working Days column or use a calendar to determine the corresponding working days. The duration is from the beginning of the Start date to the ending of the End Date.
% Complete	Update the status of this task by entering the percent complete (between 0% and 100%).
Working Days	Counts the number of working days using the NETWORKDAYS() formula, which excludes weekends. When planning work based upon the number of working days, adjust the Duration until the desired # of working days is reached.
Days Complete	This column is calculated by multiplying the Duration by the %Complete and rounding down to the nearest integer.
Days Remaining	This column is calculated by subtracting the Days Complete from the Duration.

Figure 4-4 Notes and Descriptions Associated with Columns in Figure 4-2

4.4 Chapter Summary

Using Microsoft Excel as a platform for the said 4-D schedule was economic; as MS Excel is available with all construction firms small, medium and large and also considering its ease of use. Many man-hours were invested in developing the basic schedule template. In process, many critical project coordination features have been identified and incorporated them to our model. The developed schedule was in two-dimensional bar chart formats with time as its third dimension. Using a CAD based program, developed two-dimensional plans and linked them to our three-dimensional schedule using a code in Visual Basic, an MS Excel developing feature. Now, the 4-D model is ready to test in live projects.

Chapter 5 Research Analysis and Results

5.1 Introduction

Chapter 4 presented a basic outline about the steps involved in creating “four-dimensional” model, detailed conflict report (DCR) and detailed progress report (DPR) using building information modeling (BIM) applications. Now, Chapter 5 targets on testing the aforementioned 4-D schedule, DCR and DPR on live pipeline construction projects as case studies and traditional project management practices are compared with the BIM method.

The prime contractor in all three case studies was a pipeline construction company with little experience in building information modeling. The contractor was in the process of training its staff in managing information to begin incorporating building information modeling practices. No BIM enabled software was used in the modeling practices in each of the case studies. The intent of the exercises were to use existing tools and methods and apply them in a new way to familiarize the users with the type of information management scenarios they will encounter when the company does decide to fully implement BIM practices. The case studies were intended to provide examples on how companies with limited means can use the tools and procedures available to them to begin

fostering the knowledge necessary to facilitate transition to BIM practices (Villafana, 2011).

5.2 Case Study No. 1

The first case study used supplemental two-dimensional drawings to aid in productivity enhancement, project coordination and streamlining the construction of Bonnie View Road Project No. 30227 (Paving, Drainage And Utility Improvements) located in the City Of Dallas, Texas (Limits: From Langdon Road to Wintergreen Road). These two-dimensional drawings were used in the generated four-dimensional model to give project stakeholders a visual representation of the project progress. The City of Dallas, Texas, solicited quotations by responsive bidders for the said construction project. S.J. Louis Construction of Mansfield, Texas, was the successful bidder on this project. Figure 5-1 illustrates the aerial view of 96-in. pipeline using Google maps.

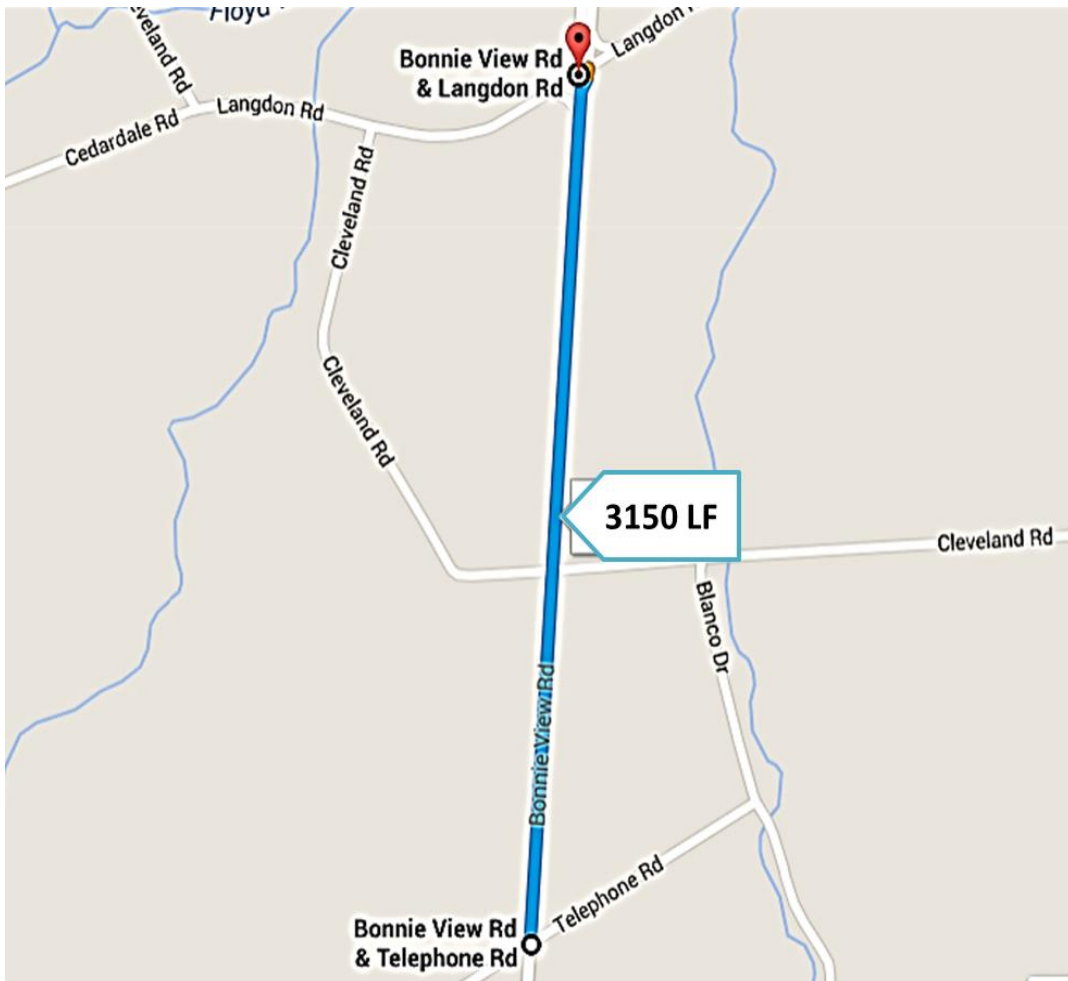


Figure 5-1 Bonnie View Road Project No. 30227 Location
(Google Maps, 2016)

The general scope of work for this 1.9-mile project consists of constructing four new lanes of concrete pavement, separated by a median. The new roadway will be constructed with 11-in. of concrete pavement (approximately 59,000 square yards), which will sit atop 8-in. of cement treated subgrade. Drainage improvements apply, generally

consisting of a storm sewer system (curb inlets, pipes, culverts). Major utility work is also included in this contract and is summarized as follows: (1) Approximately 3,150 ft of a 96-in. water transmission pipeline; (2) approximately 4,000 ft of 12-in. water main; and approximately 8,400 ft of variable size sanitary sewer main (12-in. minimum, 20-in. maximum). There were 400 working days allocated for construction of all improvements. Overall value of the project is \$11,876,779. Due to the complexity of the project a relatively small task of installing approximately 3,150 ft of a 96-in. water transmission pipeline has been selected. The project value pertaining to 3,150 ft of 96-in. pipeline is \$3,251,963. The selected scope of work for this case study was simple in nature to give the contractor a low-risk opportunity to implement “four-dimensional” modeling as a means of coordinating activities and conveying progress to the owner.

To further mitigate risk, in assembling the project team, the contractor selected subcontractors with whom it had previously successfully completed projects of similar scope. The past work experience of the project team members provided adequate environment conducive to the free flow of information exchange necessary to implement modeling practices.

5.2.1 Project Schedule

The Proposed construction right-of-way was surveyed and marked as stations. Detailed scope of work was understood and the entire scope was broken down into several tasks as per WBS (Work Breakdown Structure). These tasks have one or more subtasks and then arrange in an order as per the sequence of operations. These sequences of operations were in an order, where no task incurs conflicts, minimal or any rework and effective utilization of the resources such that no labor or equipment is idle.

5.2.1.1 Work Breakdown Structure (WBS):

The Identified tasks, then assigned a duration based on the labor and equipment productivities and also based on the site conditions, which were assessed after through site inspections and soil tests. Refer to Table 5-1 for WBS and durations.

