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Enhanced Constructability Using 4D Plus Modelling in Brownfield Sites

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Abstract

In the oil and gas industry, operations in greenfield sites are straightforward. However, there are increased risks, such as damage to existing facilities, unknown site conditions, and other complexities in brownfield sites. In addition to these physical risks, task scheduling is also complex, as vessels need to be replaced during a turnaround. To mitigate the risks of site conditions and realize a truncated schedule for Saudi Aramco's operations, 3D laser scanning was combined with 3D modeling, clash detection, and time. This integrated approach minimized the shutdown period, which resulted in cost savings, heightened safety, and enhanced stakeholder communications.

Keywords

Brownfield, Laser Scanning, 4-D Modeling, 3-D Modeling, Constructability

1. Introduction

Oil & gas industrial projects typically fall into two categories that significantly differ in their execution approach and associated risks: greenfield and brownfield. Greenfield projects are executed on property that has not been previously constructed. A brownfield project, on the other hand, refers to a project being executed within an existing facility. Thus, greenfield projects are typically new facilities, while brownfield projects are typically expansions or debottlenecking-type projects, often executed within an operating facility [1].

Executing construction projects in an operating facility is riddled with inherent risks. Due to unknowns and expected inconsistencies, implementing a brownfield project in an existing process plant entails numerous difficulties and complications. The absence of historical data, drawings, design calculations, and updated/as-built drawings are significant contributing causes of challenges during execution [2]. This case study addresses one of the more significant risks:

identifying the "as-is" configuration of the site.

One of the core tools used to set construction strategy is the constructability review, which is the process of imparting construction knowledge to the project design [3]. According to the US Department of Energy, a constructability review is "A technical review to determine the extent to which the design of a structure facilitates ease of construction, subject to the overall requirements for the completed form" [4].

In recent years, there has been a significant increase in the use of three-dimensional (3D)/four-dimensional (4D) model applications in construction management [5]. Although these models are helpful when executing a brownfield project, the critical application element of the actual site condition is missing. To overcome this drawback, this paper promotes 4D plus models for enhanced constructability in brownfield sites, as the "plus" provides the actual site in a digital format that can then be manipulated through the inputs of 3D and 4D models.

2. Our Challenges

Saudi Aramco is often faced with the challenge of executing projects in brownfield sites. This particular project involved nine oil processing facilities and the replacement of 16 pressure vessels. With between 1 to 3 vessels per facility, these massive vessels were to be replaced on an expedited basis to negate hydrogen-induced cracking (HIC). To meet the challenge, the project team adopted 4D plus modeling to improve constructability to ensure that the vessel's movement within a live operating facility was efficient without compromising safety. This cutting-edge technology uses federated drawings that combine 3D models and laser scans with scheduling data and clash detection to create a timeline and coordinate the movement and installation of the vessels. It allowed for significantly easier visualization of the project, and provided an overview of all components to ensure everything was in order. Additionally, it also made it easier to identify potential issues before they occurred, allowing the project team to mitigate and address them quickly. Through the use of clash detection, all pre-shutdown work could be identified and executed before the vessel arrived at the site. All this resulted in an unprecedented level of efficiency and safety.

3. Minimizing Shutdown Periods

Each pressure vessel to be replaced was in an active, busy, congested area within facilities built in the 1970s, which were expanded and modified through the years. The vessels measured approximately 4 m × 46 m each and weighed around 200 tonnes, leaving no room for error during the replacement process. In addition to working in a congested area of an operating facility, the vessels were to be replaced during a special shutdown. Also known as a turnaround, shutdowns halt production, and the associated losses accumulate with each passing day of the shutdown. While the turnaround is a planned outage, extending beyond the official oil-in date may also result in staggering production losses. Using 4D plus modeling, Saudi Aramco was able to plan the projects in more detail than ever before and drastically reduce shutdown periods thanks to the precision planning of work with cranes and Self-Propelled Modular Transporters (SPMTs).

4. Modeling in 4D Plus

Removing and replacing massive vessels is an arduous task. The successful execution of the project required precision planning and an accurate understanding of the path the vessel would take through the site. This is where 4D plus modeling added value as it simulated vessel navigation through the site, identified potential clashes with existing facilities, ensured efficient crane positioning, facilitated coordination between other projects being executed simultaneously, and ultimately ensured unimpeded vessel movement during the shutdown. This process can be broken down into three key elements—laser scanning, 3D modeling, and clash detection to create a 4D plus modeled route. Safety is paramount for Saudi Aramco and 4D plus modeling enabled the company to take all necessary precautions proactively. The technology provided a detailed view of the best simulated sequence of events to minimize potential issues during the execution of the plan.

