Utilizing 4D Visualization for Complex Schedule Analysis

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The Metro Wastewater Reclamation District (MWRD), located in Denver, Colorado, began construction of the PAR 1085 South Secondary Improvements Project at the Central Wastewater Treatment Plant (WWTP) in February 2011. The project adds 100 million gallons/day (mgd) of capacity to the secondary treatment process and insures compliance with more stringent nutrient discharge limits prior to the December 31, 2014 deadline. To mitigate a portion of the substantial risk in a large, expedited project, Carollo Engineers Inc. (Carollo), the design engineer and owner's representative during construction, recommended the utilization of 4D Visualization technology to analyze the contractor's construction schedule for contract compliance. Linking the contractor's 12,500+ activity schedule to the elements in the engineer's 3D model, allowed for a visual representation of the contractor's intended construction sequence. Detailed analysis of the 4D Visualization yielded a number of schedule issues that would have been difficult to identify using conventional schedule analysis techniques. The 4D Visualization identified concrete pour sequence compliance issues, missing activities/links, a visual assessment of actual vs. projected completion deadlines, and identification of contract non-conformance. In addition, Carollo was able to validate the contractor's ability to complete the project within the contractual timeframe.

Key Words: 4D Visualization, Schedule Analysis, Project Controls, Building Information Modeling (BIM)

Introduction

The Metro Wastewater Reclamation District (MWRD), located in Denver, Colorado, is responsible for providing wastewater treatment services to roughly 1.7 million people across a 715-square mile service area including the cities of Denver, Arvada, Aurora, Brighton, Lakewood, Thornton and Westminster (Metro Wastewater Reclamation District, 2013). In February 2011, MWRD began construction on the PAR 1085 South Secondary Improvements Project at the Central WWTP. The project was constructed using a traditional design-bid-build method of project delivery. Upon completion, the project adds 100 mgd of treatment capacity to the secondary treatment process using biological nutrient removal (BNR) and insures compliance with the more stringent future discharge limits for nutrients as required by the Colorado Department of Public Health and Environment (Carollo Engineers, 2013). To meet the compliance schedule issued by the State of Colorado, the South Secondary Improvements Project must be operational by December 2014. Failure to meet the compliance schedule would result in substantial daily fines. To reach Substantial Completion of the project and allow MWRD to operationally test the new facility prior to the compliance deadline, the contractor needed to place approximately 70,000 cubic yards (cy) of concrete and install/test most of the major electrical, mechanical, and instrumentation equipment in 2 1/2 years.

In an effort to mitigate a portion of the substantial risk in a large, expedited project, Carollo Engineers Inc., the design engineer and owner's representative during construction, recommended the utilization of 4D visualization technology for complex schedule analysis. 4D Visualization uses four-dimensional (4D) modeling to link three-dimensional (3D) elements within geometrical computer aided design (CAD) models with one or more applicable construction schedule activities. (Chau, Anson, & Zhang, 2004; Waly & Thabet, 2003). Assigning or "linking" the schedule data to a 3D model allows for a visual representation of the intended work sequence. Historically, 4D visualizations were predominantly utilized during the design or pre-construction phase of a project and were rarely employed during construction (Meadati, 2009). Proper linking of schedule data and comprehension of the output can yield detailed schedule information that would be extremely difficult to identify in a conventional schedule review. This paper will utilize the PAR 1085 project as a case study to understand the 4D Visualization tool beyond the design and pre-construction phase. It will explore how extrapolation of the data provided by a 4D Visualization can yield significant schedule information and improve the quality of complex schedules.

4D Visualization Development

Personnel

As the design engineer and owner's representative during construction, Carollo was responsible for the 3D model as well as the development and utilization of the 4D Visualization. To execute the 4D Visualization, Carollo assigned the responsibility to a 4D team consisting of four senior level CAD staff members and the Project Controls for the PAR 1085 project. CAD staff were tasked with physically linking the schedule activities to the 3D model, while making modifications to the 3D model to better match the contractor's submitted schedule. The Project Controls lead was responsible for managing the CAD personnel, as well as coordinating the 4D Visualization with progress updates being made onsite.

