4D BIM for Improving Plant Turnaround Maintenance Planning and Execution: A Case Study

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Abstract –

Four-dimensional (4D) Building Information Modelling (BIM) has been credited with improving construction planning procedures. The integration of 3D model with schedule information has enabled the effective detection of design and planning flaws in many construction projects. Due to the lack of research on using 4D BIM in Turnaround Maintenance (TAM) projects, this paper firstly introduces a novel framework of applying 4D BIM to improve TAM process planning and execution. Then, a real TAM project was selected to validate the effectiveness and efficiency of the proposed framework. Finally, benefits such as time and cost reduction, and safety improvement are calculated and explained.

Keywords –

BIM; Turnaround Maintenance; Planning

1 Introduction

Turnaround maintenance (TAM), as a periodic comprehensive programme which contributes significantly to the long-term stability and continuous production availability of the oil and gas plants, is one of the most important maintenance strategies to minimise the risk of production losses [1]. TAM project is known for its complexity due to the involvement of massive man powers and financial resources during its planning and operation [2-4]. It is reported that a major TAM can potentially cause an annual productivity loss of 2-3% [5]. The peculiarities of high labor intensity and capital concentration make TAM project a time-sensitive project that any delay or inefficiency can lead to catastrophic failure.

Traditional project management techniques, such as Critical Path Method (CPM)/ Program Evaluation Review Technique (PERT), are commonly applied to manage TAM projects. However, these methods are believed to be inadequate to accommodate the complexity of TAM projects.

Building Information Modelling (BIM) is emerging as a method of creating, sharing, exchanging and managing the information throughout project life cycle among all stakeholders [6, 7]. A Four-dimensional (4D) BIM model results from the linking of 3D model to the fourth dimension of time [8]. In the 4D model, the temporal and spatial aspects of the project are inextricably linked, as they are during the actual construction process [9]. In project shaping stage, 4D BIM is useful in communicating and validating construction plans and processes, while during construction phase, they are helpful in identifying errors in the logic of the schedule, potential time-space conflicts, and accessibility issues [10, 11].

In recent years, 4D BIM has been largely implemented on building and infrastructure projects, and proven its capabilities in planning simulation and optimisation [12-16]. However, there is a lack of 4D BIM studies in TAM projects. Therefore, it is worthwhile to investigate the capabilities of 4D BIM in improving TAM planning and execution. This paper firstly introduces a novel framework of applying 4D BIM to improve TAM process planning and execution. Then, a real TAM project was selected to validate the effectiveness and efficiency of the proposed framework. Finally, benefits such as time and cost reduction, and safety improvement are calculated and explained.

2 Framework of Applying 4D BIM to Improve TAM Planning and Execution

This section describes a 4D BIM framework for improving TAM planning and execution (as shown in Figure 1). In the left part, a typical TAM project structure is developed which consists of six levels of details based on the functional logic [5, 17]. The first level is defined based on a TAM project unit, which explains the project scope, cost, planning, governance, key performance indicators, health, safety, environment and quality, and emergency response. For a major shutdown, a TAM project will contain jobs conducted in two or more independent trains. Therefore, a major TAM campaign is always divided into several sub-campaigns. Given a train-related sub-campaign, the third level classifies the jobs into a number of sub-sub-campaigns according to the plant unit, such as Compressor or Turbine. The fourth level further divides the related jobs within a sub-sub-campaign into different work orders according to the system unit, such as Piping, Mechanical, and electrical systems. The last two levels detail the work order into batch and activity units respectively. For instance, for a given work order of a spool removal, there are a number of elbows need to be uninstalled, in addition, detailed process for uninstalling a specific elbow also needs to be explained.

According to the TAM project structure, four levels of the 4D BIM simulation are developed including Plant, System, Batch, and Activity level (as shown in the right side of Figure 1). For a given level, the 4D BIM simulation is developed based on the corresponding level-of-detail 3D model and schedule. Each of them is explained in detail in the following sub-sections.