5. Laser Scanning

The first step of the process involved laser scanning the area to capture the existing site digitally. This provided a detailed view of the existing site and potential obstacles for the vessel's route, allowing for more accurate planning. Laser scanning analyses real-world objects or environments to collect data on their shape and possibly their appearances, such as color or texture. The laser scan output produces a "Cloud Point", which replicates the actual site as a digital 3D image, see **Figure 1**.

There are various types of 3D scanners available in the market today, such as desktop, handheld, or tripod-mounted, industrial or consumer-grade, photo cameras and photogrammetry software, contact-based measuring systems, smartphones or tablets with built-in LiDAR (Light Detection and Ranging) sensors, mobile, terrestrial, airborne systems, and more. LiDAR technology is an active remote sensing system which means that the system itself generates energy that will be projected in the form of a rapidly firing laser to measure ranges and the exact distance of an object on the earth's surface [6]. Terrestrial LiDAR technology was applied to the 4D plus modeling constructability exercise used for this project.

A LiDAR sensor has three primary components; a Laser to transmit pulses, a scanner to record the time delay between light pulse transmission and reception, and a specialized GPS receiver to monitor the location of the system with the LiDAR sensor [7]. In addition to 3D laser scanning, this article discusses the integration of 3D modeling and clash detection technologies used in creating a 4D plus model of the in-plant transportation and installation logistics of vessel replacement in a recent Saudi Aramco project installed and commissioned during 2021-2022.

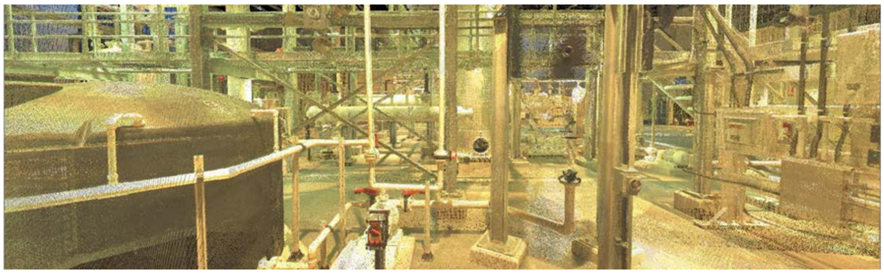


Figure 1. Typical "Cloud Point" image.

5.1. 3D Laser Scanning

3D Laser Scanning is a "non-contact, non-destructive technology that digitally captures the shape of physical objects using a line of laser light" [8]. 3D laser scanners create "point clouds" of data from the surface of an object. In other words, 3D laser scanning captures a physical object's exact size and shape, into a human-machine interface, as a digital 3-dimensional representation.

It also captures free-form objects and generates highly accurate point clouds with fine detail and is ideally suited for complex geometries requiring massive amounts of data for accurate description. 3D laser scanning has multiple applications and can be found in fields such as architecture, construction & preservation of buildings and monuments [9].

3D laser scanning enables a fast, reliable, and inexpensive 3D survey of existing structures, equipment, and buildings. In building construction, laser scanning is typically used for capturing building facades, elevations, floor plans, etc., which contribute to the Building Information Model (BIM) as well as to perform dimensionally accurate surveys. Using the results obtained from the laser scanner, the user can create volumes, surfaces, layouts, sectional views, and more. Laser scanning is the optimal method for Building Information Modeling (BIM) [10]. Other laser scanning applications are reverse engineering, forensics, building projects & constructions, archeology, and mobile mapping [11].

Some laser scanners allow the option of downloading the model as point clouds. In contrast, others automatically convert it into a triangulated mesh, which can then be transformed into a CAD model or a full-colored 3D model if texture recording is supported. There are different types of laser scanners, such as Time of flight, Phase shift, and Triangulation, with advantages ranging from ease of use, accuracy, photo-realism, completeness, contactless operation, light-free operation, repeatability, and low cost, to name a few [12].

5.2. 3D Modelling

3D modeling refers to the process of creating a mathematical representation of any three-dimensional surface of an object using special software. It helps to create a realistic portrayal of any project, revealing even the most minute details and features [13]. In this study, 3D models integrated non-existing elements such as the crane, new vessels, SPMTs, and existing elements such as the vessels to be removed (**Figure 2**). 4D plus models integrate 3D models of components that currently exist outside the laser scan's "cloud point". The 4D plus model creates a federated drawing representing a composite of existing site conditions (the cloud point) and 3D models of the objects to be maneuvered through the site.

6. Clash Detection

Effective clash detection, according to Wang [14], is a method that iteratively identifies, categorizes, assesses, and resolves project conflicts until a coordinated model with few or acceptable clashes is identified. It typically compares two or more models, in this case, the laser scan of the existing site and 3D models of the non-existing, future components consisting of the crane, new/existing vessels, and the SPMTs. All these elements are brought together in a federated drawing depicting the projected path of the vessel to check for any potential collisions or other risks. Clashes are deemed to occur when two model elements occupy the same space, as shown in **Figure 3** [15]. Clash detection allows for identifying, inspecting, and reporting the elements that might cause a problem before any movement commenced.

