

Article

An Integration of Project Management Body of Knowledge and Project Management Information System to Improve On-time Deliverable of Liquefied Natural Gas Station Construction Projects

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Abstract. The objective of this study is to improve the liquefied natural gas station construction project to achieve on-time delivery. Diverse tools and techniques are integrated to make various interrelated activities in the project occur effectively as planned with less cost, suggested by the Project Management Body of Knowledge (PMBOK) guideline and the Project Management Information System (PMIS). To implement the PMIS along with the PMBOK, the project management software and Internet of Things (IoT) are utilized for real-time long-distance monitoring and control of the project. The proposed approach is implemented at a real demonstration project. The results reveal that the proposed approach is quite effective, which help increase the number of projects completed on schedule from 75% in the last year to 100% this year. Moreover, the implementation of the PMIS also results in substantial reductions in the employment allowance for routine site inspections and the travel expense for round-trip vehicles travelling from the company to the site.

Keywords: Liquefied natural gas station, construction project, project management, PMBOK, PMIS.

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1. Introduction

In 2021, the demand for Liquefied Natural Gas (LNG) in Asia accounts for more than 70% of global LNG imports [1], making Asia the largest LNG importer in the world. Since the case study company (called “the company” afterwards) is a fully integrated petroleum and petrochemical company in Thailand, it wants to become a regional LNG hub by using Thailand's competitive advantages, i.e., the established foundation for LNG infrastructure, the geographical location at the centre of the ASEAN region, and the continuously increasing average LNG consumption.

The company has engaged in various energy-concerned businesses, including investing in the construction of the LNG receiving terminal, exporting LNG to China by LNG carrier, and exporting LNG to Cambodia by LNG truck through the border. This case study focuses only on the business of the LNG station construction carried out by the company. The site of the construction project in which the supply of LNG is needed to fuel the production process is always located in the customer's factory. Often, the preliminary geographical investigation by the company indicates that the location of the factory is far from the existing natural gas pipeline. As a result, the construction of the natural gas pipeline from the factory to the existing natural gas pipeline is not worth the investment; hence, the factory is inevitable to acquire the company's service to build the LNG receiving station on its site.

Till now, the project engineering division of the company has constructed a total of six LNG station construction projects. Four projects have already been completed, while the other two are under construction in 2021. Among the completed projects, three of them (75%) are delivered to the customers (factories) according to the committed schedules, and one (25%) fails to do so.

The inability to deliver the LNG station as planned has urged all engineers in the project engineering division who are the owners to brainstorm and analyze all possible root causes of the problems. Based on the data collected from the four previously completed projects, the engineers categorize the causes of problems according to the guideline as recommended by the Project Management Body of Knowledge (PMBOK). The result is summarized in the Pareto chart, as shown in Fig. 1. It is evidenced that the causes of the problems are related to the problems as categorized by the PMBOK guideline in five aspects. The top rank problem concerns the lack of an effective project schedule management resulting from an inappropriate and/or incomplete listing of activities in the project, poor activity sequencing, inaccurate activity duration estimation, and improper project schedule development. Under an inefficient project schedule, critical activities in the project cannot be identified, which causes ineffective project risk management planning.

For project resource management, the lack of a Work Breakdown Structure (WBS), the hierarchical outline of the activities required to complete the construction project,

affects the ability to accurately estimate the manpower requirement for each activity. This domino effect causes a delay in the project delivery.

The project quality management is ineffective due to a lack of quality planning and quality control for each activity. Currently, the owner suspends the hiring of a project consultant to help monitor and supervise construction works at the site as in the past because the COVID-19 pandemic decreases the overall workload of the entire division. Instead, the current project quality management is operated through weekly meetings at the construction site to monitor all critical activities as well as the progress of the project.

The last cause is inefficient project integration management which is the combination of all aspects of the PMBOK guideline. This inefficiency occurs due to the lack of an effective Project Management Information System (PMIS) to use as a tool to monitor and control the progress of the project from the beginning to the end.

Based on the problems mentioned above, this study aims to improve the efficiency of the LNG station construction project management to deliver the project as planned. The tools and techniques from the PMBOK guideline and the application of the PMIS in project management are adopted to improve the project management process as a whole. Three project management software are utilized for different purposes, i.e., Microsoft Project, Trello, and Sitearound. In addition, Internet of Things (IoT) technology is also employed to facilitate real-time monitoring of the project, i.e., CCTV cameras and Bluetooth Beacon.

The subsequent sections of this paper are organized as follows. Section 2 presents the survey of literature related to project management. The research methodology is discussed in Section 3. Results obtained from the actual implementation at a demonstration project and conclusions are given in Sections 4 and 5, respectively.

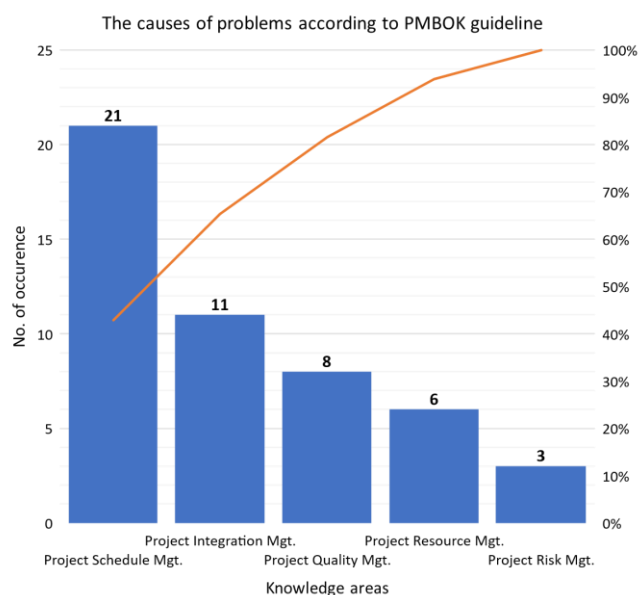


Fig. 1. The causes of problems according to the PMBOK guideline.

2. Literature Survey

2.1. Project Management in Construction Projects

Project management is the basis of any construction project, which ensures that the project is completed on time, on budget, and with acceptable quality. Each construction project may have its unique characteristics depending on the project's size, complexity, and type [2]. Regardless of which project is working on, the goal is to achieve all of its objectives. The sequence of the project from beginning to end is referred to as a project life cycle. There are four stages to a project's life cycle [3], i.e., 1. Starting the project, 2. Organizing and preparing, 3. Carrying out the work, and 4. Closing the project. The critical path method is commonly used to create a project schedule and to assist the project team in creating a timeline or Gantt chart. If any project activity on the critical path is delayed, the entire project will be delayed as well [4]. Construction project failure can be the result of schedule delays, cost overruns, or poor quality [5].

2.2. Project Management Body of Knowledge (PMBOK) Guideline

It is necessary to rely on appropriate knowledge areas in the implementation of project management to achieve the objectives. In the mid-twentieth century, the book was written to disseminate worldwide recognized project management knowledge. The "Project Management Body of Knowledge", or PMBOK, was published by the Project Management Institute [3]. Nutsiri et al. [6] adopted the PMBOK guideline as a technique to improve the project management process in a chemical plant. It involves the management of schedule, cost, quality and risk. The results show that this guideline works quite well, and the number of projects finished on time increased from 41% to 90%, compared to the previous year. The PMBOK guideline will be employed in this study to enhance project management process efficiency based on all applicable knowledge. The five areas of knowledge are listed below.

1. Project integration management - integrating project management tasks. This ensures that project progress is evaluated and monitored throughout the project so that the project objectives can be achieved [7]. The more complicated the project is, and the greater the stakeholder expectations are, the more important this knowledge becomes. The processes involved in this study include the following: 1. Developing a project charter to serve as information for communicating with project stakeholders and officially informing them of project details, and 2. Monitoring and controlling the project using a project management plan and PMIS.

2. Project schedule management - the process of developing a future schedule that is utilized as a guide for project execution [8]. The processes involved in this study include 1. Defining activities, 2. Sequencing activities, 3. Estimating activity duration, and 4. Scheduling the project with the critical path method.

3. Project quality management - the process of monitoring work quality through the use of quality control techniques [9]. The quality management plan is used in this study to identify the project's quality standards or specifications to control the project thoroughly.

4. Project resource management - the process of allocating resources such as manpower, permanent equipment, consumable materials, and so on to meet project goals within the schedule and budget constraints [10]. The processes involved in this study include 1. Estimating activity resources to estimate manpower demand, and 2. Controlling resources by tracking actual manpower versus planned manpower in the form of a histogram to ensure adequate manpower.

5. Project risk management - the process of identifying, evaluating, and responding to project risks [11]. The risk management plan is used in this study to reduce the potential risks and to respond to various risks that may arise during the project.

2.3. Project Management Information System (PMIS)

PMIS is a computer-based system that helps the project team plan, monitor, control, and report on the construction project more efficiently [12]. However, the use of PMIS is not a replacement for the project team's expert judgment, but it can be a tool that aids in more efficient decision-making on a variety of issues [13]. The following are the details of the PMIS application, which consists of project management software and the Internet of Things (IoT).