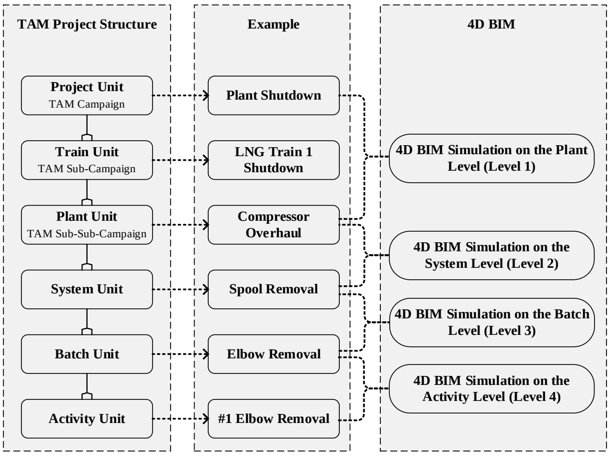

Figure 1: Framework of Applying 4D BIM to Improve TAM Planning and Execution

2.1 4D BIM Simulation on the Plant Level

The main objective of this level of 4D BIM simulation is to effectively engage core teams (i.e. Operations, maintenance & Integrity, and Turnaround Lead) to review the project scope. If the scope does not align with the initial plan, additional works, such as revising plans, need to be conducted before proceeding to the next stage. Therefore, the reviewing process is very critical to the turnaround success.

4D BIM modelling and simulation on this level is developed based on the 3D Plant Model and TAM milestone plan. In order to accelerate the agreement establishment among plant operation, maintenance, and turnaround teams, the 3D Plant Model should have all the main 3D objects (i.e. Compressor, Turbine, or Heat Exchanger) that defined within the project scope, and their functional location information. In addition, a general plant site model including site layout information should be also incorporated into the 3D Plant Model. The TAM milestone plan should lay out the key checkpoints and delivery dates for the planning cycle and form the basis for forecasting planning resources.

The plant-level 4D BIM simulation should be developed ten to twelve months before starting the field execution. For small turnaround projects with no major material lead times, the completion data of this simulation can be 6-8 months before actual starting.

2.2 4D BIM Simulation on the System Level

The main objective of this level of 4D BIM simulation is to engage teams of Planning, Work Pack Development, Engineering, and Procurement to: (1) communicate and review terms of reference, discuss initial risks, functional requirements, likely resources and establish delivery strategy; and (2) review initial scope against turnaround acceptance criterial, prioritise tasks and establish initial work list.

4D BIM modelling and simulation on this level is developed based on the 3D System Model and TAM work development plan. In order to efficiently review and confirm initial work list and initial preparations plan, the 3D System Model should include: (1) all the connected components (i.e. Spools and steel structures) of the instruments that plan to be replaced; and (2) major construction equipment, such as mobile cranes, that plan to be used to perform lifting tasks. The TAM work development plan should include: (1) an integrated plan (schedule, equipment and resources); (2) preliminary critical path schedule; (3) updated preliminary work list; and (4) critical lift plans.

The system-level 4D BIM simulation should be completed six to eight months prior to the shutdown of the plant or equipment.

2.3 4D BIM Simulation on the Batch Level

The main objective of this level of 4D BIM simulation is to engage external contractors and/or out-of-plant personnel to evaluate the critical path, and come up with alternative execution methods to shorten the project duration. Reviews of maintainability, reliability, and constructability are the main focus at this stage.

4D BIM modelling and simulation on this level is developed based on the 3D Batch Model and TAM detailed plan. In order to efficiently finalise the work list, the 3D Batch Model should include: (1) supported structures such as steel platforms and scaffolds; and (2) safety signs and tags such as frame signs, swing stand signs, and barricading. The TAM detail plan should include critical and sub-critical activities, lifting plans, mobile equipment requirements, detailed shop loading plans, and what-if scenarios.

The batch-level 4D BIM simulation should be completed three to five months prior to the turnaround.

2.4 4D BIM Simulation on the Activity Level

The main objective of this level of 4D BIM simulation is to ensure that all parties understand the work to be done and the sequence and details of the shutting-down process together with preparation for entry.