To expedite the linking of the construction schedule activities to the engineer's 3D model, the CAD personnel assigned to the 4D team were located in three offices across two time zones. Utilizing an office in Florida and offices in Colorado, the team was able to expeditiously link the 12,500+ schedule activities to the 3D model. The CAD staff located in Florida would begin 4D Visualization activities at 6:00am EST, concluding around 2:00pm EST. Colorado staff would then pick up the 4D visualization activities and conclude around 8:00pm EST. The Project Controls lead was located on the PAR 1085 project site in Denver and was available to the CAD staff as needed.

Software

4D Visualization software was first introduced to the construction industry by the Center for Integrated Facility Engineering (CIFE) at Stanford University (Wang, Zhang, Chau, & Anson, 2004). Although the technology has been available for almost two decades, the software and user interface has vastly improved since its inception. For the PAR 1085 South Secondary Improvements Project, the 4D team utilized four software packages to create the detailed visualizations. The following list identifies the software utilized by the 4D team and provides a brief context for software utilization. This list does not include the software required to develop the 3D model.

1. Bentley Navigator V8i
    - Navigation of the 3D model
    - Assigning or "linking" of schedule activities to the 3D model
2. Bentley Microstation V8 XM
    - Navigation of the 3D model
    - Change management implementation
    - Updated schedule importation
    - Frame creation
3. Camtasia Studio
    - .AVI creation

4. Oracle Primavera P6
    - Contractor construction scheduling

The software listed was chosen based on the infrastructure available to Carollo at the time of the 4D development. Due to compatibility issues with Primavera P6 and Bentley products, computer script was required to execute portions of the 4D visualization updates. Although the software used in this application was specific to Carollo Engineers and the PAR 1085 project, the use of 4D Visualization for complex schedule review could utilize any number of schedule and compatible modeling/visualization software applications.

Activity Linking and .AVI Creation

To achieve the 4D Visualization, the contractor's schedule was imported into Navigator V8i as a Microsoft Project (.MPX) file. Creation of an .MPX file from Primavera P6 is an export option. Once the schedule was properly imported, the 3D model was linked to the contractor's schedule using a "drop & drag" function as shown on Figure 1. A limitation in the software limited one activity to be linked to a single model element during a drop and drag. This significantly increased the amount of time to link the model, but reduced the possibility of a linking error. The full baseline schedule took roughly six weeks to link.