Table 5-1 Work Breakdown Structure and Durations for Case Study No. 1

(Unpublished Project Documents, City of Dallas, 2014):

TASK	DURATION (Calendar Days)
Submittals	159
Mobilization	1
Stage 1A	212
SWPPP	2
Stripping	7
Const. temp. widening sta 42+00 to 114+00	84
Const. temp. widening sta 42+00 to 15+58	46
Remove existing pavement	81
Install sanitary sewer sta 115+50 to 43+20	145
Install RCP between sta 43+75 and 114+00	82
Install RCP between sta 43+75 and 15+58	78
Rd exc sta 115+50 to sta 43+20	94
Install 12-in. PVC waterline	96
Place cement treated base sta 44+00 to 115+50	5
Const reinforced concrete pavmt sta 44+00 to 115+50	21
Rd exc sta 15+58 to 44+00	33
Place cement treated base sta 15+58 to 44+00	2
Const reinforced conc pavement sta 15+58 to 44+00	5
Stage 2	
Remove detour paving	1
Complete the storm sewer / utility laterals	256

TASK	DURATION (Calendar Days)
Install 96-in. water line	95
Rd exc between sta 44+00 to 115+50	256
Place cement treated base sta 44+00 to 115+50	87
Const reinforced concrete pavement sta 44+00 to 115+50	101
Stage 2B	
Rd exc between 15+58 to 44+00	14
Place cement treated base sta 15+58 to 44+00	3
Const reinforced concrete pavement sta 15+58 to 44+00	70
Install electrical	164
Const sidewalk sta 15+58 to 115+50	271
Pavement marking sta 15+58 to 115+50	5
Const sidewalk sta 15+58 to 115+50	74
Place topsoil	206
Seed and sod	12
Install signs	4
Completion	1

5.2.1.2 Baseline Schedule:

A baseline schedule was then made using the aforementioned work breakdown structure and durations in Microsoft Project by the scheduling team of S.J. Louis Construction of Mansfield, Texas, received from Dallas

Water Utilities, City of Dallas. Refer to Figure A-1 for the baseline schedule.

5.2.2 Importing the Baseline Schedule into 4-D Model and Tracking the Progress

Four-dimensional schedule has nine columns as shown in Figure A-2, which are task, task lead, start date, end date, duration (including holidays), percentage complete, actual working days (duration minus holidays), days complete and days remaining. The task details in the appropriate column in the baseline schedule needs to be imported and then adjusted for start and end dates as per the forecasted durations. All the percentage completes for respective tasks in the baseline schedule have an initial zero percent progress. After the transfer, the balance of the columns in the developed 4-D model will calculate automatically and a bar chart will be plotted. The two-dimensional drawings must be linked to the appropriate task for a pop-up view. The DPR (Detailed Project Report) and DCR (Detailed Conflict Report) must be linked to the 4-D Model stated above as work sheets. Then the baseline schedule can be imported and set to track the project progress. Refer to Figures A-10 and A-11 for sample DCR and DPR.

5.2.2.1 Tracking the Project Progress:

An inspector will be assigned to each and every project, who aids in monitoring and reporting the project progress. With the help of the contractor and the assigned inspector, information about the project progress, conflicts, work stoppage, accidents and low productivity was received. The flow of information was scheduled weekly and/or biweekly. In accordance with the received information, updated the 4-D Model and save it in the cloud. Access to the cloud was given to all stakeholder associated with the project to review and comment. Refer to Figures A-2 to A-4 for 4-D schedule tracking.

5.2.3 Project Coordination Results

By fostering an environment of collaboration the project team was able to:

- Minimize site disturbance by establishing site access routes.
- Coordinate subcontractor work to eliminate interference.
- Streamline the construction schedule to complete the project early.

Refer to Table 5-2 for project savings in terms of cost and duration.

Table 5-2 4-D Modeling Project Savings for Case Study No. 1

DESCRIPTION	QUANTITY	UNITS	COSTS (2015 \$)
Allocated Construction Duration for 96-in. Main	30	Days	
Actual Construction Duration	28	Days	
Reduction in Schedule	2	Days	
Total Cost Savings			\$216,797

5.3 Case Study No. 2

The second case study used supplemental two-dimensional drawings to aid in productivity enhancement, project coordination and streamlining the construction of the following project: Cultural District/Will Rogers Sanitary 4 Sewer Improvements, Part 4 Montgomery St (Sanitary Sewer Installation) located in the City of Fort Worth, Texas, (Limits: From Byers Ave to Harley Ave on Montgomery St). These two-dimensional drawings were used in the generated four-dimensional model to give project stakeholders a visual representation of the project progress.

“On September 9, 2010, the City Council authorized an Engineering Agreement with Kimley-Horn and Associates, Inc., Fort Worth, Texas, to prepare the plans and specifications for the Cultural District/Will Rogers Water and Sanitary Sewer Improvements. This Mayor and Council Communication (M&C) was to authorize a construction contract for

sanitary sewer improvements on Montgomery Street (Byers Avenue to Harley Avenue) to accommodate the proposed parking garage to serve the Fort Worth Multi-Purpose Arena at Will Rogers Memorial Center and will allow for the abandonment of existing sanitary sewer mains that are in direct conflict with the garage” (Source: Unpublished project Documents).

Figure 5-2 illustrates the aerial view of the pipeline using Google maps.

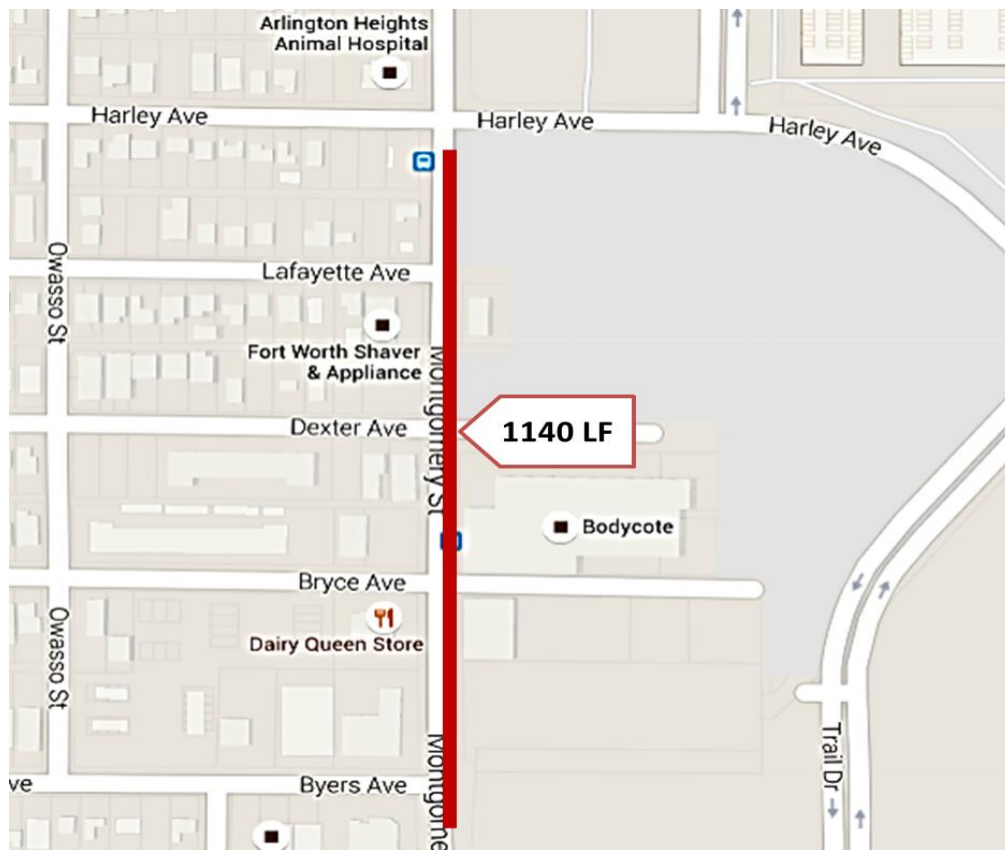


Figure 5-2 Cultural District/ Will Rogers Sanitary 4 Sewer Improvements, Part 4 Montgomery St Location

(Google Maps, 2016)

On May 21, 2015, the City Council authorized execution of the contract with S.J. Louis Construction of Mansfield, Texas, in the amount of \$1,645,417 for project: Cultural District/Will Rogers Water and Sanitary Sewer Improvements, Part 4. There were 150 working days allocated for construction of all improvements. Due to the complexity of the project, for this thesis, a relatively small task of installing approximately 1,140 ft of 24-in. sanitary sewer carrier pipeline was selected. The selected scope of work for this case study was simple in nature to give the contractor a low-risk opportunity to implement “four-dimensional” modeling as a means of coordinating activities and conveying progress to the owner.

To further mitigate risk, in assembling the project team, the contractor selected subcontractors with whom it had previously successfully completed projects of similar scope. The past work experience of the project team members provided adequate environment conducive to the free flow of information exchange necessary to implement modeling practices.