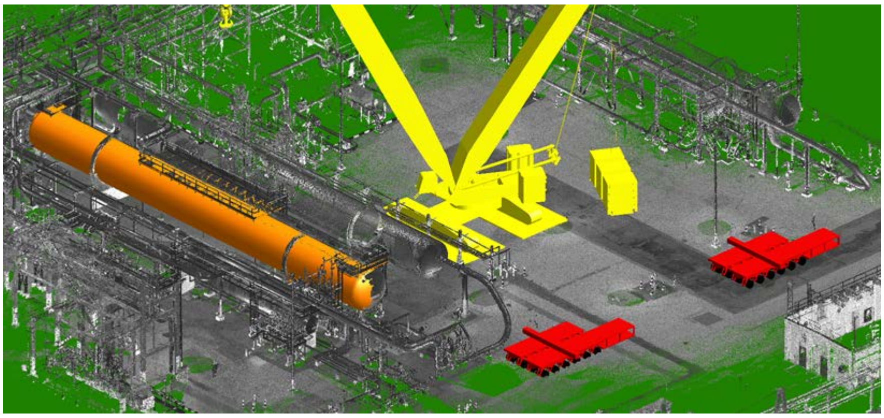


Figure 2. Existing vessel, crane, and SPMT are depicted as 3D models.

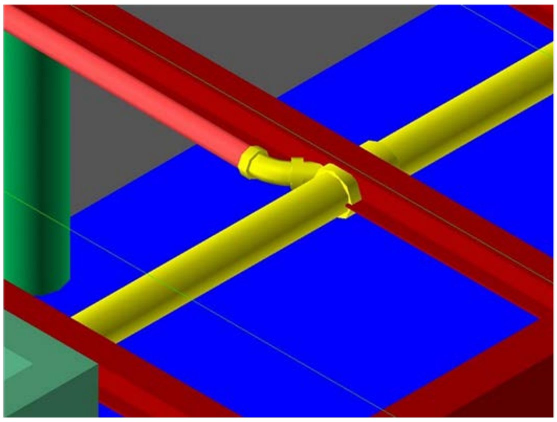


Figure 3. A typical hard clash between piping and structural models.

Two types of clashes were defined—soft and hard. A soft clash was any predicted moment that resulted in one object being close to another, while a hard clash was any anticipated moment where two objects were in the same physical space, see **Figure 4**. The 4D plus model helped identify clashes that could become safety and schedule risks in a virtual environment.

For the project to gain full advantage of using the 4D plus model for enhanced constructability, the model is required to identify each and every clash during the planning stage. The clash detection process involves embedding modeled elements into the 3D laser-scanned as-built environment, where clashes in the vessel route, crane placement, and other elements of the constructability review can be detected. The 4D plus model can virtually see what potential hard and soft clashes appear along the vessel route, see **Figure 5**. Failure to identify clashes along the route prior to the planned shutdown may lead to complications at multiple locations, negatively impacting cost and schedule during the most critical phase of the project.

Being an iterative process, the sequences of steps involved in a clash detection and resolution process comprise creating the 3D Laser Scan, 3D Models, Clash Detection, Generate Clash Reports, Clash Resolution, and Model Updates. When applied to 4D plus models for enhanced constructability, clash resolution can be realized through various methods. For instance, site fixtures that clash with the proposed route can be removed or relocated prior to vessel movement. Alternate routes can also be explored to avoid clashes, or in case of a soft clash, the project team may choose to accept the soft clash and address it during vessel movement.

6.1. Hard Clashes

Three of the eight identified hard clashes (C1 to C3) occurred around the crane spreader mat, with a 4th clash (C4) between the crane's counterweight and a lighting column during the slewing of the crane. These were overcome by adjusting the crane's position and relocating the lighting column. Additionally, bollards had to be removed (C5 and C6), the site gate widened with a post strut, an area of the fence temporarily removed (C7), and a crash protection barrier at the site entrance cut back (C8). **Figure 6** and **Figure 7** illustrate some of these examples of hard clash identification.

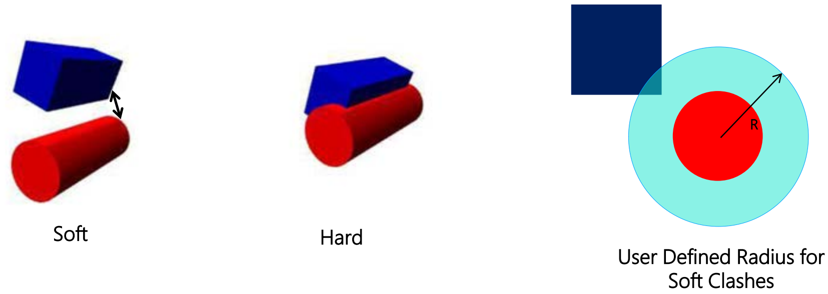


Figure 4. Soft and hard clashes where soft clashes are user-defined.