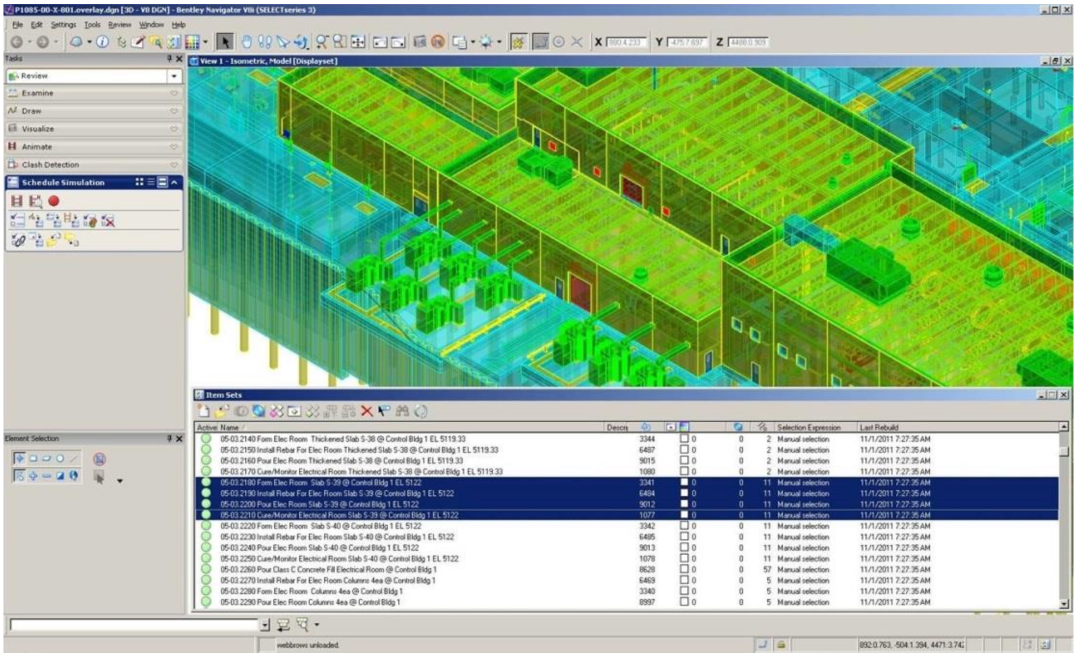

Figure 1: Activity linking to 3D model in Navigator V8i (Courtesy of Carollo Engineers)

Upon completion of linking the 3D model to the contractor's construction schedule in Navigator V8i, the model was opened in Bentley Microstation software. Within Microstation, a frame creation option was used to allow the 4D team to render images of the model based on a defined timeline. Setting the timeline to match the construction activity dates produced a daily look at the contractor's projected work sequence. To create a video sequence that could play the images, the frames were imported into Camtasia Studio, a screen recording and video editing software that allows users to set frame speed and insert data dates (TechSmith, 2013). The resulting video could be played back by using any number of media players that accept the .AVI file extension.

4D Visualization Results

Utilizing 4D Visualization for a complex schedule review requires a thorough understanding of the contract, the work restrictions associated with the project, and proper construction techniques. Without knowledge in these areas the visualization will yield little more than the projected construction sequence. While this simplistic level of visualization can be beneficial to clients or the general public, it does not provide the necessary insight into a schedule that an Owner's Representative would need to properly accept a contractor submission. It should be noted that a 4D Visualization should not replace a conventional schedule review, but rather supplements the work done by the reviewer. The following outlines the results achieved on the PAR 1085 South Secondary Improvements Project.

Concrete Pour Sequence Compliance

The technical specifications for a construction project identify a number of requirements for concrete mix design and placement. These requirements can include temperature, admixtures, cure cycles, seasonal requirements and many other items the need to be addressed while placing concrete. For PAR 1085, Carollo used the 4D Visualization to verify that the contractor had appropriately accounted for the required 14-day calendar cure cycle, as well as verifying that the sequencing of the concrete placements were in conformance with project specifications and industry best practices. To execute a comprehensive review of the concrete placements, the 4D team developed an overview visualization of the entire project and independent views of individual structures.

In the PAR 1085 construction schedule, the contractor inserted four activities for the placement of concrete elements. Each concrete element was assigned a "set forms," "install rebar," "pour concrete," and "cure" activity in the schedule with an applicable duration. To show an "in progress" element in the model, Navigator V8i displays the item in a dull green color as shown in Figure 2. Once the concrete element has completed the assigned cure cycle, the item changes color to match the level color it was assigned during the design phase. In Figure 2 the design level color for walls and slabs is shown in light blue.