1. Project management software - the automated project management tools that help project teams plan, organize, and manage the resources that contribute to the project's objectives. With the growing number of project management software in the market, it is necessary to choose appropriate software for their project management needs [14]. Sharma and Pathak [15] proposed the Microsoft Project as a tool to create a work breakdown structure (WBS), schedule the project, assign manpower, identify critical paths, and track project progress. The findings revealed that the Microsoft Project helped enhance the project team in aspects of time and resource management efficiently. Kaur [16] proposed the Trello for hospital librarians to collaborate and manage a project efficiently. The Trello software is a cloud-based software that is available in a free version allowing users to create private or group boards using a list and card system. The Trello can track all project's activities by updating the progress or details using lists and cards that can be moved across the screen and located on one board. Singhaputtangkul et al. [17] developed the Sitearound as a cloud-based construction management software to assist project teams in managing project schedules, controlling project documents, and storing data in the cloud. More importantly, the Sitearound software can integrate with an IoT system, allowing the project team to monitor real-time valuable data.

2. Internet of Things (IoT) - a system of internet-connected objects that can transmit and receive data through cellular networks regarding changes in their current physical surroundings nearby them [18]. The four main components of an IoT system are 1. Sensors - a field device gathering data from the surrounding environment, 2. Gateway - transferring data to the cloud via various communication channels such as cellular networks, Wi-Fi, and so on, 3. Data analysis - once the data has been uploaded to the cloud, the software converts analogue data from sensors into useable data, and 4. User interface - the visible element of the system that users can access. Leung et al. [19] used a CCTV system as a site surveillance system. It was implemented on two construction sites. The findings revealed that the project team could monitor construction progress and manage work quality in real-time over the internet. A CCTV camera is a device that captures continuous video and transmits it by cable or wirelessly to the network video recorder (NVR), which is a recording device. An internet protocol camera (IP camera) is currently used because it can observe motion and manage the camera's view in real-time via a web browser or an Internet application. Dror et al. [20] used a Bluetooth Beacon system to track the location of resources in construction projects. One of the field experiments was conducted on a real construction site with Bluetooth Beacons connected to materials, equipment, and construction workers. Bluetooth Beacons can send signals to a Bluetooth gateway that is fixed in place. The data is then sent to the cloud via a cellular network, where the software compares the signal strength (formally known as "Received Signal Strength Indicator (RSSI)") of each beacon to determine the distance from a Bluetooth gateway, whether it is in the construction zone.

According to the previous literature review, most papers have attempted to improve project management with only a single project management tool or technique. By doing so, the big picture of the project may not be appropriately considered. To explain clearly, this paper is quite similar to the mentioned research papers, for example, a research paper from Nutsiri et al. [6] focusing on adopting the PMBOK guideline only without employing PMIS in the project. In addition, Sharma and Pathak [15] propose only Microsoft Project as a project management software without any PMBOK guidelines and an IoT system. However, the difference of this paper is to propose an approach that integrates all important aspects of the project management from the PMBOK guideline and the PMIS (including project management software and IoT system) to improve the project management capability in LNG station construction projects to achieve timely completion.

3. Research Methodology

The research methodology used in this paper is illustrated in Fig. 2 which is a flow diagram explaining the procedure sequence being done to achieve the research objective.

The proposed methodology consists of two main parts, including 1. The proposed method for improving the project management process, and 2. The IoT system is designed for project monitoring and control. The proposed methodology is implemented at the demonstration project (LNG station construction project in Thailand's Samut Sakhon province). The details of each part are given in the following subsections.

3.1. Proposed Method for Improving Project Management Process

As mentioned earlier, the causes of the problems are related to five aspects of the PMBOK project management guideline. Therefore, tools and techniques for improvement must be properly selected to enable the achievement of the project objectives. To improve the project management process from the beginning to the end, the owner has to focus on project monitoring and control through the use of the PMIS, i.e. project management software and IoT. The improved project management process can be shown in Fig. 3. The detail can be explained with the demonstration project in the next section.

3.2. IoT System Design for Project Monitoring and Control

The improvement of the new project management process is done by applying IoT to monitor and control the project. Two types of sensors are installed at the construction site, i.e., 1. CCTV cameras, and 2. Bluetooth Beacons. To install the IoT system at the construction site to effectively monitor and control the progress of the project, the equipment has to be properly designed, whose detail is as follows.

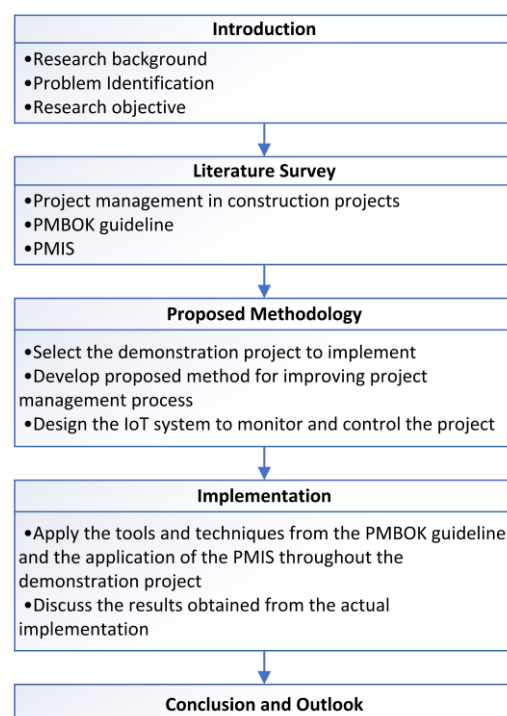


Fig. 2. Research methodology diagram.

3.2.1. CCTV system design

3.2.1.1. Conceptual design for the CCTV system

The design objective of the CCTV system to be installed at the construction site is for real-time monitoring of the project progress, which must be able to display on the Sitearound software.

It begins with gathering feedback from the owner and contractor to define exact zones on the actual construction site layout. Based on the comments gathered, it can be concluded that the installation of the IoT system at the construction site must not obstruct the equipment installation area and construction operations. The zones can be divided into four zones, as shown in Fig. 4.

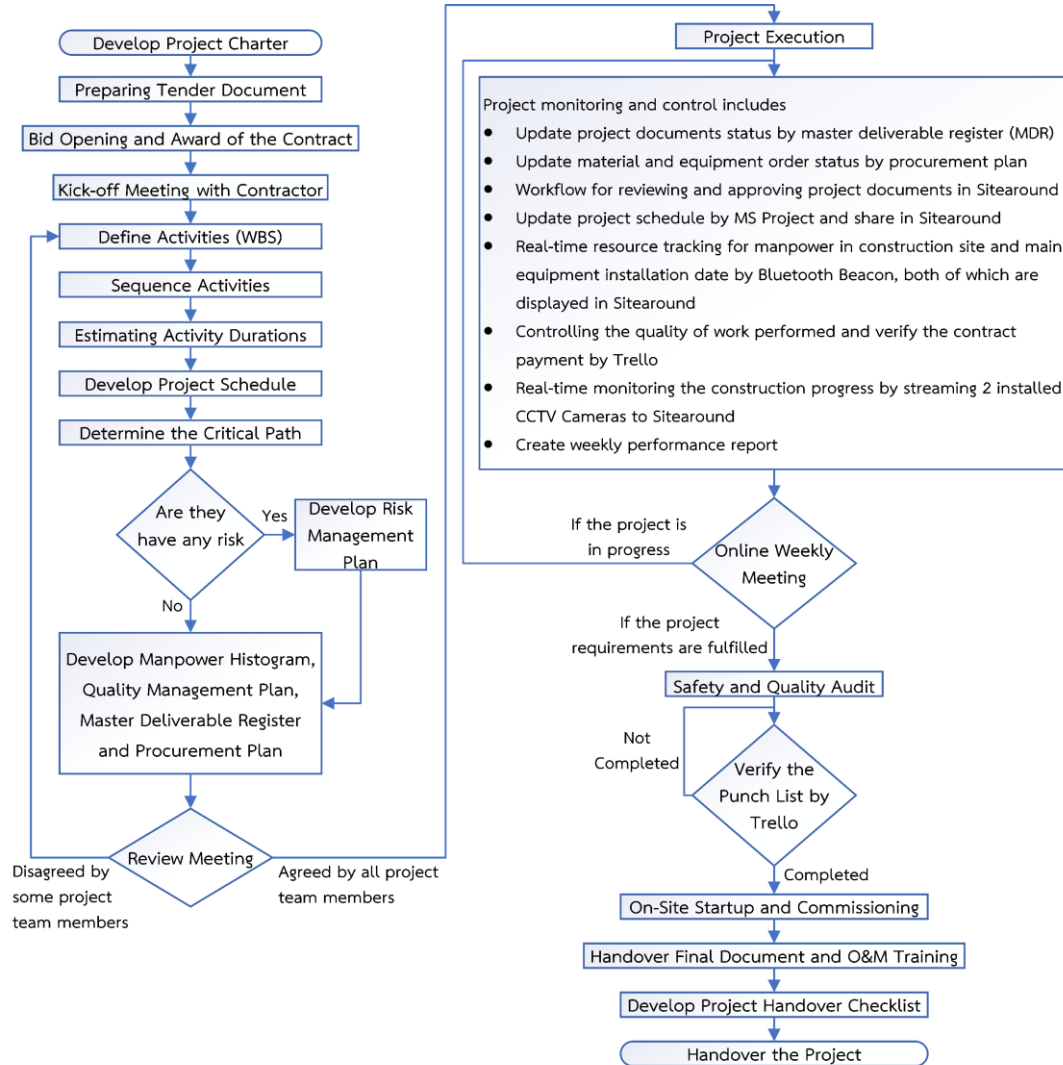


Fig. 3. Improved project management process.