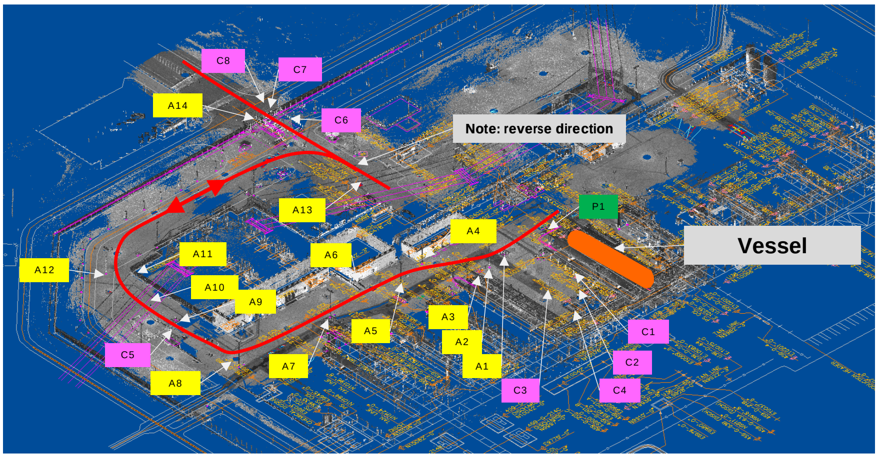


Figure 5. Clash Report with hard clashes shown in purple and soft clashes shown in yellow.

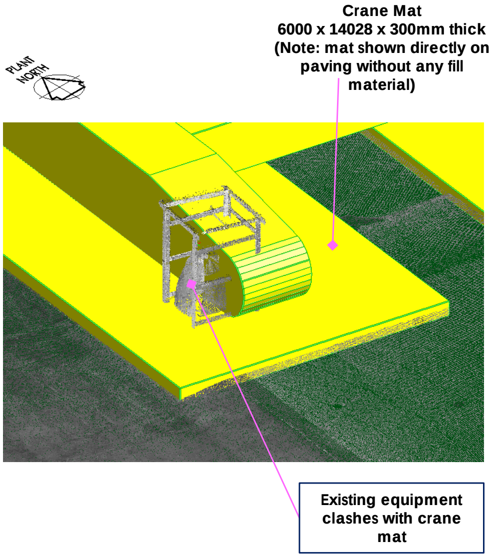


Figure 6. Clash C3—Crane clashes with existing equipment.

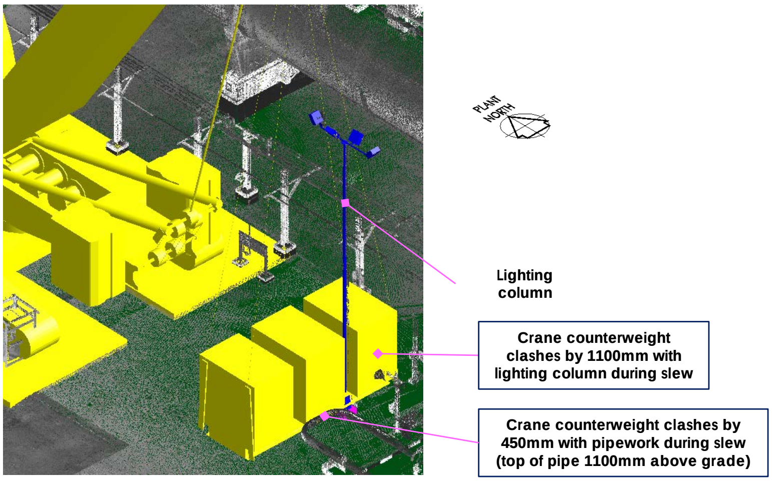


Figure 7. Clash C4—Crane's counterweights clash with the lighting pole during the slew.

6.2. Soft Clashes

The remaining 14 soft clashes were addressed by adjusting the vessel's route or removing the clashing item prior to the turnaround and carefully monitoring the surrounding area throughout transit. Once identified, these hazards were assessed to decide whether to remove or avoid them without significant construction or adaptation works. Examples of soft clashes pertaining to this study included fire hydrants, lighting columns, access ramps and handrails, overhead cables, and the gatehouse building, some of which are illustrated in Figure 8 and Figure 9.