4D BIM modelling and simulation on this level is developed based on the 3D Activity Model and TAM execution plan. In order to efficiently (1) train operations, maintenance, and contractor personnel and (2) review environmental and safety requirements, the 3D Activity Model should include: (1) temporary facilities such as temporary offices, stores, tool houses; (2) functional equipment such as lighting tower, gas detector, and hydrostatic test unit; and (3) virtual avatar. The TAM execution plan should include: (1) shutdown and unit clean out sequences, (2) start-up plan; and (3) detailed execution sequences.

The activity-level 4D BIM simulation should be completed two weeks to two months prior to the turnaround.

3 Case study

The case study was conducted based on a major plant turnaround project that consists of LNG Train 5 and Fractionation Train 1. The key activities involved in this turnaround include: (1) Turbine major inspection; (2) Statutory vessel inspections; (3) Compressor blade carrier change-out; (4) Bearing and seal inspections; (5) Tray modifications; (6) Molecular sieve bed change-out; (7) Mercury guard bed change-out; and (8) Valve overhauls, upgrades and replacements.

3.1 3D Model Development

The selected gas plant was built more than 30 years ago. There is a lack of a 3D model that can be used to create a 4D simulation. Fortunately, the laser scanning technology is becoming mature enough, and is affordable for current industry. There are lots of automated methods that have been developed for transforming point cloud data into 3D model [18]. However, in this case study, the 3D model was created manually by engineers in order to assure the modelling accuracy. The underlying reasons are twofold: (1) Most of the existing algorithms developed for automatically transforming point cloud data into 3D model, are focused on building industry. When applying them in gas plant domain, the average accuracy of the transforming process is not acceptable. (2) The scope of this TAM project is small, only covering the Compressor-related area, thus both time and cost spent for creating the 3D model are affordable. Figure 2 shows the point cloud data, and Figure 3 shows the converted 3D model.

Figure 2: 3D Point Cloud Model

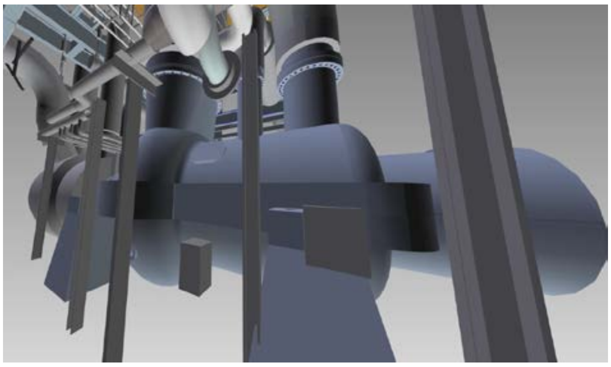

Figure 3: Converted 3D Model

3.2 4D BIM Simulation Implementation

In this case study, the four levels of 4D BIM simulation defined in Section 2 were developed as the project progresses. The aim of the 4D BIM simulation on the plant level is to help decision-makers to efficiently gain a better understanding of project scope and critical works. Figure 4 shows the 4D BIM simulation on the plant level which visualises the major activities defined within the project scope.

The simulation was created by the TAM core team and presented to the project steering committee for guidance. Through the simulation, the steering committee had gained a better understanding of

- The thirteen major maintenance happened in LNG train 5, such as: gas turbine overhaul of *5KT1410* and *5KT1430*, process compressor overhaul of

5K1410, *5K1420*, *5K1430* and *5K1450*, statutory inspections of 43 vessels, and *5C1410* tray modifications; and

- The nine major maintenance happened in LNG train 4 and Frac-3, such as: thirty control valve installations, three exchanger installation, product exchange of 4C2501, and compressor overhaul of *4K4401* and *4K4403*.