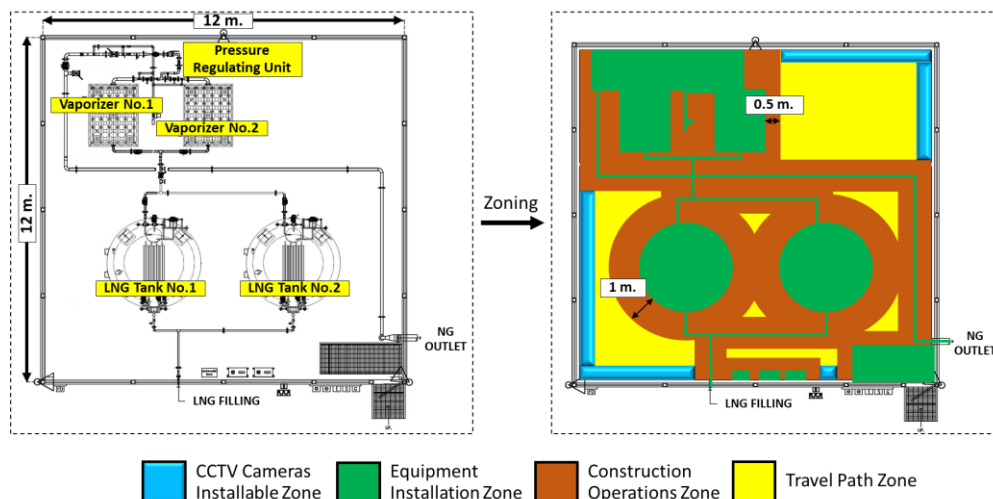


Fig. 4. Zoning of the actual construction site layout.

As shown in Fig. 4, four zones at the construction site are classified as follows.

1. CCTV cameras installable zone - an area that CCTV cameras can be mounted to the pole.
2. Equipment installation zone - an area for all equipment installations at the construction site.
3. Construction operations zone - an area for workers operation during construction that has a 0.5 m. radius around the equipment, except LNG storage tanks which have a 1 m. radius around the equipment.
4. Travel path zone - a vacant space that is generally utilized as a pathway for workers or for temporary equipment laid down during construction which does not obstruct any construction operations.

The CCTV cameras must be installed in a limited outdoor area and must be able to real-time record at night. Device compatibility is also necessary. As a result, the CCTV camera specification is defined according to the mentioned limitations with all seven attributes as follows.

1. The zone where CCTV cameras will be installed, as shown in Fig. 4, is relatively narrow and limited, so the camera lens must be the fisheye type. Choosing a lens with a narrow field of view will result in ineffective project monitoring and control. Fisheye lenses provide a panoramic view that encompasses the entire 360 degrees without any blind spots, allowing users to receive the most comprehensive view of the construction site.

2. It must have Infrared technology to produce clear images in full darkness (light intensity equal to 0 Lux) since it may be necessary to operate at the construction site from evening until late night to accomplish as planned.

3. Support Power on Ethernet (PoE) according to 802.3 of standard due to the limited space of the construction site. PoE is hardwired connecting between network video recorder (NVR) and CCTV cameras. It can transmit data and power simultaneously using only a single ethernet cable, making the installation process more flexible and easier.

4. Support Real Time Streaming Protocol (RTSP) for video streaming. Since CCTV cameras images are displayed on the Sitearound software in real-time, CCTV cameras need to support the RTSP protocol for establishing and controlling media between endpoints over the internet network.

5. Support Open Network Video Interface Forum (ONVIF), allowing CCTV cameras to communicate with NVR regardless of the same device manufacturer. In the case that the NVR is damaged during operation, a spare NVR of a different manufacturer can be utilized instead.

6. It must reach an Ingress Protection (IP) rating of 65 or above protection rating because the construction site is outdoor and may be exposed to wind or rain. As a result, CCTV cameras must be dust-tight and watertight. The first number, 6, denotes that the CCTV cameras are fully dust-tight. The following number, 5, indicates that the CCTV cameras can protect against low-pressure jets of directed water from any angle.

7. It must be able to work with ambient temperature from 43.5 degrees Celsius onwards. Because CCTV

cameras must be operated outdoor at all times, they must work properly when the temperature rises to at least 43.5 degrees Celsius. This is based on the Meteorological Department's highest climatic statistics in 2020 of Thailand, where the construction site is located.

3.2.1.2. Selection of the best CCTV cameras to use for project monitoring and control

For the selection of the best CCTV cameras to use for monitoring and controlling the construction project, the analytic hierarchy process (AHP) method is used for this decision making. The criteria are derived from the data collected from the questionnaire responded by six experts from the Project Engineering Division who are directly responsible for the construction project management. Therefore, they are regarded as the most experienced in the field. It is found that the important factors are price, warranty period, camera resolution, and company profile. In this regard, the alternative solutions are determined by selecting the CCTV camera that meets all mentioned specifications and is available for purchase in Thailand, namely CCTV Camera Brand A Model A1, CCTV Camera Brand B Model B1, and CCTV Camera Brand C Model C1. Fig. 5 shows the hierarchical structure of decision-making.

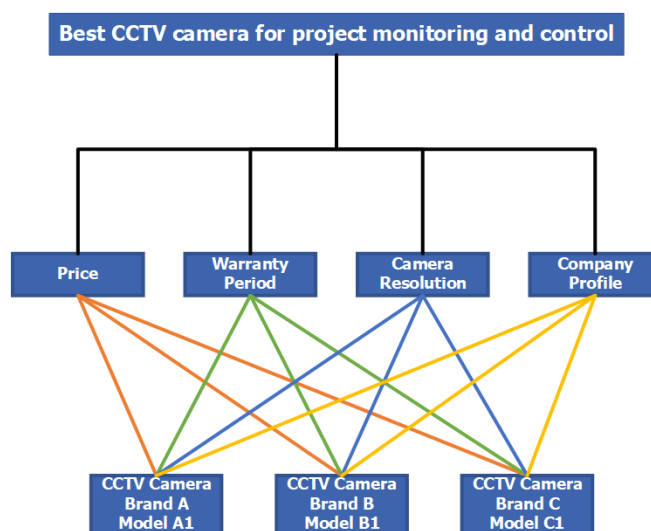


Fig. 5. The AHP hierarchical structure of the CCTV camera selection.

Next, the important assessment of the criteria from the questionnaire received from the experts are prioritized, as shown in Fig. 6. The result shows that the price is the most important criterion, with a relative importance of 0.439. The company profile comes second with a relative importance of 0.323. The third is the warranty period with a relative importance of 0.154. The fourth is the camera resolution, with the lowest relative importance of 0.084. The consistency ratio (CR) of the data obtained from questionnaires is less than 0.1, implying that all of the experts' pairwise comparisons that assign a score to each factor are consistent and reliable [21].

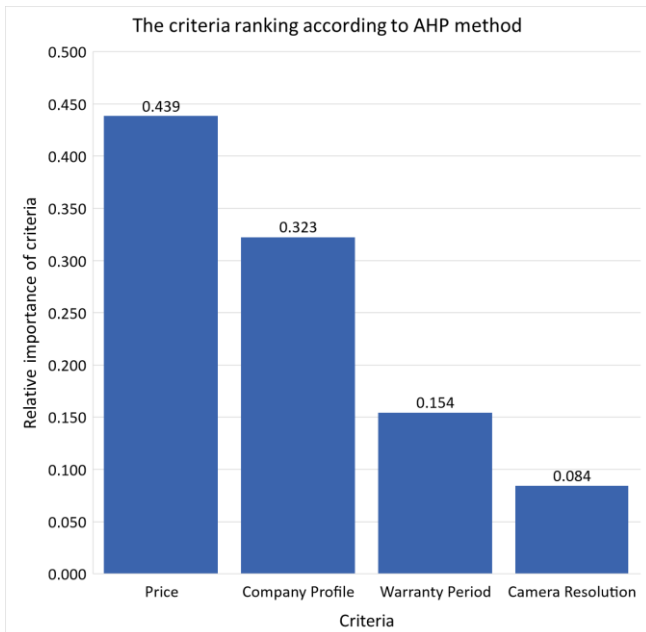


Fig. 6. The criteria ranking according to the AHP method.

Finally, the overall weights of alternatives are summarized by assessing the importance of each alternative obtained from the questionnaires of the six experts (as shown in Fig. 7). The CCTV Camera Brand B Model B1 is found to be in the first rank, with a weighted sum of 0.42. The CCTV Camera Brand A Model A1 comes second with a weighted sum of 0.36. The third is the CCTV Camera Brand C Model C1, with the lowest weighted sum of 0.22. This means that Brand B Model B1 can achieve better requirements than the others. As a result, CCTV Camera Brand B Model B1 is chosen due to its highest weighted sum.

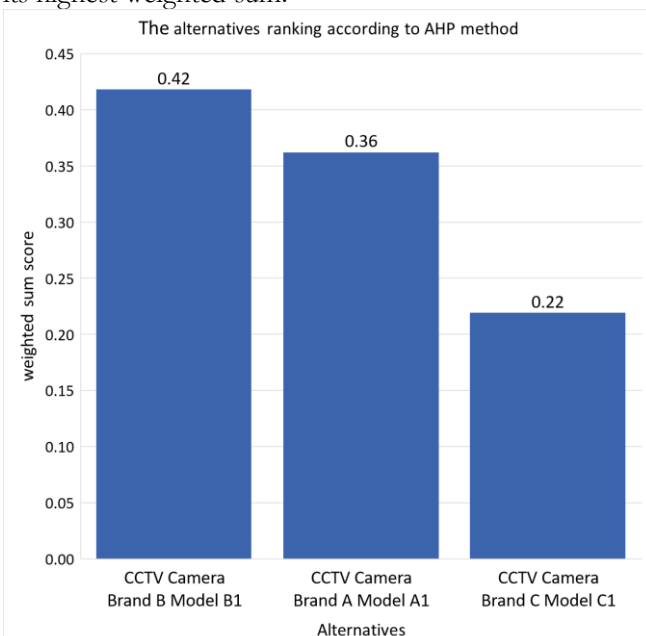


Fig. 7. The alternatives ranking according to the AHP method.