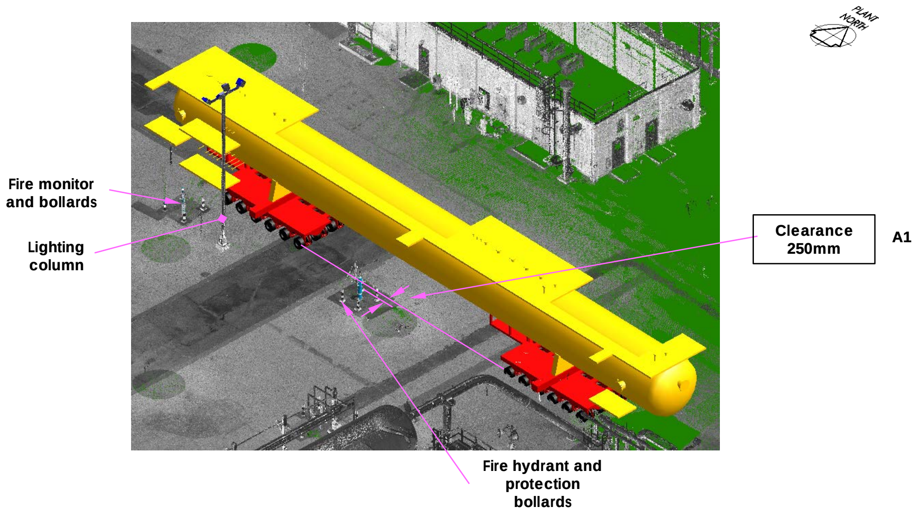


Figure 8. Clash A1 – Fire monitor and hydrant.

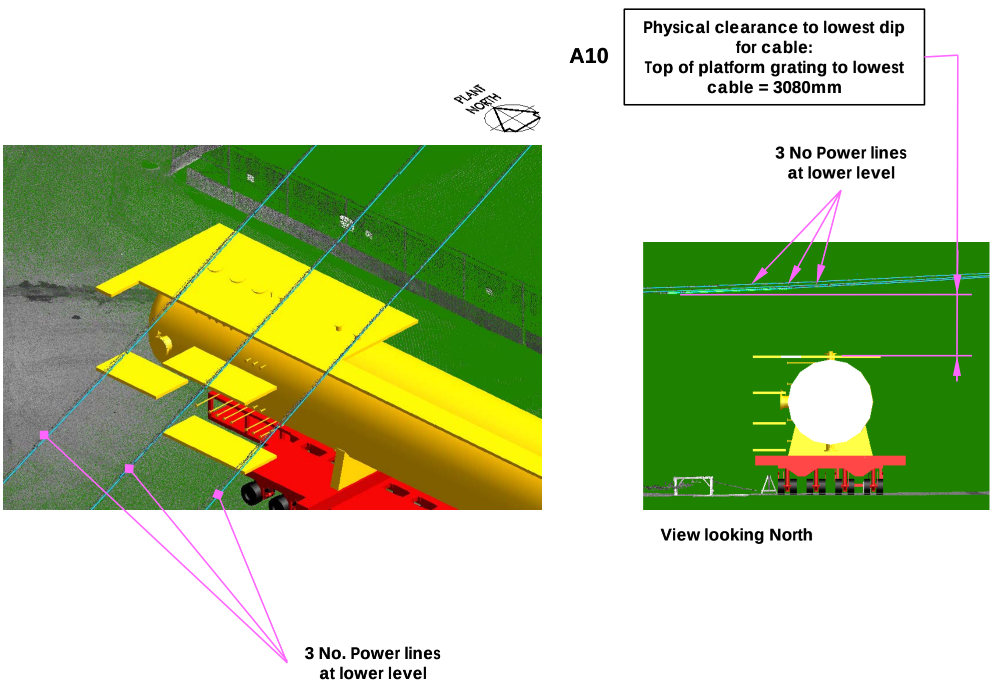


Figure 9. Clash A10 – Overhead power lines.