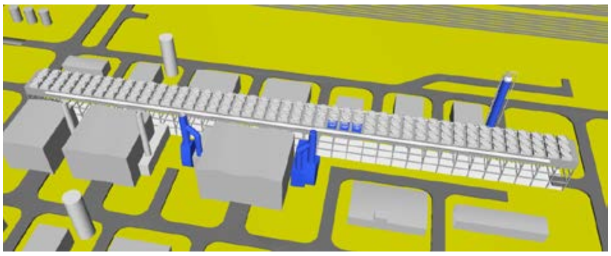

Figure 4: Screenshot of the 4D BIM Simulation on the Plant Level

In addition, one critical workscope and three sub-critical workscopes were also determined in terms of their durations and dependences. The *5K1410* compressor overhaul was the critical one and it would take 20 days to complete. The sub-critical workscopes includes: *5KT1430* turbine overhaul (24 days), *5KT1430* turbine overhaul (25.5 days), and *5C1410* internal tray modification (13 days).

Figure 5 shows the 4D BIM simulation on the system level which not only visualises the sequence of the main activities, but also evaluates the constructability and efficiency of the lifting and access plans created by the TAM execution team.

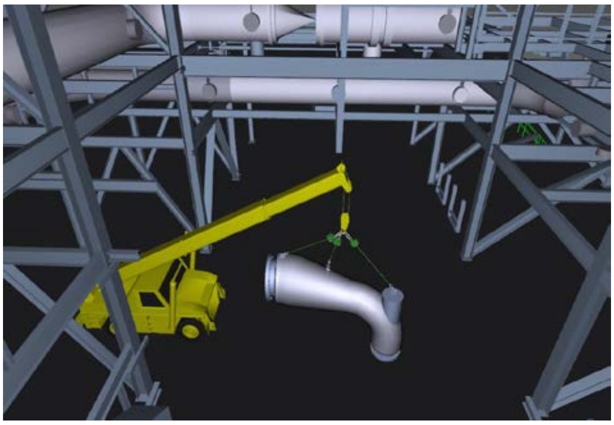

Figure 5: Screenshot of the 4D BIM Simulation on the System Level

Take LNG Train 5 as an example, the original lifting plan contains six mobile cranes. The working location and lifting capacity of each crane are shown in Figure 6a. According to the simulation result, seventeen major conflicts were identified between the planned construction sequence and the original lifting plan. For instance, Crane 2 was occupied by two main activities simultaneously during 9:30-10:18 on the 11th September 2015, and Crane 4 was occupied by two main activities simultaneously during 6:45-7:51 on the 18th September 2015. If these conflicts were not solved successfully before field execution, there would be fifty hours schedule delay and more than two hundred man-hours waste. These numbers were estimated by the TAM core team.

In order to solve the seventeen lifting conflicts, the TAM core team went through these conflicts one by one, and found that fourteen of them were related to the Crane 2 and 3. Therefore, they decided to add another crane located between Crane 2 and 3 to share the lifting load. The other three lifting conflicts were related to the Crane 4. Instead of adding a new crane, the TAM core team decided to enlarge the lifting capacity of Crane 5 from 20 tonnage to 50 tonnage so that it can share the lifting load of Crane 4. In addition, the working locations of Crane 4 and 5 were also adjusted to assure the lifting efficiency. Figure 6b illustrates the revised lifting plan for LNG Train 5.