5.3.1 Location and Description of Project

The major work will consist of the following (Unpublished Project Documents):

- 850 ft of 48-in. tunnel liner plate or 36-in. casing by other than open cut
- 850 ft of 24-in. sanitary sewer carrier pipe
- 290 ft of 24-in. sanitary sewer by open cut
- 75 ft of 18-in. sanitary sewer by open cut
- 35 ft of 12-in. sanitary sewer by open cut
- 165 ft of 6-in. sanitary sewer by open cut

5.3.2 Project Schedule

The Proposed construction right-of-way was surveyed and marked as stations. Detailed scope of work was understood and the entire scope has been broken down into several tasks as per WBS. These tasks had one or more subtasks and then arranged in an order as per the sequence of operations. These sequences of operations were in an order, where no task incurs conflicts, minimal rework and effective utilization of the resources such that no labor or equipment is idle.

5.3.2.1 Work Breakdown Structure (WBS):

The Identified tasks, then assigned a duration based on the labor and equipment productivities and also based on the site conditions, which

were assessed after through site inspections and soil tests. Refer to Table 5-3 for WBS and durations.

Table 5-3 Work Breakdown Structure and Durations for Case Study No. 2
(Unpublished Project Documents, S.J. Louis Construction, Inc., 2015)

TASK	DURATION (Calendar Days)
Contract award	1
Preconstruction meeting	1
Notice to proceed	1
Submittals approval	14
Surveying	7
Erosion control	5
White line	2
Locates	5
Mobilization	2
Traffic control plan	147
Tunneling	59
Entry shaft sta. 0+30	5
Tunneling from sta. 0+30 to 3+00	11
Intermediate shaft sta. 3+00	5
Tunneling from sta. 0+30 to 6+00	14
Intermediate shaft sta. 6+00	3
Tunneling from sta. 6+00 to 9+00	12
Exit shaft at sta 9+00	3
Main 24" frp sanitary sewer line	12
Sta. 0+30 to 2+78	2

TASK	DURATION (Calendar Days)
Sta. 3+08 to 5+91	2
Sta. 6+06 to 9+38	2
Sta. 9+50 to 11+25	4
Main mh installation	21
Mh sta. 11+36	3
Mh sta. 10+98	5
Mh sta. 9+43	3
Mh sta. 6+06	3
Mh sta. 2+93	5
Testing of main mh & 24-in. pipe line	3
Connection to existing at sta. 0+00	4
Lateral line a1 & mh installation	3
Lateral line a2 & mh installation	6
Lateral line a3 & mh installation	5
Lateral line a4 & mh installation	4
Lateral line a5 & mh installation	1
Connection to existing 24-in. line at sta. 11+36.81	2
Removal of existing mh	1
Abandonment of existing lines	6
Restoration	7
Substantial completion / punch list	12
Final completion	1

5.3.2.2 Baseline Schedule:

A baseline schedule was made using the aforementioned work breakdown structure and durations in Microsoft Project by scheduling team of S.J. Louis Construction of Mansfield, Texas. Refer to Figure A-5 for the baseline schedule.

5.3.3 Importing the Baseline Schedule into 4-D Model and Tracking the Progress

Four-dimensional schedule has nine columns as shown in Figure A-6, which are task, task lead, start date, end date, duration (including holidays), percentage complete, actual working days (duration minus holidays), days complete and days remaining. The task details in the appropriate column in the baseline schedule needs to be imported and then adjusted for start and end dates as per the forecasted durations. All the percentage completes for respective tasks in the baseline schedule have an initial zero percent progress. After the transfer, the balance of the columns in the developed 4-D model will calculate automatically and a bar chart will be plotted. The two-dimensional drawings must be linked to the appropriate task for a pop-up view. The DPR (Detailed Project Report) and DCR (Detailed Conflict Report) must be linked to the 4-D Model stated above as work sheets. Then the baseline schedule can be imported

and set to track the project progress. Refer to Figures A-10 and A-11 for sample DCR and DPR.

5.3.3.1 Tracking the Project Progress:

An inspector will be assigned to each and every project, who aids in monitoring and reporting the project progress. With the help of the contractor and the assigned inspector, information about the project progress, conflicts, work stoppage, accidents and low productivity was received. The flow of information was scheduled weekly and/or biweekly. In accordance with the received information, updated the 4-D Model and save it in the cloud. Access to the cloud was given to all stakeholder associated with the project to review and comment. Refer to Figures A-6 to A-9 for 4-D schedule tracking.

5.3.4 Project Coordination Results

By fostering an environment of collaboration the project team was able to:

- Minimize site disturbance by establishing site access routes.
- Coordinate subcontractor work to eliminate interference.
- Streamline the construction schedule to complete the project early.

Refer to Table 5-4 for project savings in terms of cost and duration.

Table 5-4 4-D Modeling Project Savings for Case Study No. 2

DESCRIPTION	QUANTITY	UNITS	COSTS (2015 \$)
Allocated Construction Duration	150	Days	
Actual Construction Duration	145	Days	
Reduction in Schedule	5	Days	
Total Cost Savings			\$54,847

5.4 Comparison between Traditional Planning Models
and BIM-based 4-D Model

The traditional planning models include Microsoft Project; Primavera etc. were built on a different software platform and are expensive to purchase their license. But the 4-D Model was built using MS Excel as a platform and is very inexpensive to procure. Contractors are ready to incorporate new technology into their business operations, but because of the training expenses and loss of productivity during the initial stages of its application, they were not able to make a decision. By using this 4-D Model, contractor's organization can get familiarize with the building information modeling applications and also the importance of project coordination tools. The comparison between the traditional planning models and BIM based four-dimensional model is given below in Table 5-5.

Table 5-5 Comparison between Traditional Planning Models and BIM based Four-Dimensional Model

SL. NO.	DESCRIPTION	TRADITIONAL PLANNING MODELS	BIM BASED 4-D MODEL
1	Gantt Charts	Yes	Yes
2	Manpower Histograms	Yes	Yes
3	Percentage Completion	Yes	Yes
4	Critical Paths	Yes	Yes
5	Visual Interpretation	No	Yes
6	Communication	No	Yes
7	Conflict Reports	No	Yes
8	Progress Reports	No	Yes
9	Ease of Use	Medium to High	High
10	Storage Space	Medium to High	Low
11	Training Requirements	Extensive	Limited
12	Training Expenses	Medium to High	Low
13	Cost of License	Medium to High	Very Low
14	User Interface	Complicated	Simple

5.5 Chapter Summary

The two case studies used in this thesis identified the benefits of implementing BIM concepts without having to fully develop a digital 3-dimensional model of the project, as provided by such software as Revit. Both case studies have used supplemental two-dimensional drawings to aid in productivity enhancement, project coordination and streamlining the construction. These two-dimensional drawings were used in the generated four-dimensional model to give project stakeholders a visual representation of the project progress. This 4-D Model will aid contractors

to take their first steps towards implementing fully integrated building information modeling techniques. Also it will provide contractors another tool or management technique to aid them in coordinating and managing projects to minimize delays and enhance productivity. By implementing the said 4-D Model, a significant savings in terms of schedule and cost can be observed. Finally, it can be said that the pipeline industry will slowly recognize the benefits of BIM leveraged by other construction industries and will incorporate it in design, cost estimation, and planning of pipeline construction projects.

Chapter 6

Conclusions and Recommendations for Future Research

This chapter includes the conclusions drawn from the research conducted on enhancing productivity by using building information modeling applications in pipeline construction projects. It also includes the recommendations for future research for the same subject area.

6.1 Conclusions

The following conclusions that can be derived from this thesis:

- Enhancing project coordination in conjunction with project management tools as discussed in this thesis can reduce rework and delays caused due to unforeseen conditions in pipeline construction projects.
- Developing 4-D models using Excel or similar software, as was shown in this thesis, will aid pipeline construction companies to adopt BIM practices.
- Implementing 4-D models in pipeline projects from the planning stage can produce positive results, such as:
 - Improved project coordination and management.
 - Improved productivity.
 - Improved profit margin.

6.1 Recommendations for Future Research

The following topics are recommended for future research:

- Develop the existing 4-D model to incorporate manpower and equipment histograms.
- Develop a model to record conflicts and minimize information losses.
- Develop suitable metrics to measure benefits of BIM in pipeline construction industry.
- Add a communication tool to existing 4-D model for enhancing field operations.