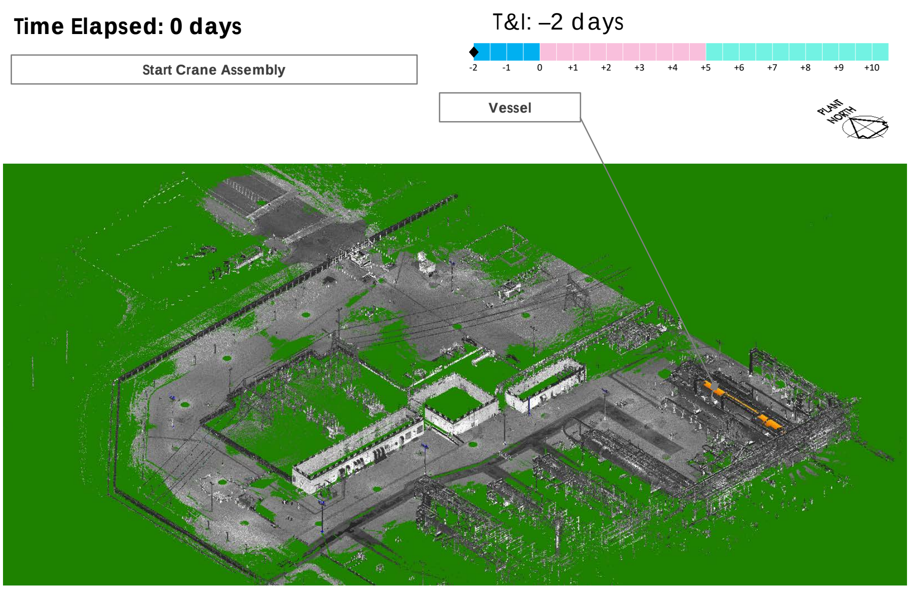
7. Time

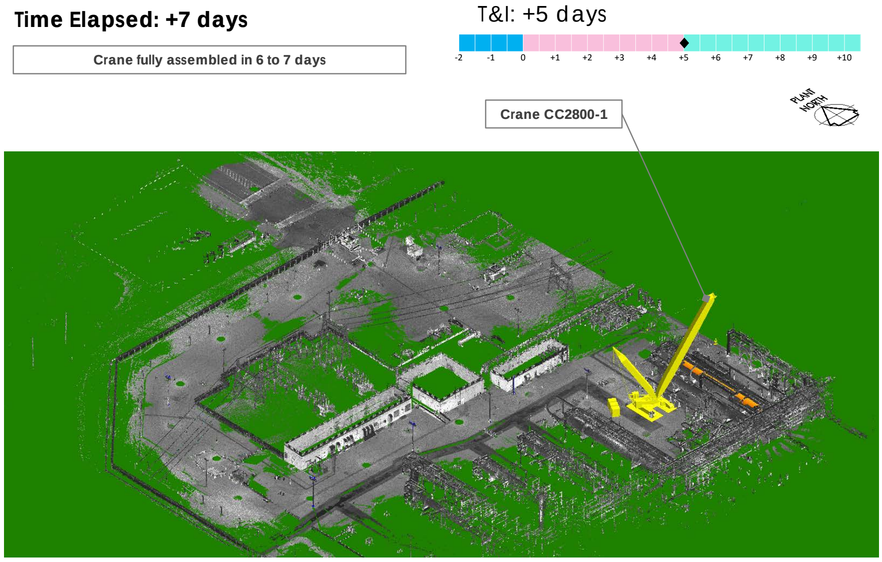
Much of the discussion to this point has been centered around preparing the 3D laser scans and models along with clash detection. The 4th element of the 4D plus model is time. The three elements of the 3D scanning, 3D modeling, and clash detection progressed against the 4th dimension, time, to ensure that all project elements were addressed as the projects moved forward.

The turnaround schedule was aggressive due to market demands at the time of execution. While clash detection was required to identify and isolate potential issues during the vessel's transit through the facility, the schedule issue needed to be addressed to confirm whether the task could be completed within the allotted time frame of the shutdown. The planned outage was formally agreed to as 40 - 44 calendar days, depending on the number of vessels per site. However, the first five days are dedicated to de-inventory and cleaning, while the last seven days are set aside for commissioning and start-up. Hence, the actual time available to replace the vessels was only 28 - 33 calendar days.

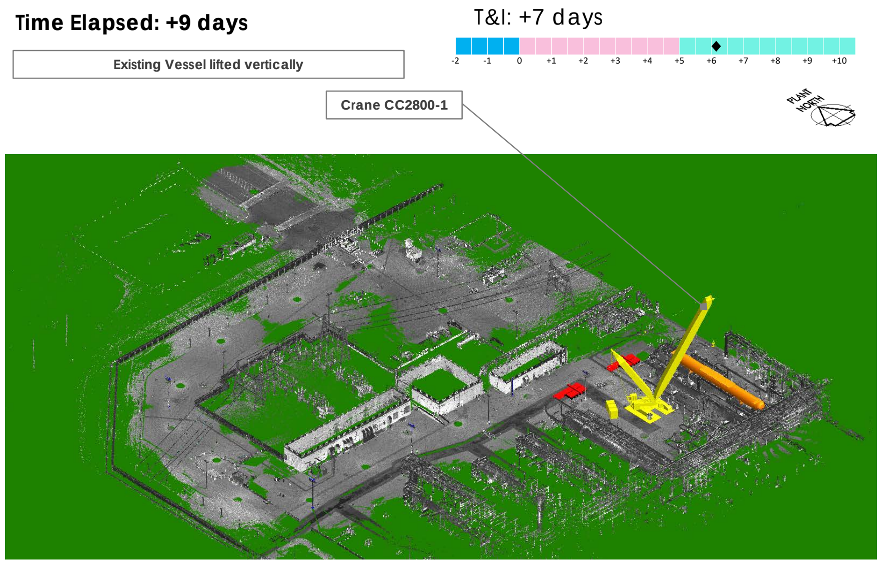
The use of federated drawings, where the embedded 3D model elements can be manipulated through the virtual as-built site conditions, allows for a simulation of crane assembly, SPMT movement, vessel lift, and transit through the facility. Each aspect of the vessel replacement could be assigned a duration and sequence, allowing the replacement to be set against a time frame, see **Figure 10**.