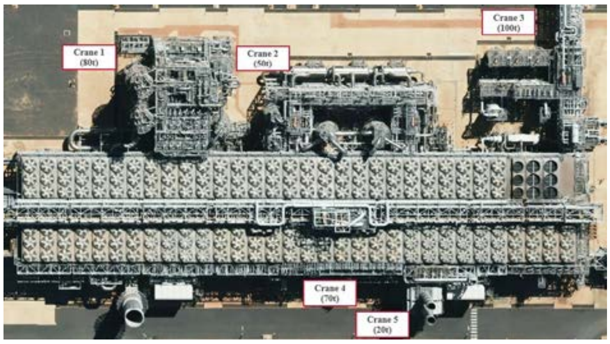

Figure 6a: The Original Lifting Plan for LNG Train 5

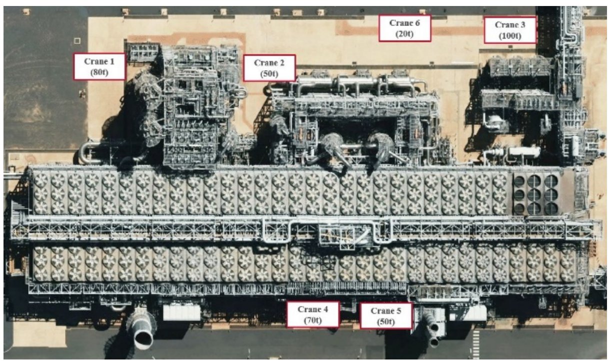

Figure 6b: The Revised Lifting Plan for LNG Train 5

The 4D BIM simulation on the batch level was developed by the TAM execution team, which visualises the sequence of all the activities involved including temporary jobs such as scaffold erection and dismantling (as shown in Figure 7). In order to improve site productivity and better focus on critical activities from stopping to restarting production, operations and maintenance teams were engaged at this stage to identify potential constructability issues and duration reduction opportunities. A cloud BIM platform (as shown in Figure 8) was also developed to allow people from other shutdown projects but has similar working experience to easily access this simulation and comment their ideas remotely.

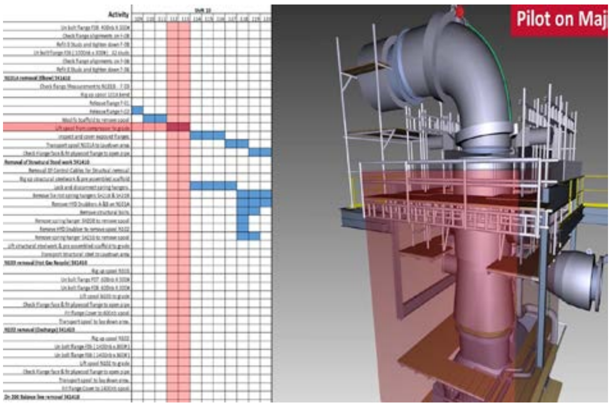

Figure 7: Screenshot of 4D BIM Simulation on the Batch Level

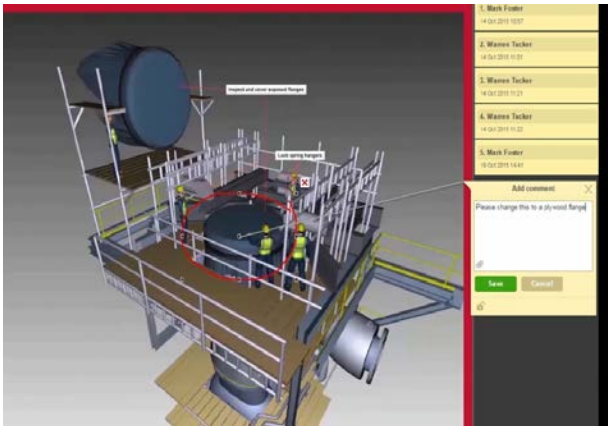

Figure 8: A Cloud BIM Collaboration Platform for Constructability Review

Figure 9 summarises the issues identified at this stage. A total of 104 issues were found by the TAM internal and external teams. These issues were further classified into eight categories, i.e. issues of Crane, Equipment & tools, Safety, Material, Work space, Permit, Activity Sequence, and Work front access. Incorrect activity sequence was the top one issue which accounted for 27% of the total issues. For instance, “This handrail is only installed once the steelwork has been removed”, “The scaffold should be modified first before removing the spool N101A”, “Remove spring hanger SH216 first before removing the spool”. Incorrect permit was the second most serious issues which accounted for 22%. TAM work requires extensive permits for every shift to ensure each work is performed safely. The plant engineering and operation teams contributed significantly on identifying these permit issues. For instance, they found that six activities were lack of appropriate permits, and another seventeen permits were incomplete and needed further development. Sixteen safety issues (i.e. 15%) and thirteen crane operation issues (i.e. 13%) were also detected through the Cloud BIM Collaboration Platform. The other three types of issues are work space (10%), work front access (9%), and equipment & tools (4%), respectively.