Appendix A

Baseline Schedule for Case Study No. 1

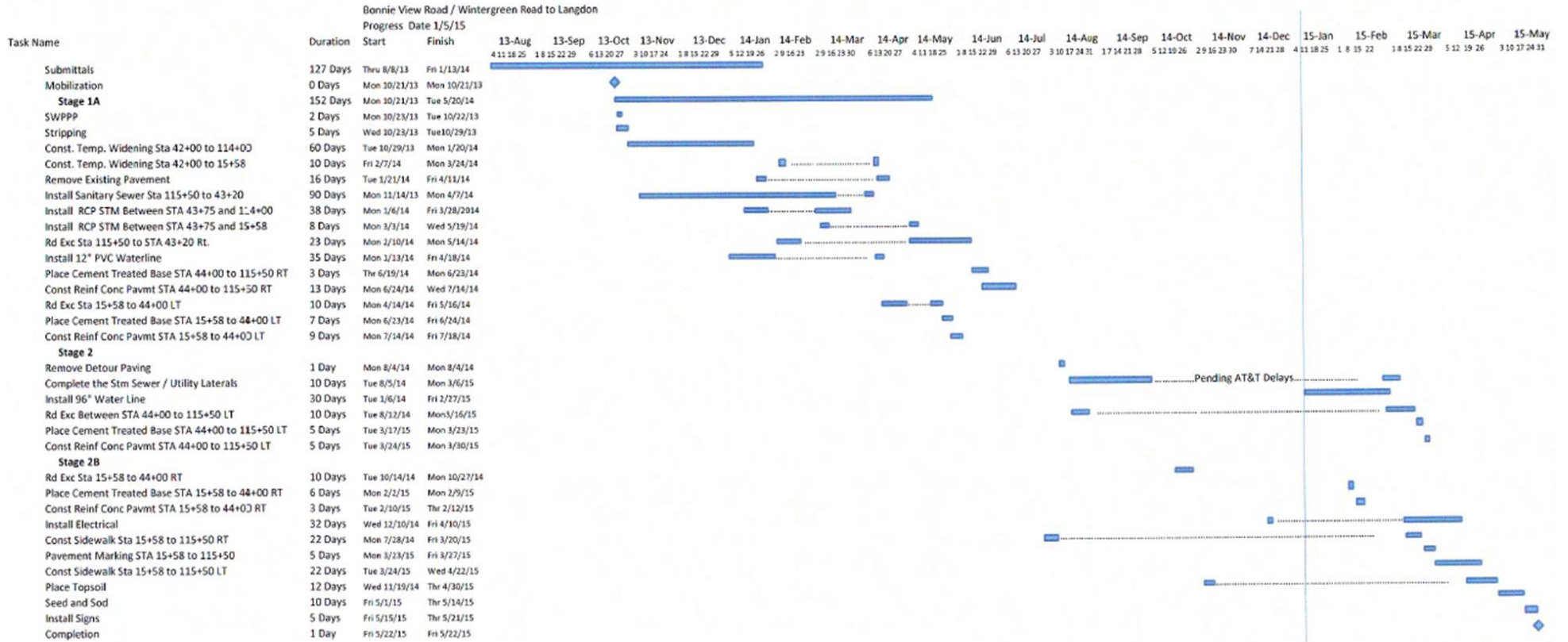


Figure A-1 Baseline Schedule for Case Study No. 1

4-D Model for Bonnie View Road MCIP Project (City Of Dallas)