The 4D plus model was essential for the successful completion of this project, providing us with visual information related to time, site, design, and logistics. These federated drawings create the 4D plus model, which was then used by the project team to help visually plan, design, and execute the vessel replacement. By anticipating potential issues and tackling precautions proactively, the 4D plus model allowed for the safe movement of large vessels effectively, with minimal disruption to the surrounding environment.




Time Elapsed: +7 days
Crane fully assembled in 6 to 7 days
T&I: +5 days
-2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8 +9 +10
Crane CC2800-1
PLANT NORTH


Time Elapsed: +8 days
Rigging to vessel – one complete day
T&I: +6 days
-2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8 +9 +10
Crane CC2800-1
PLANT NORTH


Time Elapsed: +9 days
Existing Vessel lifted vertically
T&I: +7 days
-2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8 +9 +10
Crane CC2800-1
PLANT NORTH

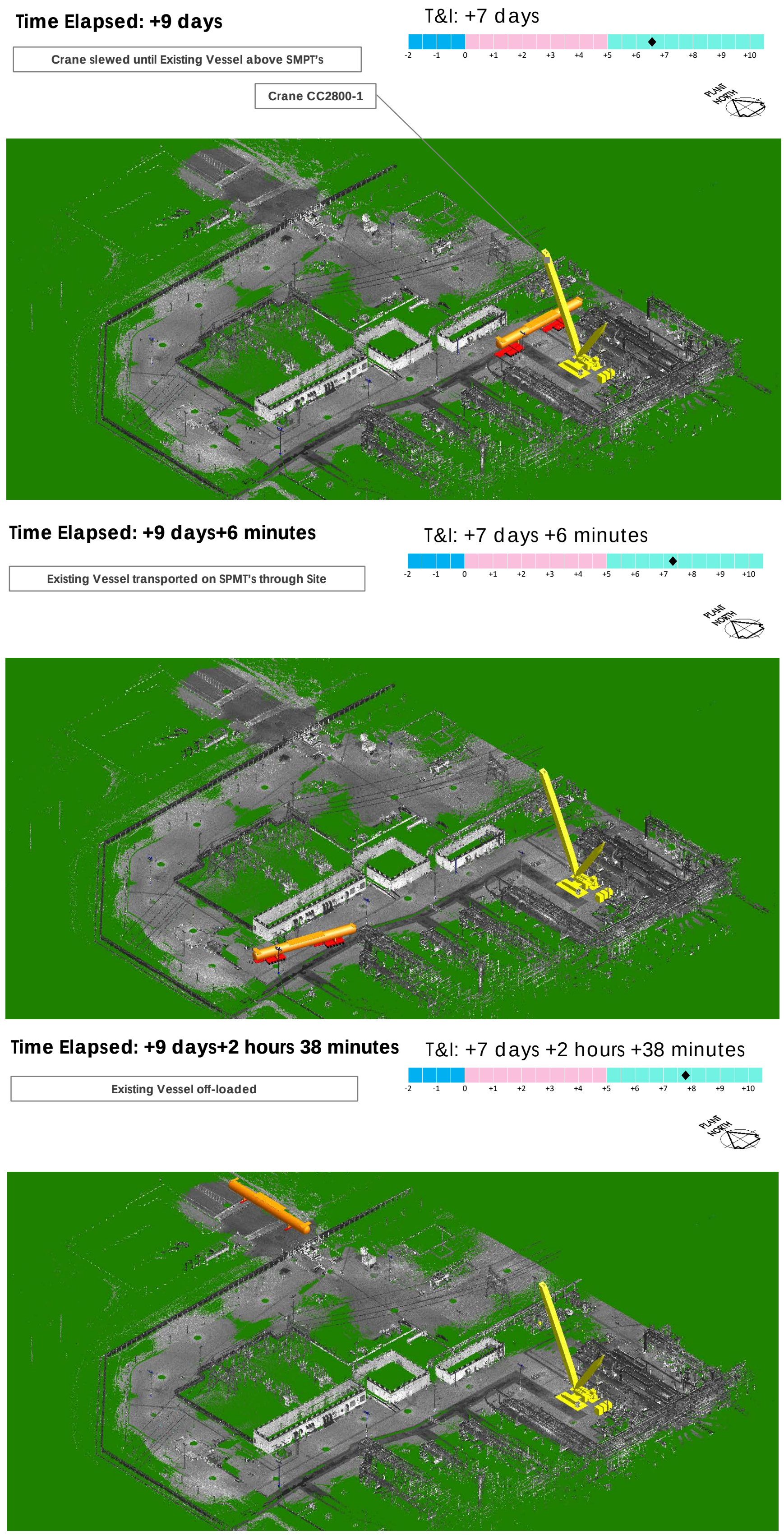


Figure 10. Crane set up and vessel movement against the timeline.

8. Plan Approval

The first step before any project commencement is getting the plan approved. To do this, the Saudi Aramco team presented the 4D plus model of the vessel replacement logistics plans to the project stakeholders. Thanks to a visual simulation of vessel movement through the facility, final approval was granted quickly with minimal delays due to design changes or discrepancies between the modeled work and the actual site conditions.

Interestingly, there were two sites where it was necessary to plan vessel movement and crane placement, with two other projects being executed concurrently, which increased the job's complexity significantly. The 4D plus model helped the different teams plan out the movements of all process and construction equipment in relation to where they were situated. All teams were able to proceed with constructing activities without compromising safety considerations of any existing piping, conduits, tanks, accessibility issues, or other obstacles that needed to be avoided. Thus, ultimately, these 4D plus models expedited the approval process and buy-in of the execution plan by site proponents.

9. Removal of the Existing Vessel

The vessels were to be replaced during a turnaround, which is a planned shutdown of a facility intended for maintenance, inspection, testing, and replacement of process materials and equipment. Assembly of the crane necessary to lift and move the vessel was initiated two days before the agreed commencement of the facility shutdown. Further, any clashes along the vessel route that could be addressed pre-shutdown were performed, such as relocation of fire monitors, removal of crash barriers, etc. This allowed for an uninterrupted process, as clashes were mitigated, and the crane was set and tested before the start of the turnaround. On the 7th day of the project, concurrent with the completion of de-inventory and cleaning, the crane was fully assembled, and the vessel's movement became possible. The following day, all necessary rigging was attached to the vessel and tested for safety. The SPMT was then moved into position following the 4D plus model recommendations, and the vessel was removed and lowered onto the waiting SPMT in a safe and timely fashion. The SPMT then maneuvered the vessels through the site, including complicated reversing of the vessel and vehicles to correctly position them to exit through the main site entrance. Overall, it took less than one hour for this enormous vessel to be removed from the site.