3.2.1.3. Simulation of the CCTV camera placement

After the completion of the CCTV camera selection, the next step is to use the IP Video System Design Tool

software to determine the camera placement, the number of cameras, and the height of the camera on the actual construction site. To find the best camera placement under specific conditions, different simulation models in 2D and 3D formats as well as the camera's visible and blind areas have to be investigated.

The opinions of the project manager in determining the criteria for selecting the CCTV camera placement at the construction site can be concluded as follows.

1. The camera's visible coverage must cover the construction site area as much as possible, which should not be less than 80% of the entire area.

2. The budget for the CCTV system should be as low as possible and must not exceed 30,000 baht.

3. The CCTV Camera installation must be mounted to a pole that is at least 4 meters above the ground. This is because various equipment, such as pipes or conduits, must be placed at the construction site during the operation. Because of its large size, such equipment requires a lot of space to move around. Therefore, placing the CCTV cameras at a low level may cause device damage or obstruct the construction operation. In addition, the placement of the CCTV cameras must be in the given zone where the CCTV cameras can be installed (as shown in Fig. 4).

The simulation of the CCTV camera placement using the IP Video System Design Tool software (as shown in Fig. 8) is based on the aforementioned criteria. This begins with importing an actual construction site layout from AutoCAD and scaling the layout. The next step is to develop a 3D model of the main equipment and structure to specify the camera's blind area, which is caused by parts of the main equipment and structure that block the camera view. The following step is to select the model of the CCTV camera to be used, namely Camera CCTV Brand B Model B1 from the software. Then, the height, quantity, and camera placement are set into the layout so that the software can simulate the camera's field of view.

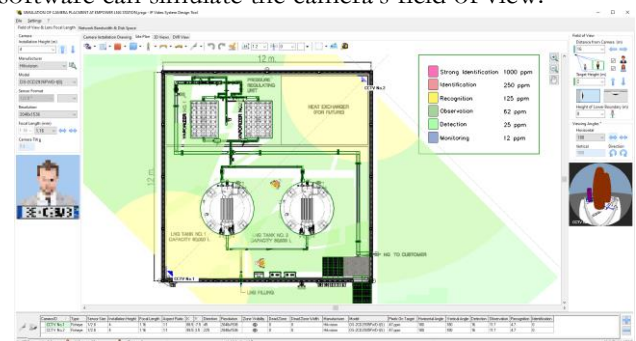


Fig. 8. IP Video System Design Tool software interface.

There are four potential alternatives to simulate the placement of CCTV cameras. The number of CCTV cameras in each alternative is varied from 1 to 4. The camera placement of each alternative is chosen by the highest camera's visible area. The installation must be in the zone where CCTV cameras can be installed at the height of 4 meters. Because the higher the CCTV cameras are placed, the lower the image resolution is due to the distance between the CCTV cameras and the visible object.

The costs of a CCTV system include CCTV cameras, poles, ethernet cable, NVR, and labour.

From the simulated placement of the CCTV cameras with IP Video System Design Tool software, all four alternatives can be summarized as shown in Fig. 9. It is shown that alternative A has a camera's field of view of 68.15%, which is lower than the mentioned criteria. As such, alternatives B, C, or D are selectable since they can reach a field of view over 80%. However, alternatives C and D have higher installation costs than the mentioned criteria (not exceeding 30,000 baht). It can be inferred that the best-suited camera placement is alternative B, which has a cost of 27,600 baht. This alternative is considered to be the most appropriate under the specified conditions.

Furthermore, when comparing the installation cost and the field of view of the CCTV camera in each alternative to determine the cost-effectiveness, it is found that alternative B has a visible area of 22.60% more than alternative A, with a higher installation cost of 12,400 baht. Alternative C has a 4.15% larger visible area than alternative B; however, the installation cost is higher at 14,600 baht. It is found that there is a nonlinear relationship based on the data mentioned above, as shown in Fig. 10. When comparing installation cost and the camera's field of view, it is concluded that alternative B is the most cost-effective one.

Moreover, the 3D simulation of 2 CCTV cameras view in alternative B is shown in Fig. 11 (a) and (b).

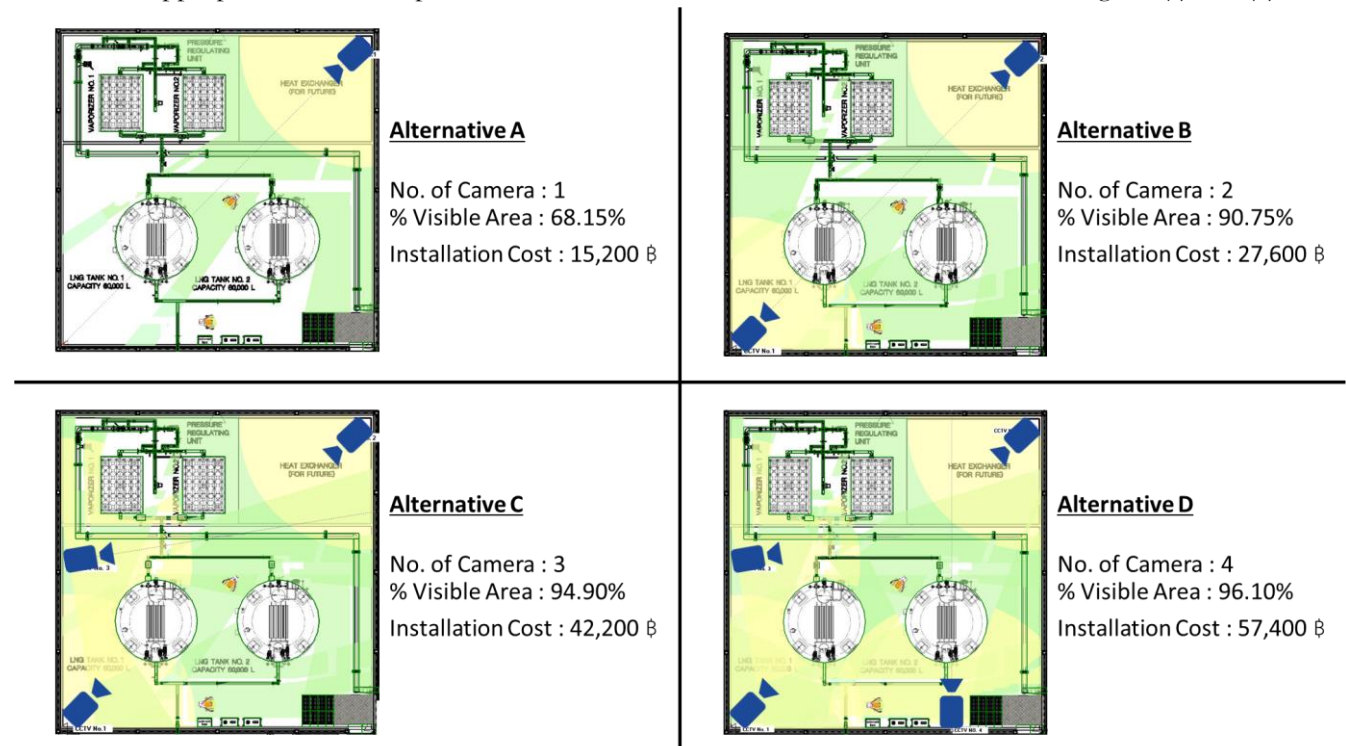


Fig. 9. Results of the CCTV camera surveillance in each alternative.

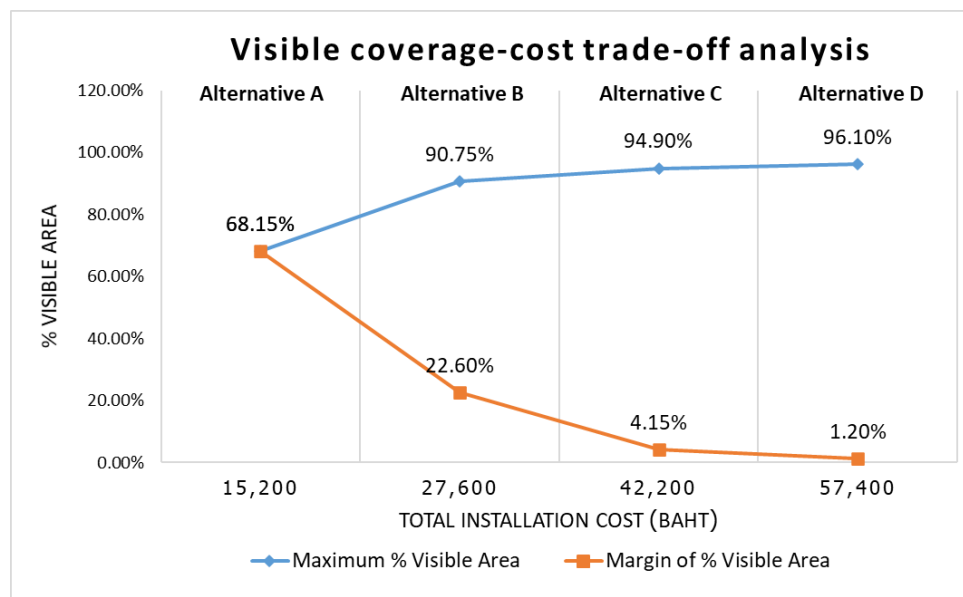


Fig. 10. Visible coverage-cost trade-off analysis.