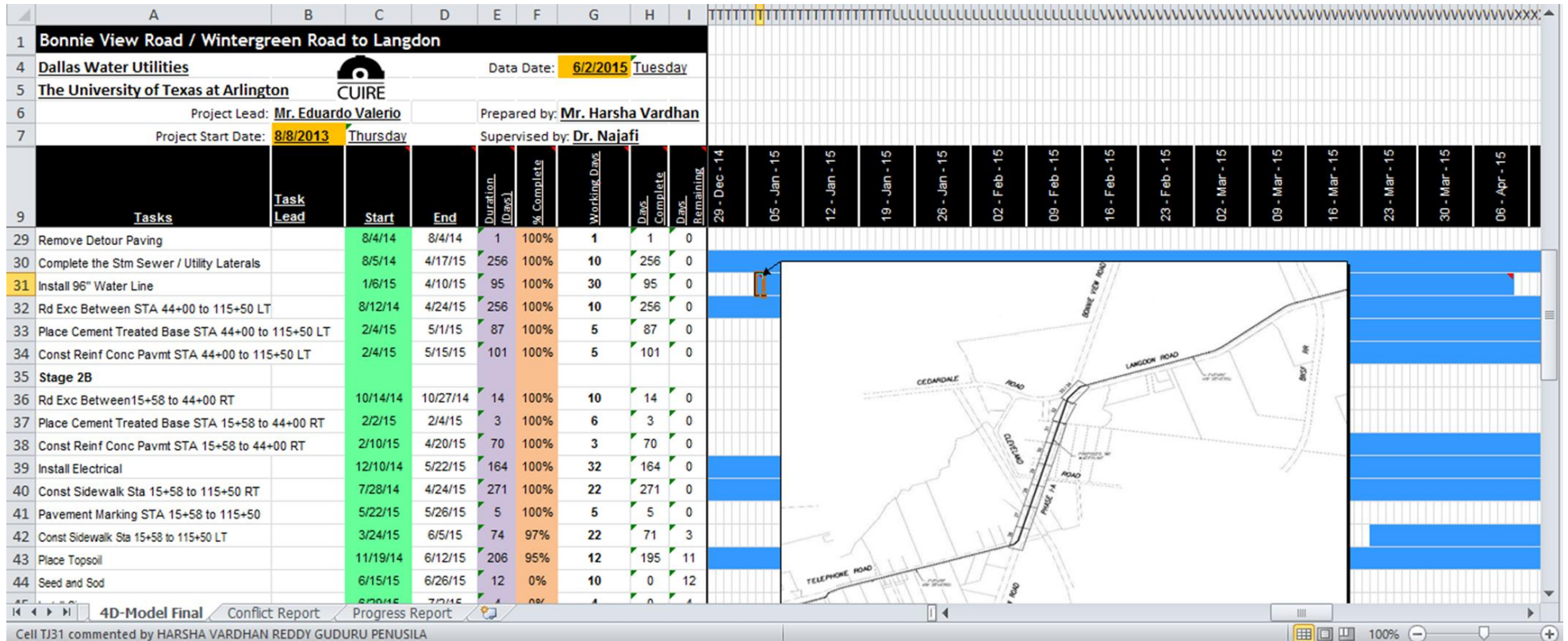


Figure A-2 Installation of 96" Water Line for 0% Complete

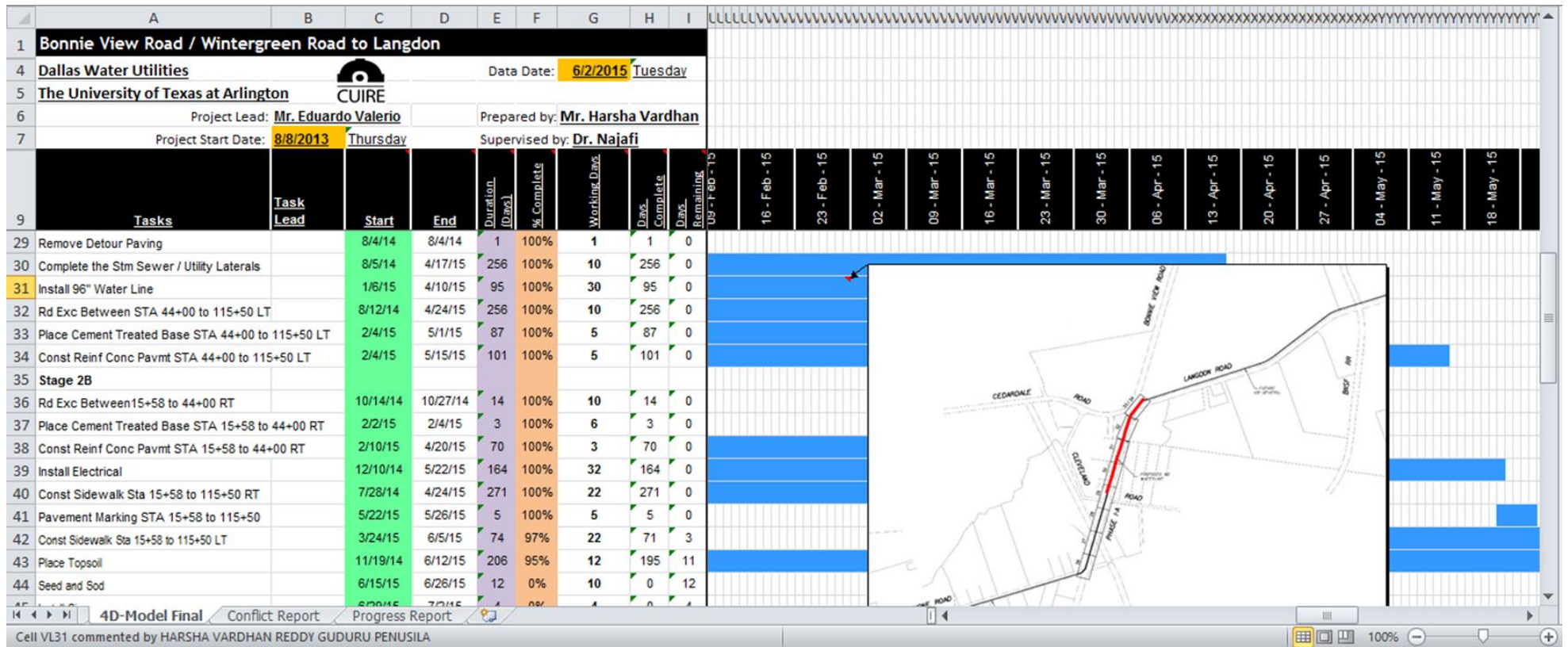


Figure A-3 Installation of 96" Water Line for 50% Complete

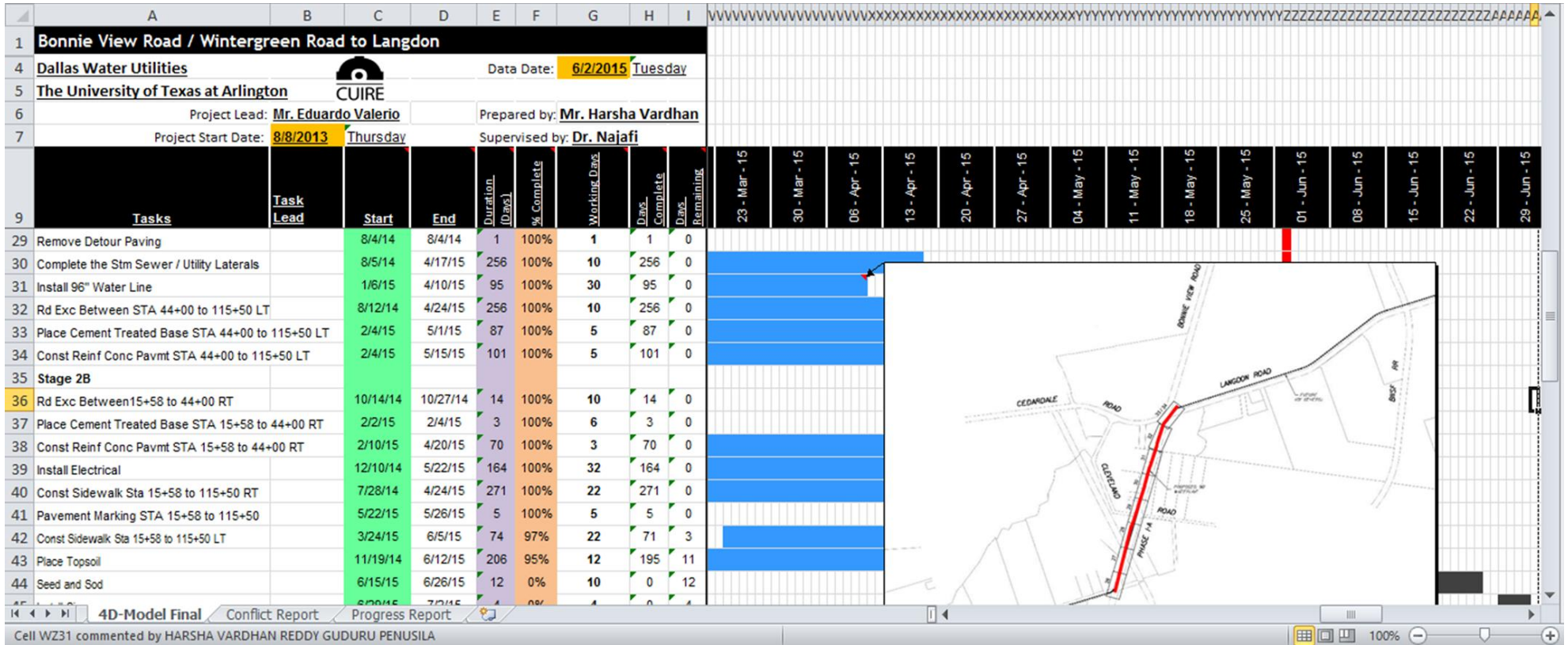


Figure A-4 Installation of 96" Water Line for 100% Complete

Baseline Schedule for Case Study No. 2

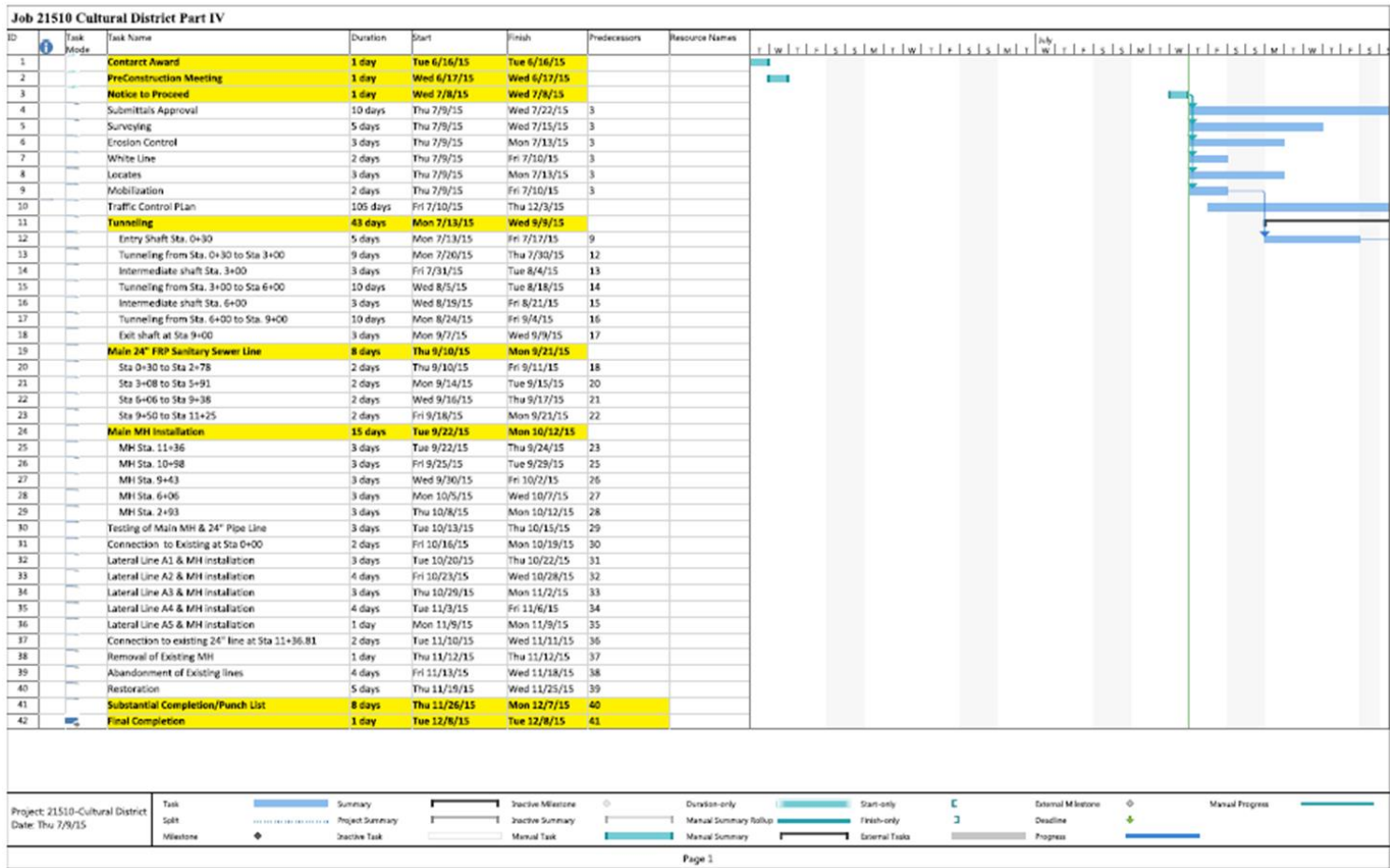
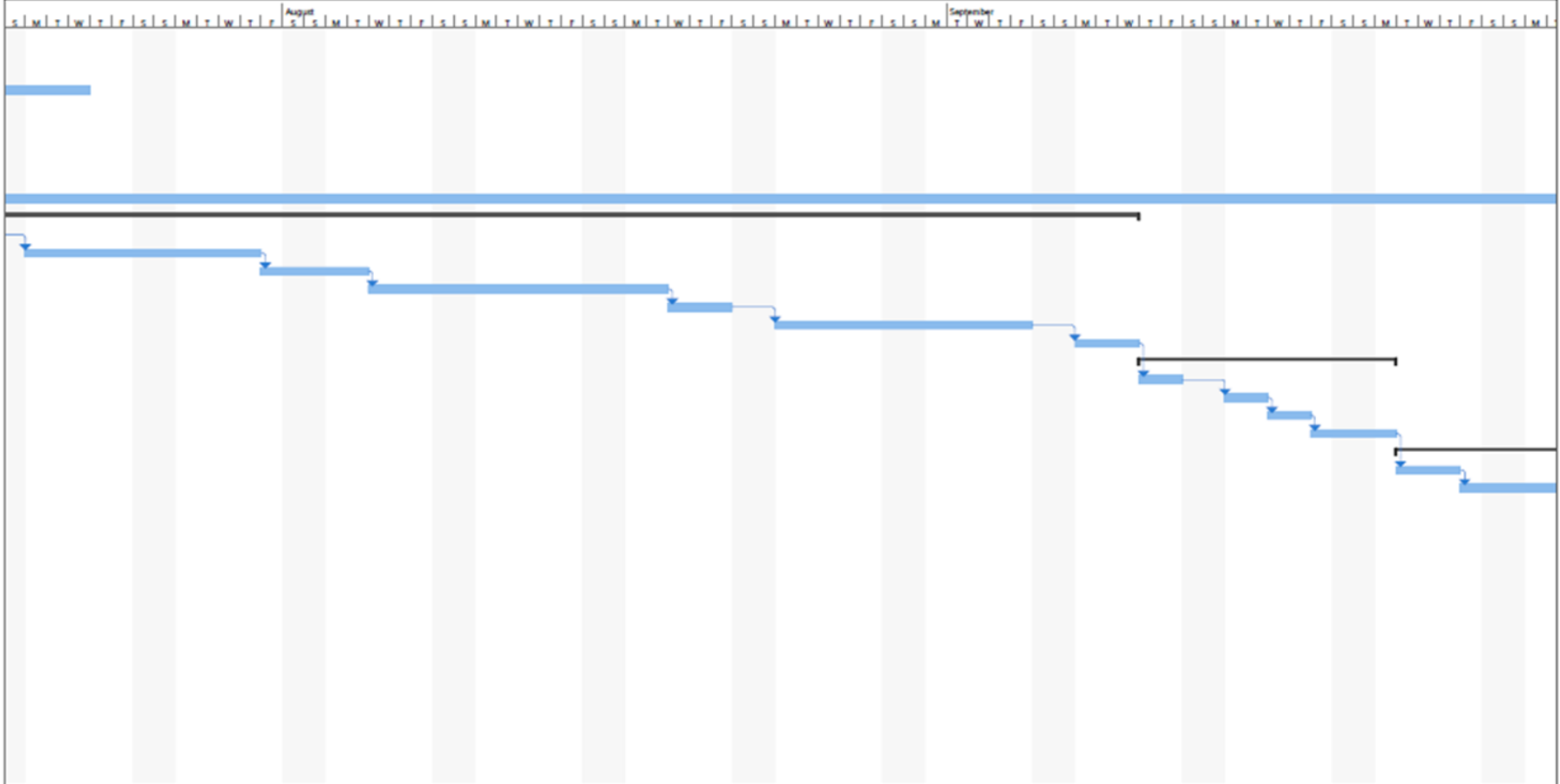