10. Installing the New Vessel

The entry of the new vessel onto the site mirrored the exit of the original, taking approximately half an hour in total to move from the site entrance to its position beside the crane. As the new vessel had been pre-positioned to enter shortly after the exit of its predecessor, this occurred on the same day the previous vessel was removed. The crane was then used to lift the new vessel off its transport vehicle and lower it into position safely and securely by the end of day 10. This enabled the installation to be complete in a further 24 hours. It is worth noting that throughout the process, the 4D plus model successfully avoided potential clashes with no unforeseen events occurring during transit or installation.

11. The Added Value of 4D Modeling

The process of 4D plus modeling allowed for the accurate assessment of pre-shutdown activities, a firm shutdown schedule, and a precise process of removal and reinstallation of vessels. Because the model outlined the vessel's exact path, disruption to other site activities was minimal, allowing traffic in other areas to proceed as usual. The use of 4D plus modeling reduced the time required for removal and installation by a third, from 10 days to 7, resulting in significant cost savings as less equipment, time, and personnel was needed. By digitally planning out every step of the process before it began, the overall process ran smoothly, with no complications or safety issues occurring during the project's execution. The success of this project is a testament to careful planning and accurate modeling, which enabled us to complete the task efficiently and safely.

Moreover, 4D modeling allowed us to increase the velocity of the entire process by providing more accurate construction time estimates for each part of the job. By leveraging this technology, we managed to reduce the amount of time it took to complete the project from 28 - 33 days to a mere 11 days at a single vessel site. With each day of interrupted plant activities costing an estimated $12 million, the savings created by the 4D plus model is estimated to be over $204 million.

In conclusion, 4D plus modeling allowed for efficient and safe removal and reinstallation of the vessels from each site with minimal disruption to existing operations. By creating a detailed 3D laser scan of the site layout and plotting the vessel's route, we were able to execute the project safely and quickly with unprecedented cost savings. The resounding success of this project is a testament to the effectiveness of 4D plus modeling technology.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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