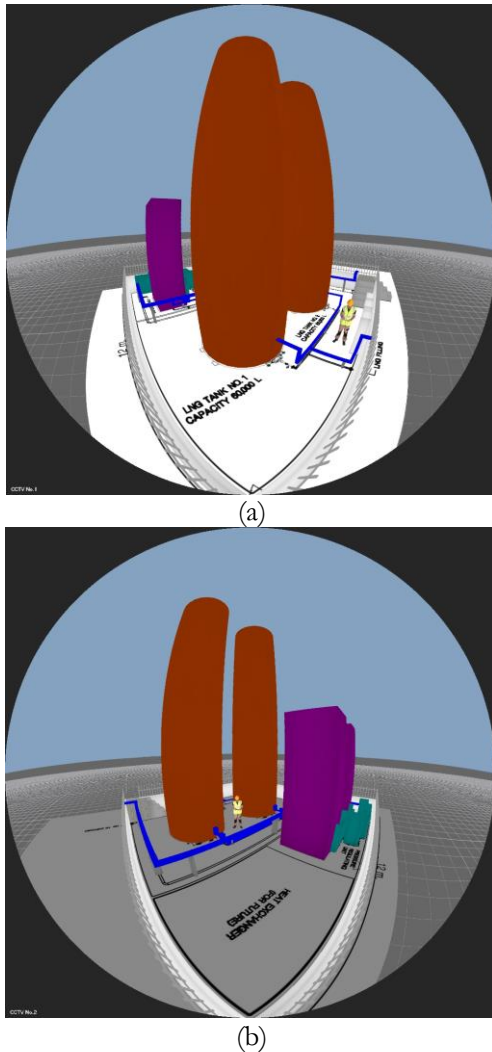


Fig. 11. The 3D simulation of 2 CCTV cameras view in alternative B: (a) Camera No.1, and (b) Camera No.2.

3.2.2. Bluetooth beacon system design

3.2.2.1. Conceptual design for the bluetooth beacon system

The Bluetooth Beacon system installed at the construction site is designed to track the status of project resources that appear at the site in real-time. This covers the status of manpower as well as the main equipment on the construction site. The resource's tracking zone covers the whole area of the construction site. If the RSSI value transmitted from any Bluetooth Beacon exceeds the RSSI threshold value, the Sitearound software will display these active Bluetooth Beacons as the active project resources.

Before each construction worker enters the site each day, the foreman will distribute a Beacon card with a neck strap to the worker to hang while working. This allows real-time tracking of manpower at the construction site. The Beacon card must also be returned to the foreman after work. This information can be used to compare with the planned manhours in the form of the manpower histogram. The project applies an analogous estimation to prepare the number of Beacon cards. The analogous estimation is the technique that uses the number of

workers who worked on the projects in the past as information for estimating the number of workers needed at present [3]. The maximum number of daily workers for this project is 16, including the foreman. Thus, 16 Beacon cards must be provided. Each Beacon card is named in the Sitearound to identify the individual construction worker, as shown in Table 1. Before moving the main equipment to install at the construction site, Beacon tags are attached to the main equipment structure to track the actual installation date in real-time. This information can also be used to compare to the plan. Each Beacon tag is named in the Sitearound to identify the main equipment, as shown in Table 2. The conceptual design of the Bluetooth Beacon system to be installed at the construction can be displayed in Fig. 12.

Table 1. Naming the Beacon card to identify the construction workers.

Beacon Card No.	Designated Beacon's Name
1	Foreman
2	Worker No.1
3	Worker No.2
4	Worker No.3
5	Worker No.4
6	Worker No.5
7	Worker No.6
8	Worker No.7
9	Worker No.8
10	Worker No.9
11	Worker No.10
12	Worker No.11
13	Worker No.12
14	Worker No.13
15	Worker No.14
16	Worker No.15

Table 2. Naming the Beacon tag to identify the main equipment.

Beacon Tag No.	Designated Beacon's Name
1	LNG Storage Tank No.1
2	LNG Storage Tank No.2
3	Vaporizer No.1
4	Vaporizer No.2
5	Pressure Regulating Unit

3.2.3. Results of IoT System for Project Monitoring and Control

From the IoT system design to be implemented for project monitoring and control, which consists of two systems, i.e., CCTV system and Bluetooth Beacon system, the final system architecture is shown in Fig. 13.

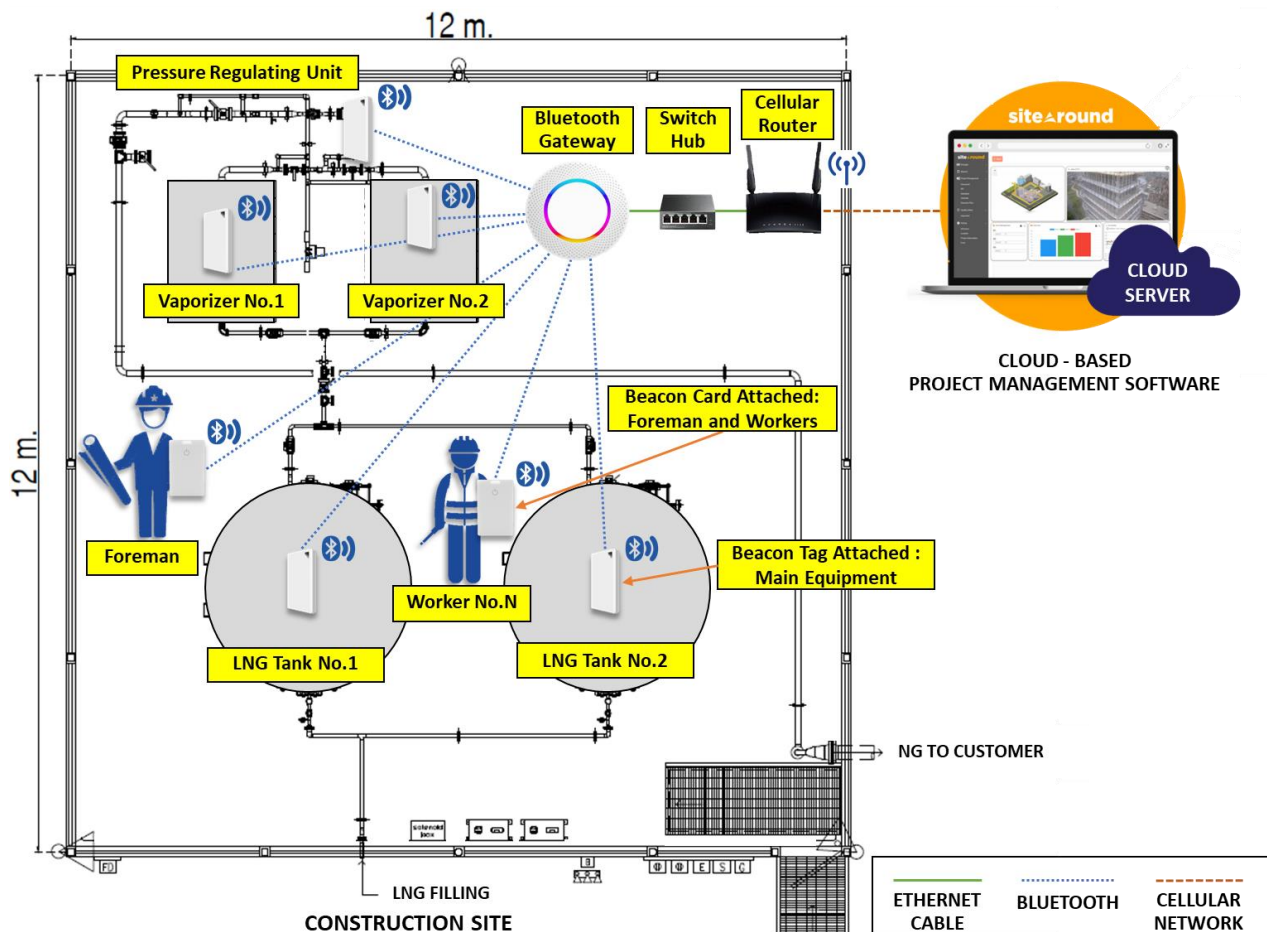


Fig. 12. The conceptual design of the Bluetooth Beacon system.