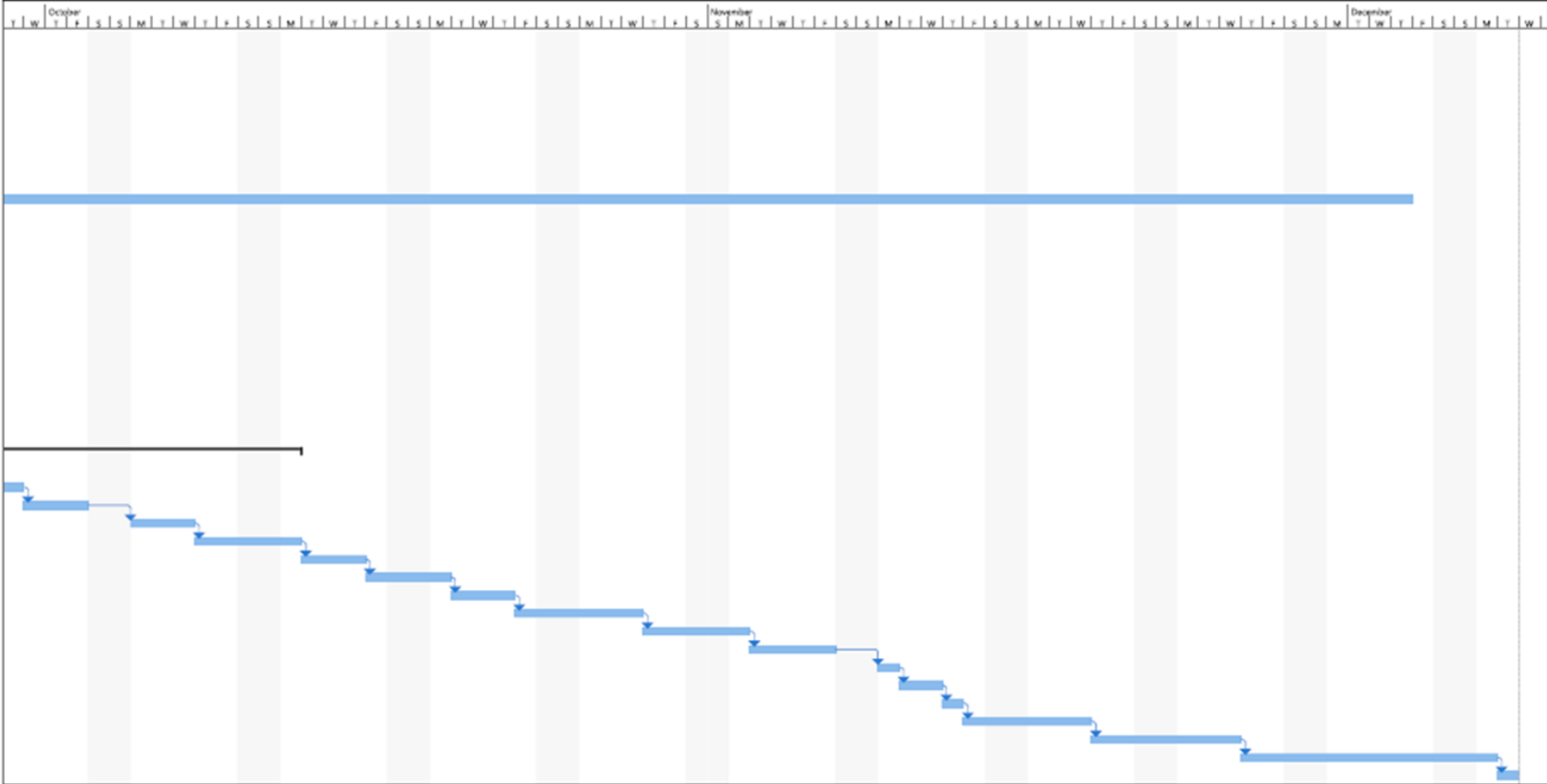
Figure A-5 Baseline Schedule for Case Study No. 2

Job 21510 Cultural District Part IV



Project: 21510-Cultural District Date: Thu 7/9/15	Task	Summary	Inactive Milestone	Duration-only	Start-only	External Milestone	Manual Progress
	Split	Project Summary	Inactive Summary	Manual Summary Rollup	Finish-only	Deadline	
	Milestone	Inactive Task	Manual Task	Manual Summary	External Task	Progress	

Job 21510 Cultural District Part IV



Project: 21510-Cultural District Date: Thu 7/9/15	Task	Summary	Inactive Milestone	Division-only	Start-only	External Milestone	Manual Progress
	Split	Project Summary	Inactive Summary	Manual Summary Rollup	Finish-only	Deadline	Manual Progress
	Milestone	Inactive Task	Manual Task	Manual Summary	External Task	Progress	Manual Progress

4-D Model for Cultural District/ Will Rogers Sanitary 4 Sewer Improvements, Part 4 Montgomery St (City of Fort worth)