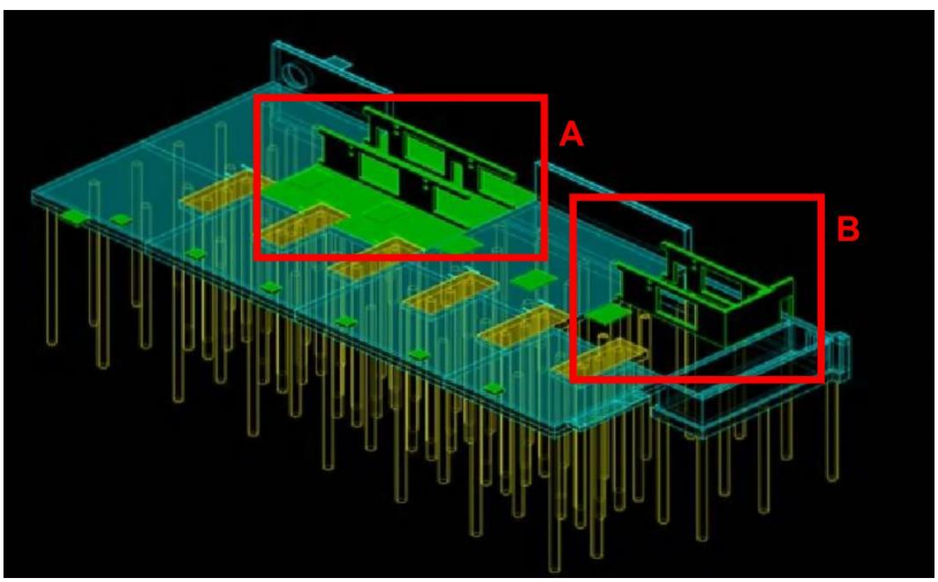

Figure 2: Concrete Pour Sequence Compliance Example (Courtesy of Carollo Engineers)

Figure 2 is a screenshot of the blower building located on the southwest corner of the South Secondary Improvements Project. This figure identifies two of the major issues encountered while reviewing the 4D

Visualization for concrete pour sequence compliance. Box "A" shows a wall being placed on top of a slab. Review of the slab under the wall placement shows this element has not completed the required 14-day cure cycle. This is apparent by the dull green color that signifies the element is still in progress. Placing concrete elements on top of items that have not completed the specified cure cycle illustrates contract non-compliance. The contractor was subsequently required to modify the logic within the schedule, creating a "finish-start" relationship between these two elements. Box "B" shows the activities for a wall element starting prior to the beginning of the slab below. Proper sequencing of these elements would require the slab to be placed and cured prior to initiation of construction of the wall above. This example reflects a schedule bust where the wall element was incorrectly tied to a predecessor element not associated with the slab below.

Impact of Concrete Pour Sequence Compliance

With over 75,000 cubic yards of concrete being placed for the South Secondary Project, review of each concrete placement for contract compliance in a conventional schedule review would be extremely difficult and time consuming. Utilizing 4D Visualization technology, the review of these schedule elements takes a fraction of the time. Concrete schedule busts could a have a significant impact on the overall float and projected sequencing for the project. The concrete placement in Figure 2, Box "B", is in the series of activities with the longest continuing duration that establishes the completion date, also known as the critical path (Smith, Currie, Hancock LLPs, 2005). Resequencing the slab construction ahead of the wall results in a minimum 14-day calendar bust. If this simple logic error were repeated a few times within the massive construction schedule, the resultant delays would be months.

Missing Activity Identification

One of the most common issues encountered within a large, complex schedule is work elements not being properly identified or omitted completely. Ideally, such omissions would be caught well before the work element is required and could be placed in the schedule with minimum impact. In a conventional review of a large schedule, identifying missing activities is onerous and in most cases is not discovered until an element is ready to be procured.

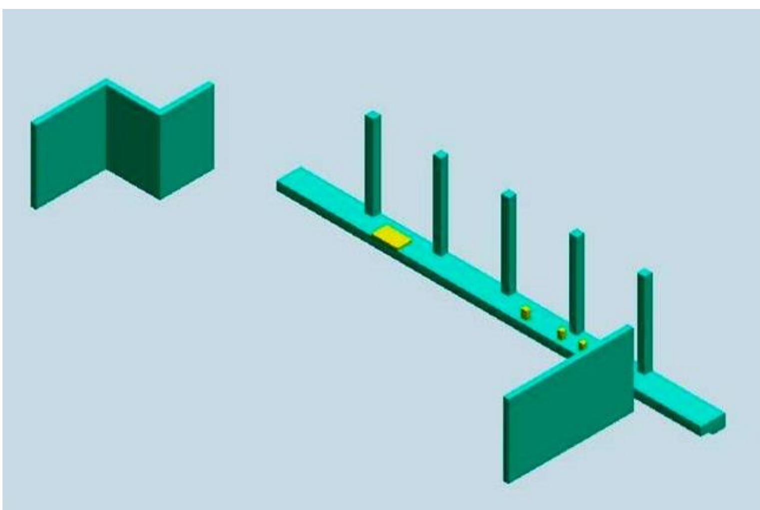

Figure 3: Missing Activity Identification in Navigator V8i (Courtesy of Carollo Engineers)