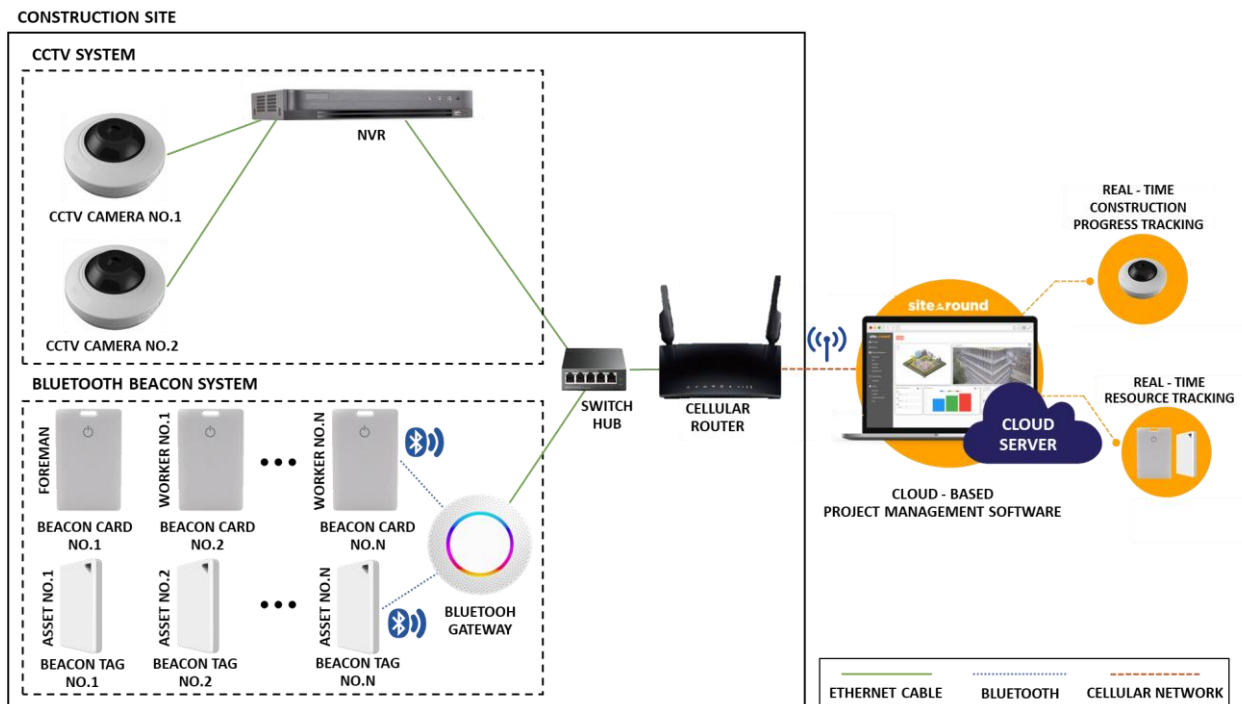


Fig. 13. The system architecture of the IoT system that implemented in the construction site.

4. Results from the Implementation

The previously mentioned project management process leads to the implementation at the case study demonstration site, detailed as follows. According to the PMBOK guideline, the project life cycle is divided into four phases. The first phase is project initiation. This phase starts after the investment is approved by the meeting of the company executives to proceed with the project charter. The project team meeting is conducted to formally notify the project scope. By doing so, the project team may identify potential constraints and resources needed so that the project sponsor can support the project as efficiently as possible. After the approval of the project charter, the tender document is prepared by the owner to hire the contractor. After that, a kick-off meeting is held to officially provide the information of the project between owner and contractor. This meeting is scheduled to introduce the project team and explain the scope of work, project constraints, project milestones, as well as provide training on how to use project management software and IoT as a tool for project monitoring and control.

The second phase involves the organizing and preparing of the project plan. The required information is collected after the kick-off meeting to develop a project management plan before executing the project. This starts with a list of activities that will be occurred in the project, which will be divided to cover the scope of work. First, the activities are divided into different broad work areas, i.e. 1. Engineering, 2. Procurement, 3. Construction, and 4. Project closeout. Next, these work areas are subdivided into smaller activities using the decomposition technique. The outcome is an activity list that identifies the work breakdown structure (WBS) in the project. After that, the WBS is sequenced to identify relationships among the project activities. It shows that all activities have a finish-to-start relationship, which means that the successor activity cannot begin until the predecessor activity has been completed [22].

Next, analogous estimating is used to estimate the duration and manpower needed for each activity. Analogous estimating is the technique that analyzes data from comparable historical projects to estimate the parameters of the current project [3]. Due to differences in the project's complexity, some parameters have to be adjusted to make them more realistic and meet the project's objectives. Finally, all mentioned information is used to develop a project schedule through the Microsoft Project, as well as the critical path of the project to determine which activities should be prioritized (critical activities). If some activities on the critical path are delayed, the project's delivery date will be delayed as well. Because most of the project's activities are on the critical path, a risk management plan is developed to mitigate potential risks associated with critical activities through risk identification, risk evaluation, and risk control. Risk identification is obtained from the brainstorming of the project team to find potential risks that may affect the

project quality, cost and delivery. Risk evaluation is then conducted by applying the risk assessment matrix to assess the level of risk by measuring the impact level and the likelihood to happen. From the risk assessment, it is found that the delay of main equipment delivery is the highest risk of this project. Therefore, risk control must be managed by risk mitigation to track the status of the procurement orders and deliveries of main equipment from the contractors. This can be done by using the procurement plan. The Bluetooth Beacon is used to display this information on the Sitearound to track the date of main equipment installation at the construction site in real-time. Moreover, other project risks must be addressed in the risk mitigation as well.

Next, a manpower histogram is developed to compare the planned and actual daily manpower requirement. This is focused only on the construction site to ensure that a sufficient workforce is prepared as given by the schedule. The quality management plan is then created to identify which activities must be quality controlled to meet the quality standards or project specifications that are defined in the term of reference (TOR). Various quality tasks are used to control the work in compliance with acceptance criteria. The next step is to develop a master deliverable register (MDR) to keep tracking of all project documents received from the contractors. The MDR can be classified into three statuses:

1. Issue for information (IFI) - for project documents that are intended to inform the owner only, including material certificate, construction report, and operation & maintenance manual.
2. Issue for approval (IFA) - for project documents that must be reviewed and approved by the owner before the construction is proceeded, including construction work procedure, engineering design & equipment sizing, equipment specification (datasheet), and construction drawing. After getting the approval from the owner, its status is changed to approval for construction (AFC).
3. Approval for construction (AFC) - for project documents that have already been approved for further construction.

The next step is to develop a procurement plan to track the contractor's order status for materials and equipment needed in the construction. The status is categorized as an issue of purchase requisition (PR), a purchase order (PO) or delivery. Finally, there is a meeting to discuss the project management plan that is developed to meet the project objectives. If any project team members disagree with the plan, it is necessary to make some adjustments and schedule another review meeting. The approved plan is utilized as a baseline for monitoring and control throughout the project if all project members agree.

The third phase is carrying out the work. After the project management plan is established, the next phase is project execution. The project management software and IoT are applied during the week to monitor and control the project. The process can be summarized as follows.

- Weekly updates project documents status through the MDR and material and equipment order status through the procurement plan. Sample forms of these plans are shown in Fig. 14 and Fig. 15, respectively.
- Main contractors initially create submittals to the owner to review and approve the shop drawings, material or any other related documents. Then approved submittals are distributed to the subcontractor. This online approval workflow is to ensure if the information meets project scope and project specifications by using the Sitearound before executing. Fig. 16 depicts the process.
- Weekly updates the project schedule using the Microsoft Project and share it in the Sitearound so that all project teams are aware of the critical activities and can compare between baseline and actual work progress as shown in Fig. 17. This tool helps to remind the project team of project delays so that they can catch up on the project.
- Real-time resource tracking is used for two purposes, i.e., 1. to track actual daily manhours in a construction site with Bluetooth Beacon attached to workers' bodies. This information can be compared to the planned daily manhours in the form of a manpower histogram and see if the manpower lacking exists, and 2. to track the actual main equipment installation date with Bluetooth Beacon attached to the main equipment's structure, which can be compared to the plan to see if there are any delays as illustrated in Fig. 18 (a) and (b).
- Use the Trello software to control the work quality in real-time by creating a project board and then categorizing project tasks into three lists (i.e., to do, in progress, and done). These lists include six cards containing all contract payments and correction of the punch list as shown in Fig. 19 (a). Each card contains a work package checklist based on the project's WBS to evaluate the scope's completeness, as well as a work quality checklist, which refers to the quality management plan, to ensure that work fulfils project specifications. Once the contractors have completed any tasks, they can deliver them to the owner along with photos or construction reports. If any payment is complete in terms of scope and quality approved by the owner, the contractor can issue an invoice by printing this card as a supporting document, as shown in Fig. 19 (b).
- Real-time construction progress tracking by streaming two installed CCTV cameras to the Sitearound for monitoring the actual progress of construction activities. Past activities can be viewed using the playback feature of the CCTV cameras, as shown in Fig. 20. Moreover, observing real-time construction activity can help the owner in detecting problems early on, allowing for timely corrective actions.
- Prepare weekly performance report to summarize the progress of the project by referring to all stated information technology, as shown in Fig. 21.

Each week, an online meeting is held to discuss the project's progress and obstacles that arise throughout the project execution and find appropriate solutions to achieve the on-time project's completion. At the end of the meeting, all updated issues are summarized in the meeting minutes and forwarded to the project team, who will follow up on those issues again the following week.

The last phase is the ending of the project. When the construction is completely done, the company's internal department conducts a safety and quality audit of the project. The contractor is then given a punch list, which is a list of tasks that must be completed before a project is officially closed out and final payment is made. the Trello is used to track the proposed correction with a card, namely Punch List Correction, which provides the details on the subjects that have to be corrected in the checklist with deadlines. Within the stipulated timeframe, the contractor must correct the punch list and submit documentation such as photos or reports to the owner for review and approval. After receiving the approval, the contractor performs a startup and commissioning, deliver the final document, arrange operation & maintenance (O&M) training for customers on the construction site, and prepare a project handover checklist to confirm that the scope of work is fully complete before delivering the project to the customer as shown in Fig. 22.