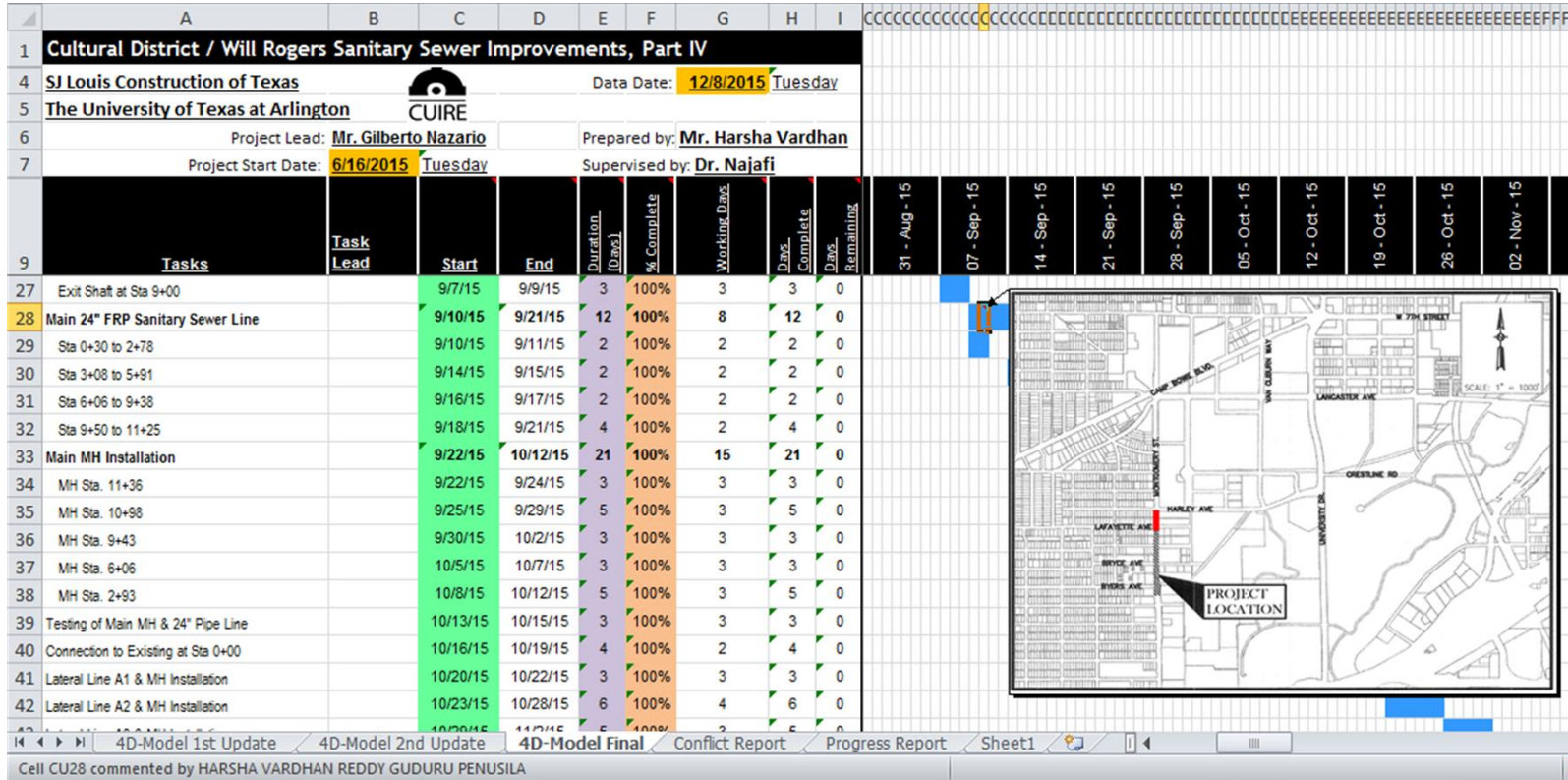


Figure A-6 Installation of Main 24" FRP Sanitary Sewer Line for 24% Complete

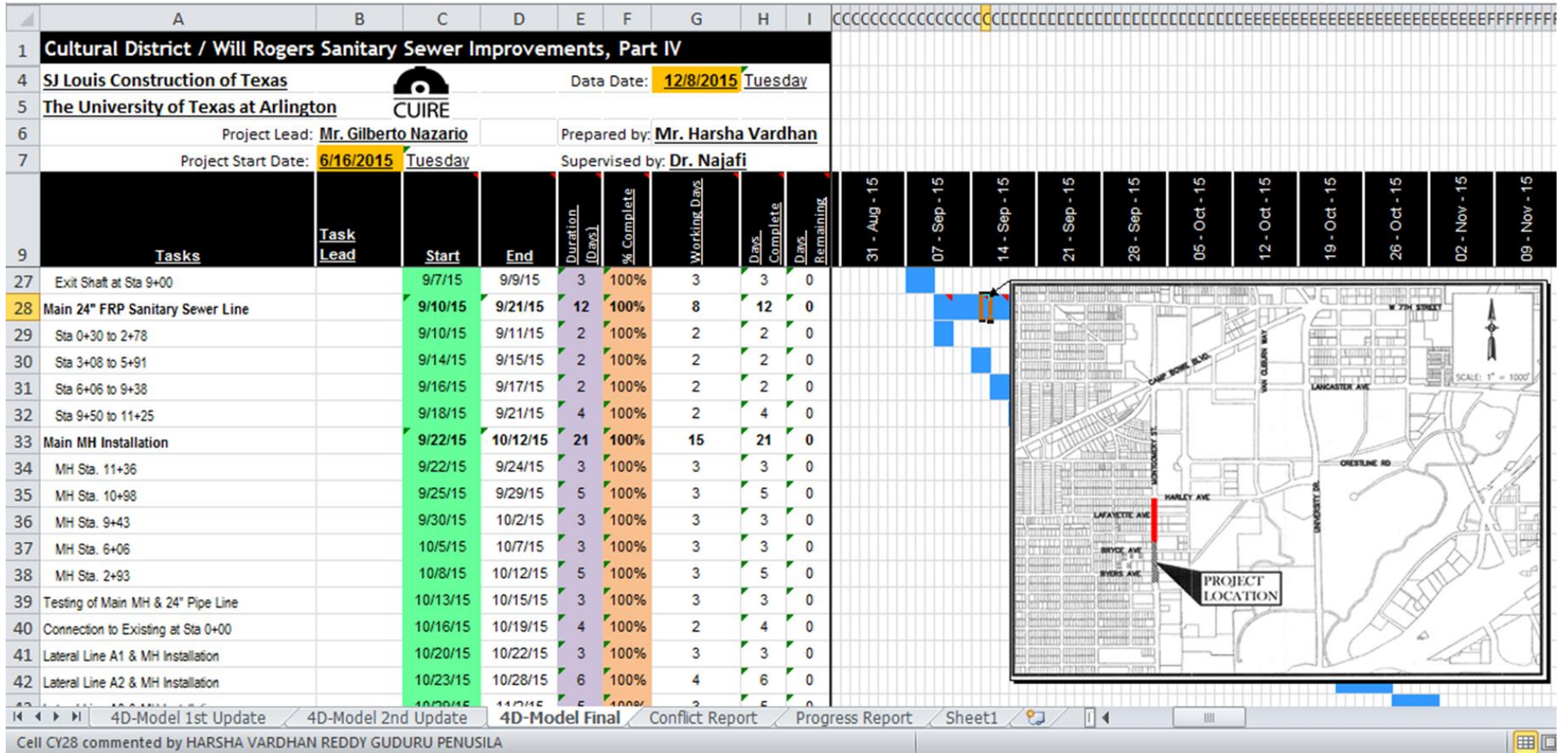


Figure A-7 Installation of Main 24" FRP Sanitary Sewer Line for 51% Complete

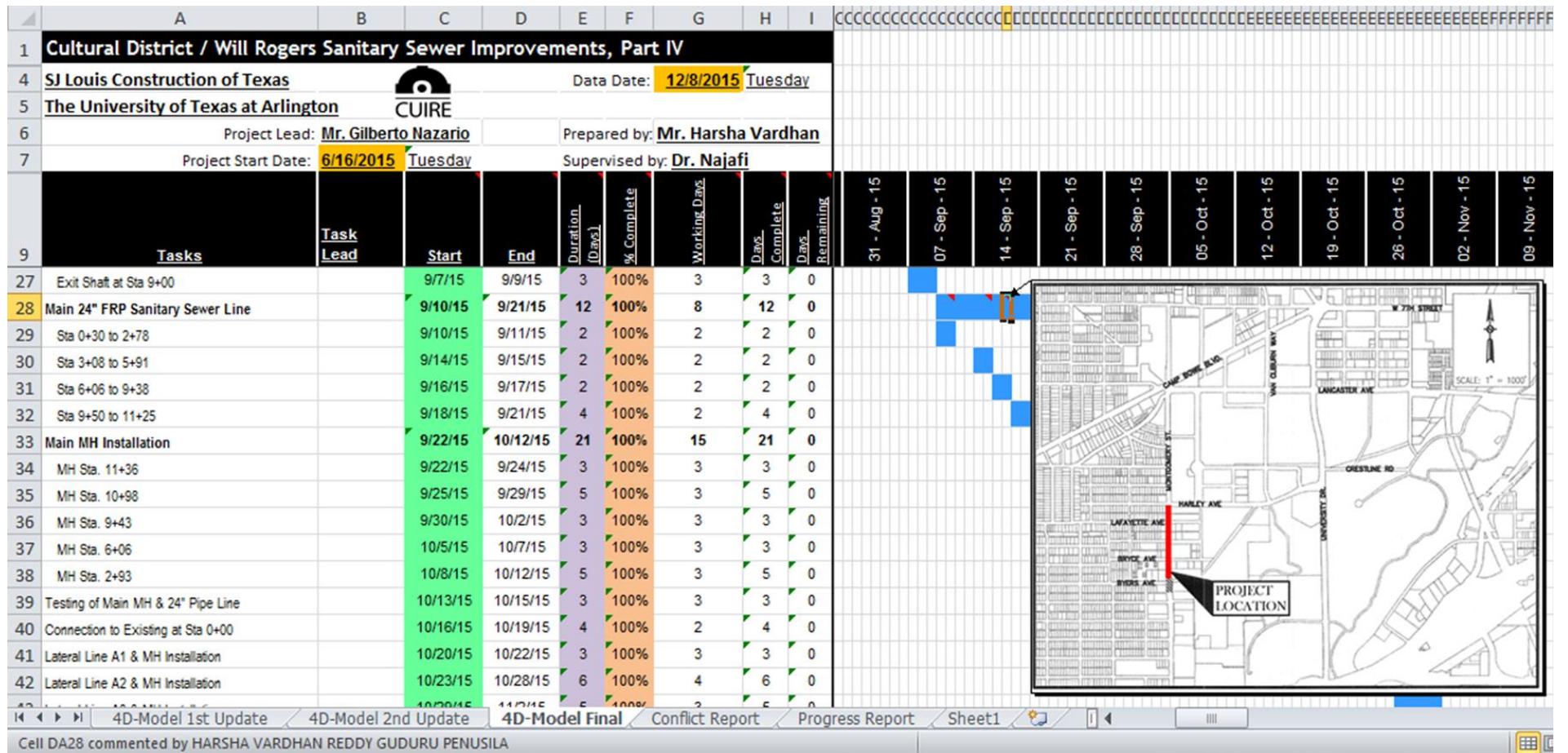


Figure A-8 Installation of Main 24" FRP Sanitary Sewer Line for 83% Complete

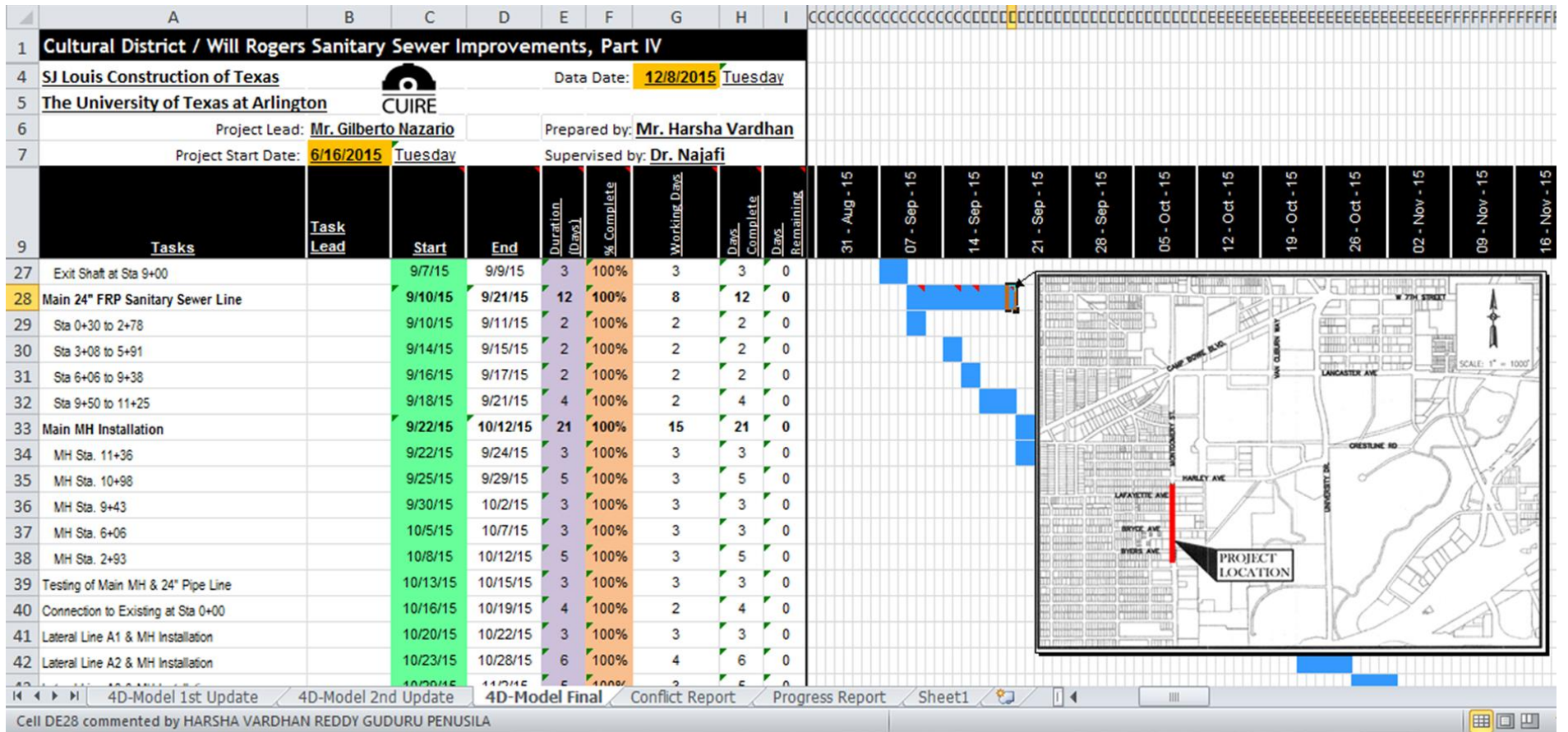


Figure A-9 Installation of Main 24" FRP Sanitary Sewer Line for 100% Complete

Detailed Conflict Report - Sample

DETAILED CONFLICT REPORT					
	1st DAY OF THE WEEK	TYPE OF CONFLICT	LOCATION	RESPONSIBILITY	REASONS
05 - Aug - 13	Low Productivity	Sta 15+58 to 44+00	Field Engineer	Cave-in due to low soil stability.	
12 - Aug - 13	Low Productivity	Sta 51+00 to 54+00	Planning Engineer	Rocky strata encountered.	
19 - Aug - 13	Unexpected Utilities			Unexpected underground utilities encountered.	
26 - Aug - 13	Accident/Work Stoppage			Excavator collapse due to low soil stability.	
02 - Sep - 13	No Conflict			N/A	

Figure A-10 Sample Detailed Conflict Report

Detailed Progress Report – Sample

		C	D
1		<u>DETAILED PROGRESS REPORT</u>	
2	1st DAY OF THE WEEK	HIGHLIGHTS	OBSERVATIONS
3			
4	05 - Aug - 13	Cloudy and Rain, high 14 C, low 5 C	Prepared trailers and equipment in yard.
5			
6	12 - Aug - 13	Cloudy and Rain, high 16 C, low 3 C	Prepared trailers in yard. Mobbed Excavator and a miscellaneous load (marker posts, signs, excavator attachments etc.)
7			
8	19 - Aug - 13	Mostly sunny, high 17 C, low 4 C	Mobbed Excavator to Site #2 (xyz location) as well as a load of rig mats - Began erecting powerline marker posts and construction signs
9			
10	26 - Aug - 13	Cloudy and Rain, high 14 C, low 3 C	Mobbed Dozer to Site#2 (xyz location) - Continued erecting powerline marker posts, signs and TC Finger markers - Hand excavated lines at Site #1
11			
12	02 - Sep - 13		
13			
14	09 - Sep - 13		