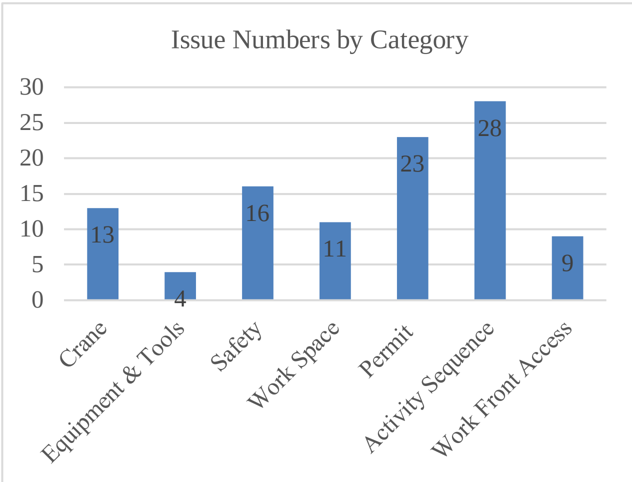

Figure 9: Issue Numbers by Category

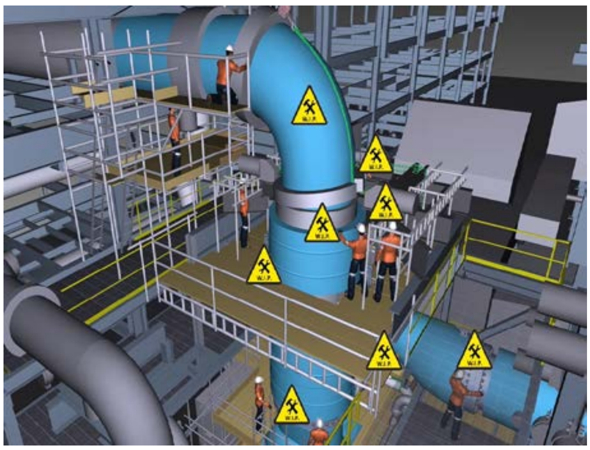

Figure 10: Screenshot of the 4D BIM Simulation on the Activity Level

Figure 10 illustrates the 4D BIM simulation on the activity level which takes account of maintenance work crews. At the peak, there are nearly 1000 people on site which creates a complex logistical task. In order to streamline the construction site work flow, locations and walking paths of each work crew were shown during the simulation, especially during those working periods that contain massive concurrent activities. Rigging plans were also visualised including shackles, turnbuckles, and slings being used.

4 Time and Cost Reduction Analysis

A quantitative analysis of the time and cost reduction is difficult because it should predict what would happen if the issues that detected by 4D BIM simulation are not resolved. Instead of directly calculating each issue effect, a previous equivalent TAM project that conducted two years ago was selected as a benchmark to measure the time and cost savings. The raw execution data of the selected case were extracted from the Document Retrieval Integrated Management System (DRIMS) (i.e. a type of corporate document management system) and SAP (i.e. an enterprise resource planning system).

Figure 11 illustrates the maintenance duration reduction. The left column with red colour indicates the actual duration of the valve replacement, i.e. 14 days. The planning of the current TAM project started from the previous one, and after the first two levels of 4D BIM simulation (i.e. Plant level and System level), the initial expected duration was adjusted to 13.5 days. Before the field execution, the TAM team set the project target duration to 12 days based on the results of the 4D BIM simulation on Batch and Activity levels. According to the final project report, this project was completed within 11.6 days.

Based on a rough comparison, the field execution work was finished 0.4 day (i.e. 9.6 hours) before the target schedule and 1.9 days ahead of the initial plan. When compared with the previous equivalent one, a total of 2.4 days were saved. Excellent results were also achieved on the health and safety front, such as: 50% reduction in minor first aid cases, no environmental incidents, no medical treatment incidents, and no high potential incidents.