MASTER DELIVERABLE REGISTER (MDR)									
Project : LNG STATION OF EMPOWER STEEL CONSTRUCTION PROJECT								Rev. : A	
Owner : PTT PUBLIC COMPANY LIMITED									
Contractor : POLYTECHNOLOGY COMPANY LIMITED								Date : 04/02/21	
Status : <input type="checkbox"/> = Planned Date <input type="checkbox"/> = Actual Date									
Document No.	Document Title	Rev.	IFI	IFA	AFC				
	Construction Work Procedure								
PR-ME-EPWS-001	Piping Fabrication & Installation Procedure		-	-					
PR-ME-EPWS-002	NDT Procedure		-	-					
PR-ME-EPWS-003	Nitrogen Purging Procedure		-	-					
PR-ME-EPWS-004	Painting Procedure		-	-					
PR-ME-EPWS-005	Cool Down & First Fill Procedure		-	-					
PR-ME-EPWS-006	Startup & Commissioning Procedure		-	-					
PR-IE-EPWS-007	Instrument Calibration Procedure		-	-					
PR-IE-EPWS-008	FAT Procedure for MDB & Control Panel		-	-					
PR-IE-EPWS-009	SAT Procedure for MDB & Control Panel		-	-					

Fig. 14. A sample form of the MDR to update project documents status.

PROCUREMENT PLAN						
PROJECT : LNG STATION OF EMPOWER STEEL CONSTRUCTION PROJECT						Rev. : A
OWNER : PTT PUBLIC COMPANY LIMITED						
CONTRACTOR : POLYTECHNOLOGY COMPANY LIMITED						Date : 04/02/21
Status : <input type="checkbox"/> = Planned Date <input type="checkbox"/> = Actual Date						
No.	Material Description	Qty	PR	PO	Delivered	
1.	Main Equipment					
1.1	LNG Tank 60,000 L.	2 Set				
1.2	LNG Vaporizer 700 kg/hr.	2 Set				
1.3	Pressure Regulator	2 Ea				
2.	Sub-Equipment					
2.1	Safety Equipment					
2.1.1	Alarm Unit	1 Lot				
2.1.2	ESD Break Glass (Ex)	1 Lot				
2.1.3	Gas Detector	1 Lot				

Fig. 15. A sample form of the procurement plan to update material and equipment order status.

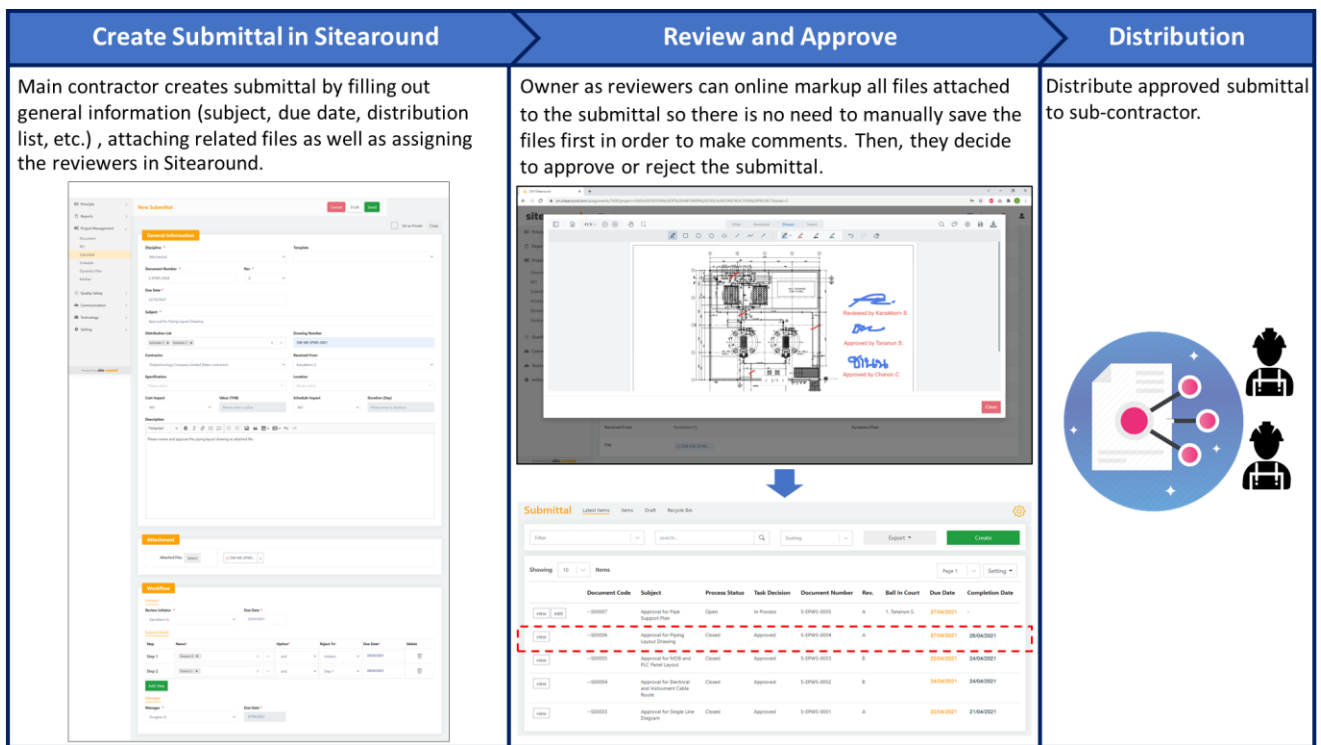


Fig. 16. The project documents approval workflow using the Sitearound.