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Figure A-11 Sample Detailed Progress Report

List of Abbreviations

ABBREVIATION	DESCRIPTION
BIM	Building Information Modeling
CONST	Construction
DCR	Detailed Conflict Report
DPR	Detailed Progress Report
EXC	Excavation
FRP	Fiber Reinforced Pipe
MH	Man Hole
PVC	Poly Vinyl Chloride
RCP	Reinforced Concrete Pipe
RD	Road
STA	Station
SWPPP	Storm Water Pollution Prevention Plan
TEMP	Temporary
WBS	Work Breakdown Structure

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Biographical Information

Mr. Harsha Vardhan Reddy Guduru Penusila graduated with a Bachelor's Degree in Civil Engineering from The Indian Institute of Technology (IIT), India. After graduation, he worked as an engineer in training at Larsen and Toubro Construction Ltd., Chennai, India, and later was promoted to senior engineer cadre within the same company. Harsha has been an excellent scholar while pursuing a Master's Degree in the area of Construction Engineering and Management at the University of Texas at Arlington (UT Arlington). Mr. Reddy was a Graduate Research Assistant during Spring 2015 and also worked for the Center for Underground Infrastructure Research and Education (CUIRE) at the University of Texas at Arlington. He was an active student member of the American Society of Civil Engineers (ASCE) and the North American Society for Trenchless Technology (NASTT) Student Chapters. Harsha also worked as an intern with MAFFCO General Contractors, Inc., Dallas, Texas, and was involved with estimating, job costing and procurement, project scheduling, and project management.

After his graduation from UT Arlington, Mr. Reddy will be joining Primoris Services Corporation as a project engineer and plans to pursue his Doctoral studies at the University of Texas at Arlington, after gaining

enough hands-on experience. His career goal is to become an entrepreneur.