For cost reduction analysis, considering the inflation and the changing prices for instruments procurement and equipment leasing, it is meaningless to compare the actual cost of the two TAM projects. Figure 12 illustrates the project cost estimated at three different stages: initial stage, pre-execution stage, and completion stage, respectively. The initial budget (i.e. AUD$ 24.1 million) was estimated based on the initial work list and estimated duration. The budget before field execution (i.e. AUD$20 million) was calculated based on the final confirmed construction schedule and resource plans. The actual cost for this TAM project was AUD$ 19 million according to the project completion report.

A total of AUD$ 4.1 million was saved when comparing the actual cost with the initial budget. Specifically, AUD$ 4.1 million cost reduction was achieved during the project planning phase while another AUD$ 1 million was achieved during the project execution phase.

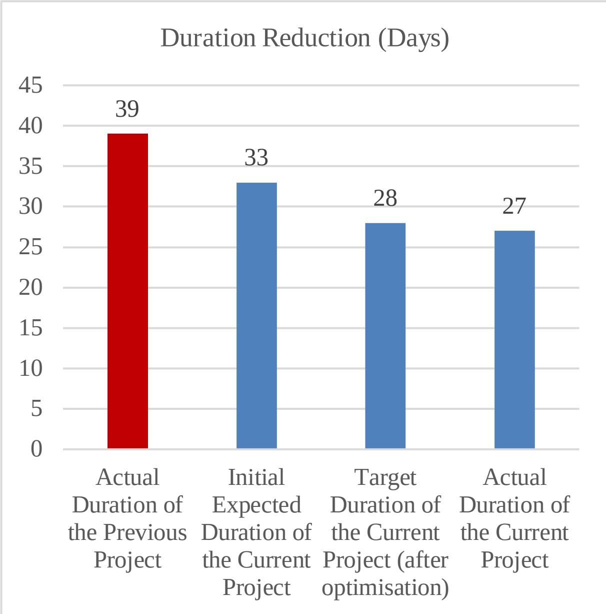

Figure 11: Duration reduction

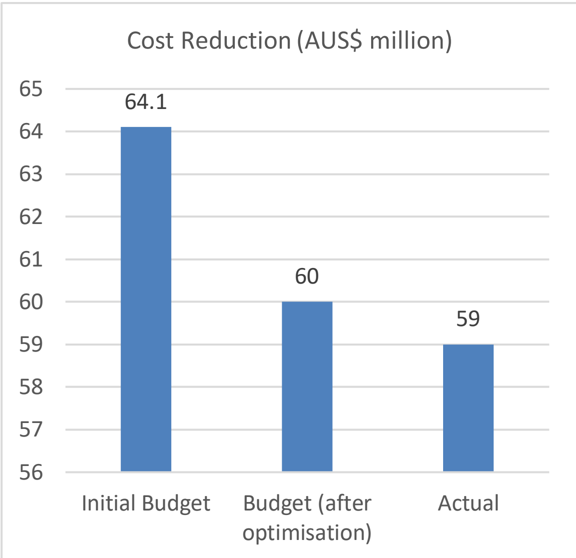

Figure 12: Cost reduction

5 Conclusions and Future Works

In this paper, a 4D BIM framework is developed for improving TAM process efficiency, which encompasses four different levels of BIM simulation, i.e. Plant, System, Batch, and Activity level. A real TAM project was selected to evaluate the effectiveness and efficiency of the proposed 4D BIM approach in waste elimination and time and cost reduction. The results show that: (1) the TAM project starts on time and finishes 0.4 day (i.e. 9.6 hours) before the target schedule and 2.4 days ahead of the original schedule; and (2) A total of AUD$ 4.1 million has been saved when comparing the actual cost with the initial budget. In the future, automated progress monitoring of planned activities will be investigated. Advanced technologies such as Ultra-Wideband [19], Photogrammetry [20], Laser Scanning [21], and Internet of Things [22] will be reviewed and tested in a plant turnaround environment for site maintenance activity tracking.

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