Upon completion of linking all the applicable schedule activities to the 3D model, Navigator V8i allows the user to hide all the model elements with assigned schedule activities. The model elements that remain visible have not been assigned corresponding schedule activities. During the development of a baseline schedule, it is not uncommon for a contractor to have a team of individuals working on assigning schedule activities to specific areas/buildings. This team approach quickly produces a schedule, however the potential for omitting activities is greater due to an assigned area misinterpretation. Figure 3 is an example of activities being omitted in the contractor's schedule. All the model elements with associated schedule activities have been hidden. The remaining model elements (shown in Figure 3) have no associated schedule activities. The model elements shown are located at a threshold between buildings. A lack of communication between the individuals responsible for schedule development at this area yielded missing activities. Elements missing from the schedule were identified and added in conformance with the contract.

Impact of Missing Activity Identification

Missing activities affect a number of items within the contractor's schedule. The key to avoiding the negative impact of missing schedule activities is early identification, ideally at the baseline submission. Aside from the obvious duration impact, omitted items can affect subcontractor coordination, cost-loaded schedule accuracy, and potential late procurement of items. Removing or minimizing the impact of omitted activities can save the project thousands of dollars and avoid float depletion.

Visual Assessment of Actual vs. Planned

For many consultants and owner's representatives, one of the many challenges is conveyance of complex technical information to the client. Utilizing visual representations of complex issues can aid in the client's technical understanding. Terms such as total float, critical path, lag, and logic may be lost on an owner; therefore simplifying the information is paramount for owner understanding and input. The use of 4D Visualization for a visual assessment of actual vs. planned project completion is a tool that simplifies the construction schedule and ease of comparison.

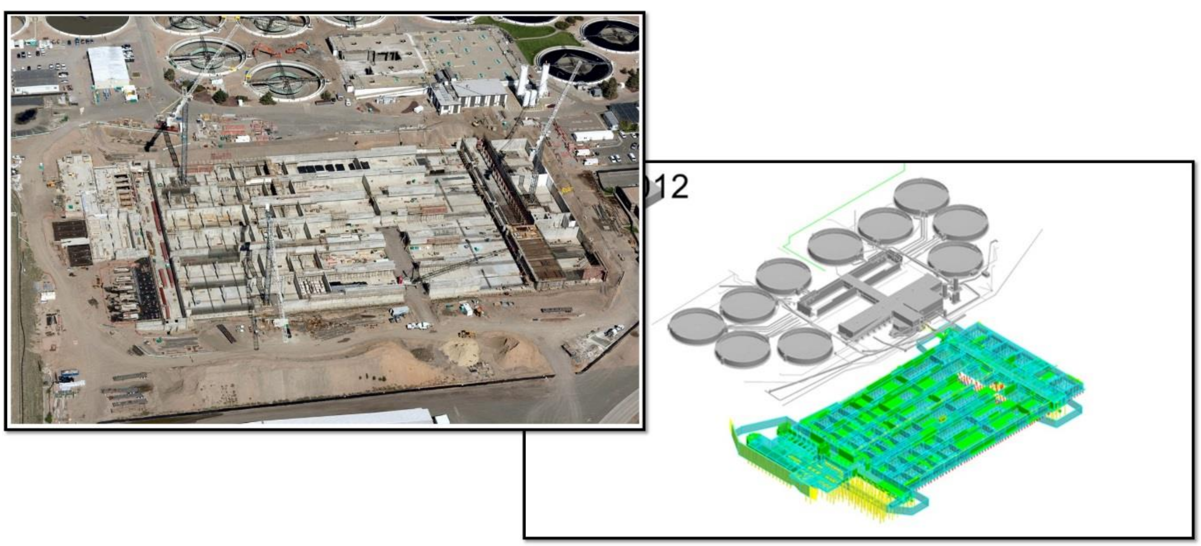

Figure 4: Visual Assessment of Actual vs. Planned – 10/02/12 (Courtesy of Carollo Engineers)

Impact of Visual Assessment of Actual vs. Planned

Figure 4 is a comparison of an aerial photo taken on October 2, 2012 and the 4D Visualization set to the same date. By simply comparing the progress shown in the two images, the client can visually compare the contractor's actual progress vs. the projected progress.

Identification of Non-Compliance

Work restrictions play a valuable role on projects where an existing facility must be maintained during new construction. This is especially true if the new construction must be tied into the existing facility. Methods of Procedures (MOPs) and project team coordination are key to minimizing the impact of the new construction. To avoid such impacts, owners/owner's representatives install milestones and constraints into the contract documents. These contract clauses are non-negotiable and must be executed as specified. Failure to do so may result in at best non-compliance, or at worst a failure of existing equipment or process. The 4D Visualization can be utilized to visually verify that date constraints are accounted for within the schedule and milestone activities being completed. For example, the PAR 1085 contract states that Milestone 2 cannot begin until the Substantial Completion of Milestone 1. To ensure that this is appropriately reflected in the schedule, a reviewer can scroll to the Substantial Completion date for Milestone 1 and verify that no Milestone 2 activities have begun.

Impact of Identification of Non-Compliance

Non-compliance of a contract is a serious concern for any project team. Contract non-compliance can lead to lawsuits, delays, project shutdown, rework, safety issues, and/or liquidated damages. Identifying and amending non-compliance issues early may eliminate a number of negative impacts to a project.

Conclusion

The use of 4D Visualization technology during the construction phase of a project can be a functional tool for complex schedule review. 4D Visualization should not replace a conventional review, but aid the reviewer in identification of issues that would be extremely difficult to identify utilizing conventional techniques. Using current market software, the PAR 1085 4D Team was able to supplement the construction schedule review and minimize the impact of incorrect logic, contract non-compliance, and activity omission. Additionally, the 4D technology was used as a tool to convey complex information to the client without the need to technically explain the details of the construction schedule. Quantifying the benefit of 4D technology for the South Secondary Improvements Project is difficult, however the early identification of schedule issues mitigated a portion of the risk associated with the complex construction of the facility.

Although the outcomes obtained from this project represent a single instance, the data extrapolations made are not unique to PAR 1085. The 4D Visualization technology in its most basic application, regardless of software, will yield many of the benefits that have been presented in this paper. However, utilizing 4D Visualization is only as powerful as the reviewers understanding of the contract, the schedule, and the project. Simply linking a 3D model to a schedule will give a projected forecast of the work, but provide no detailed schedule information without an informed reviewer assessing the results.

References

Carollo Engineers Inc. (2013). *Metro Wastewater Reclamation District, Colorado, PAR 1085 South Secondary Complex Improvements Project* [WWW Document]. URL: http://www.carollo.com/MWRD-PAR1085SouthSecondaryComplex

Chau, K., Anson, M. & Zhang, J. (2004). Four-dimensional visualization of construction scheduling and site utilization *Journal of construction engineering and management 130* (4), 598-606.

Meadati, P. (2009). BIM Extension into Later Stages of Project Life Cycle, *ASC Proceedings of the 45th Annual Conference*, *ASC*, Gainsville, FL.

Metro Wastewater Reclamation District. (2013). *Who We Are* [WWW Document]. URL: http://www.metrowastewater.com/Pages/default.aspx

Smith, Currie & Hancock LLP. (2005). *Common Sense Construction Law A Practical Guide for the Construction Professional* (3rd ed.). Hoboken, NJ: John Wiley & Sons.

TechSmith Corporation. (2013). *Camtasia Studio* [WWW Document]. URL: http://www.techsmith.com/camtasia.html

Wang, H., Zhang, J., Chau, K. and Anson, M. (2004). 4D dynamic management for construction planning and resource utilization *Automation in Construction 13* (5), 575-589.

Waly, A.F. & Thabet, W.Y. (2003). A Virtual Construction Environment for preconstruction planning *Automation in Construction 12* (2), 139-154.