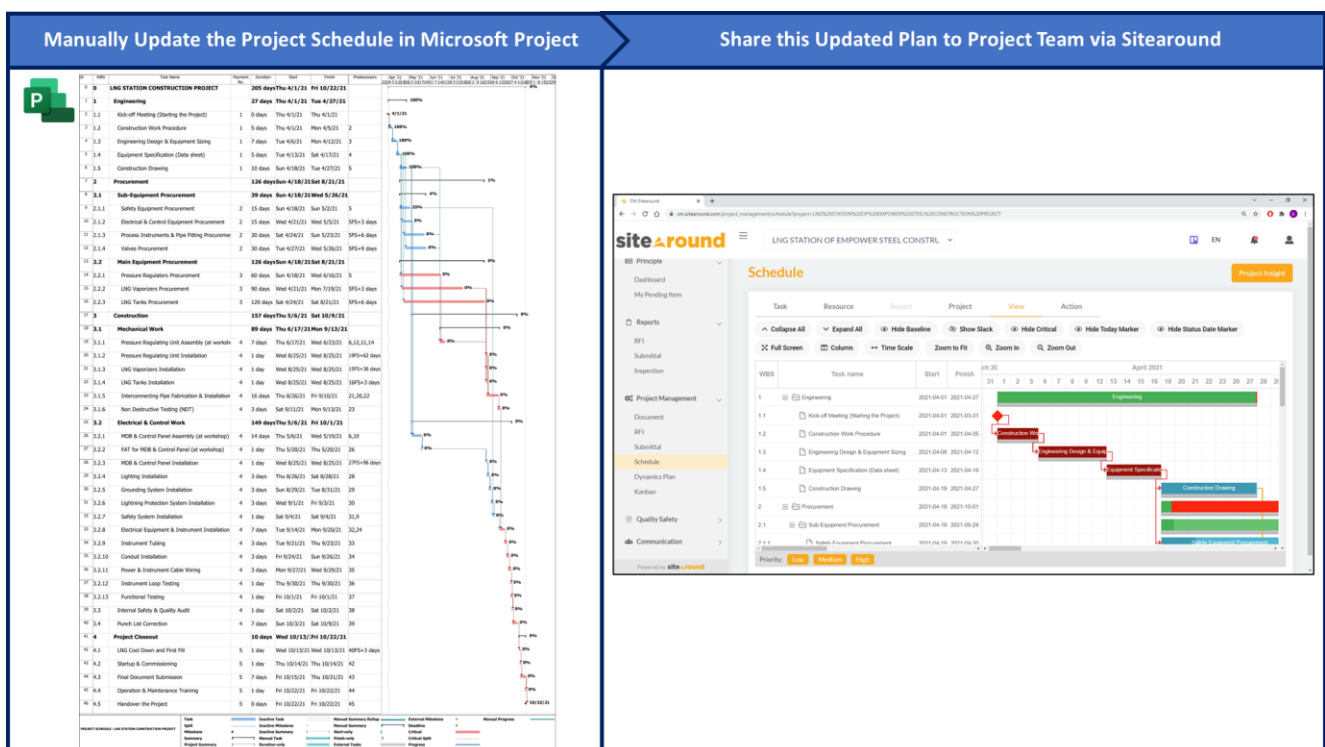
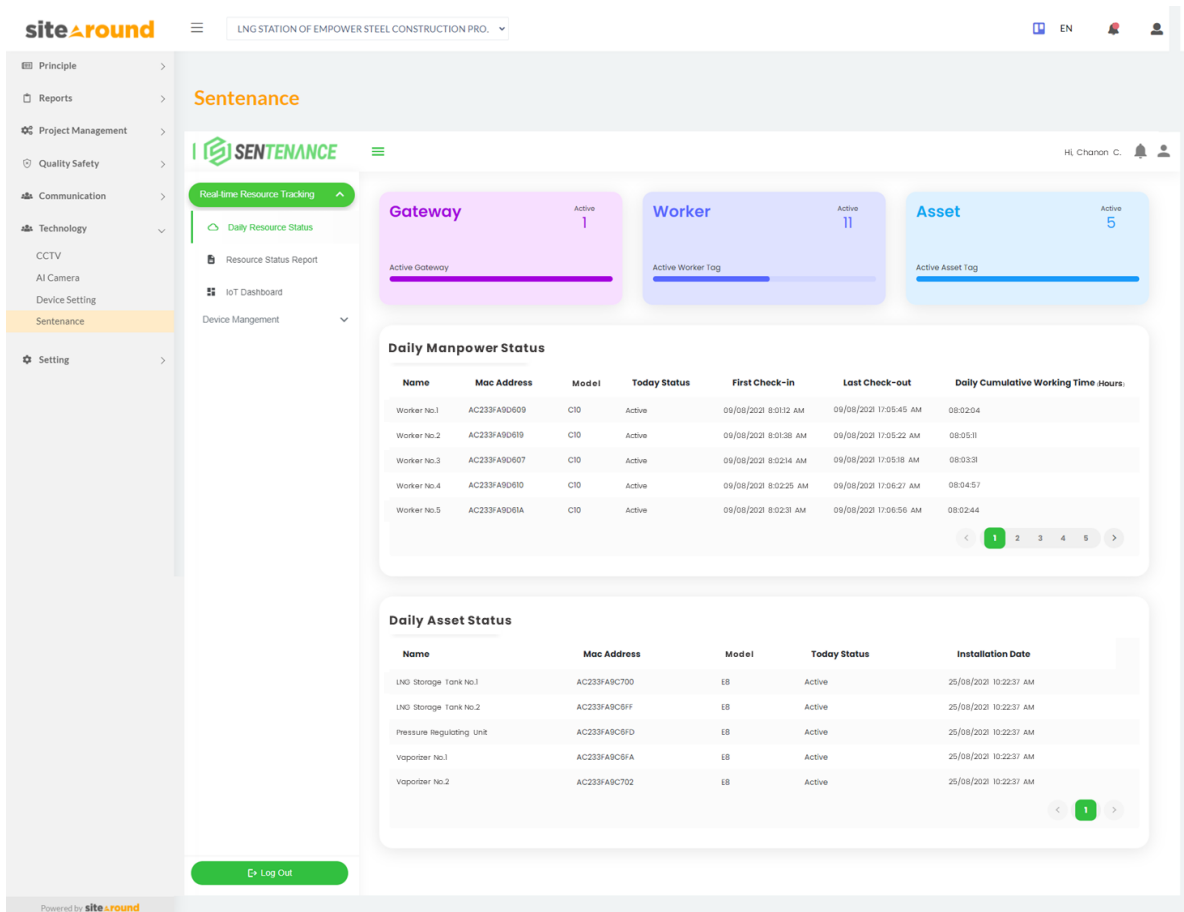
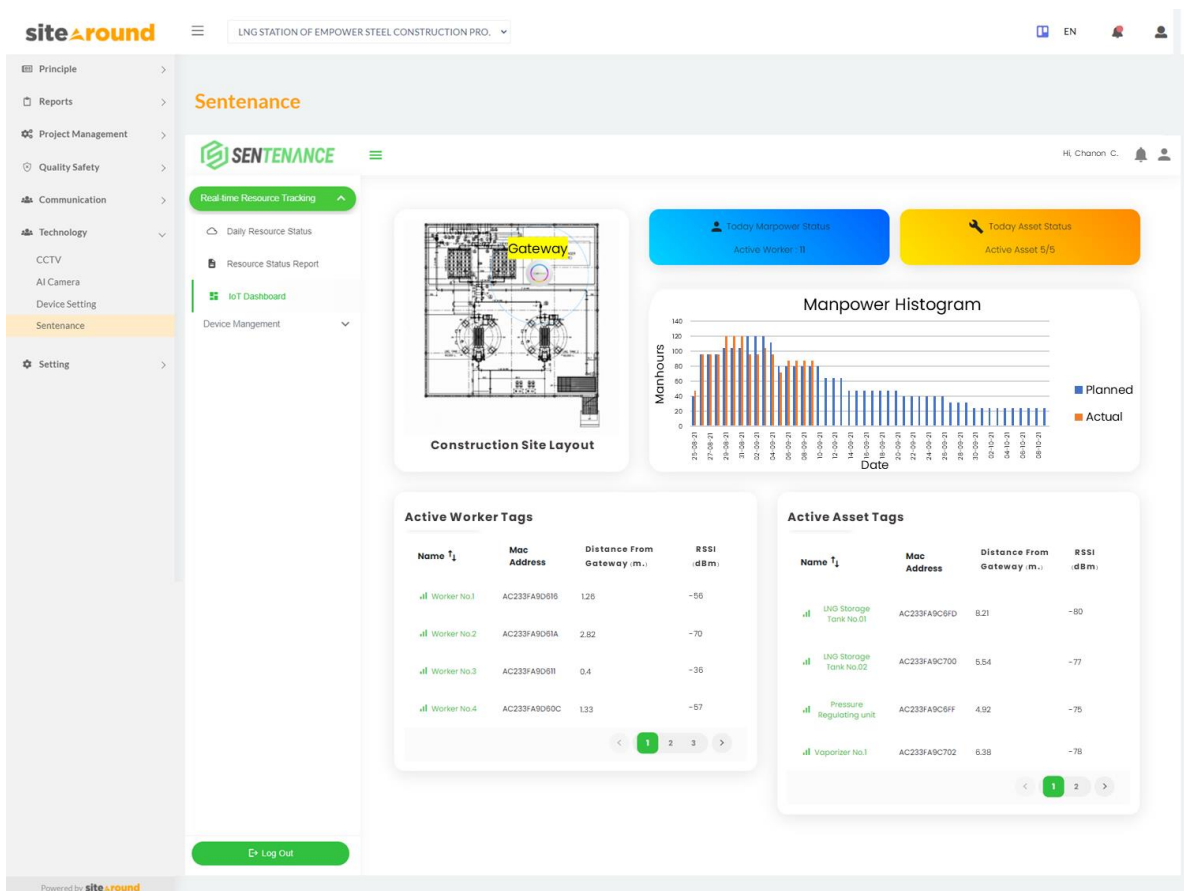


Fig. 17. The updated project schedule was shared via the Sitearound software.

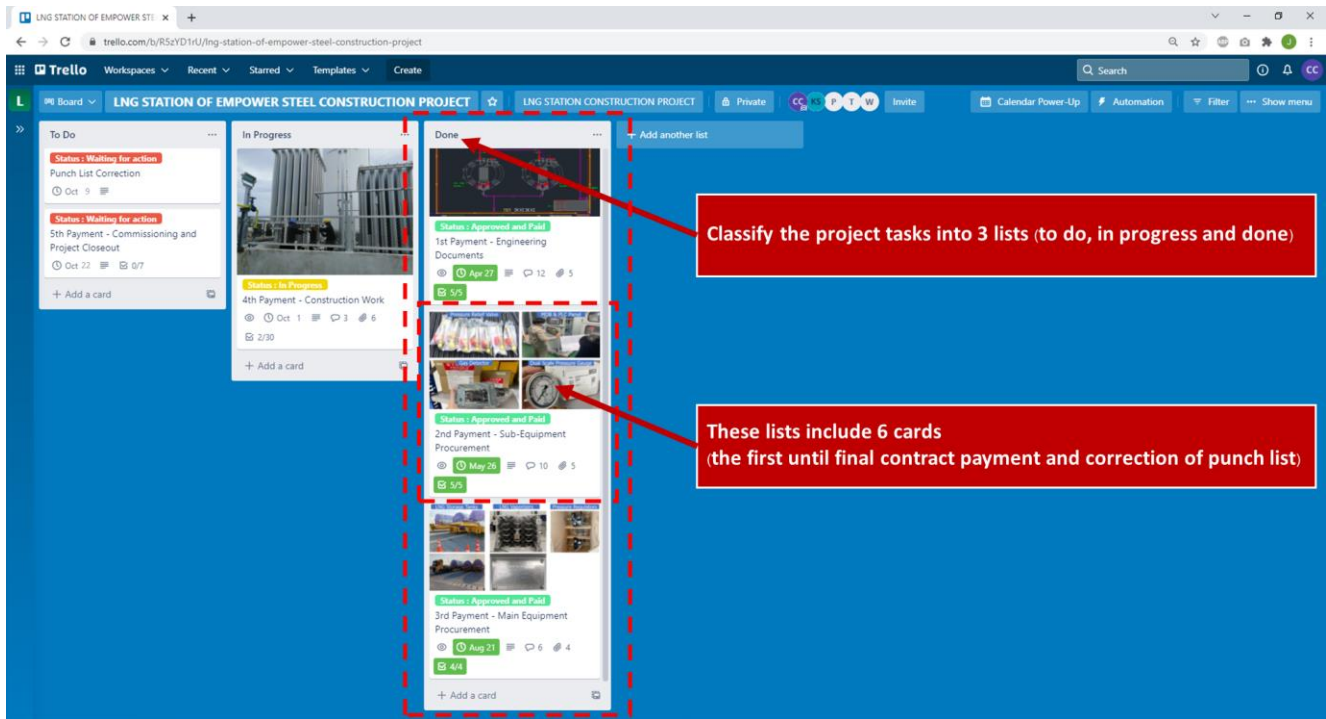


(a)

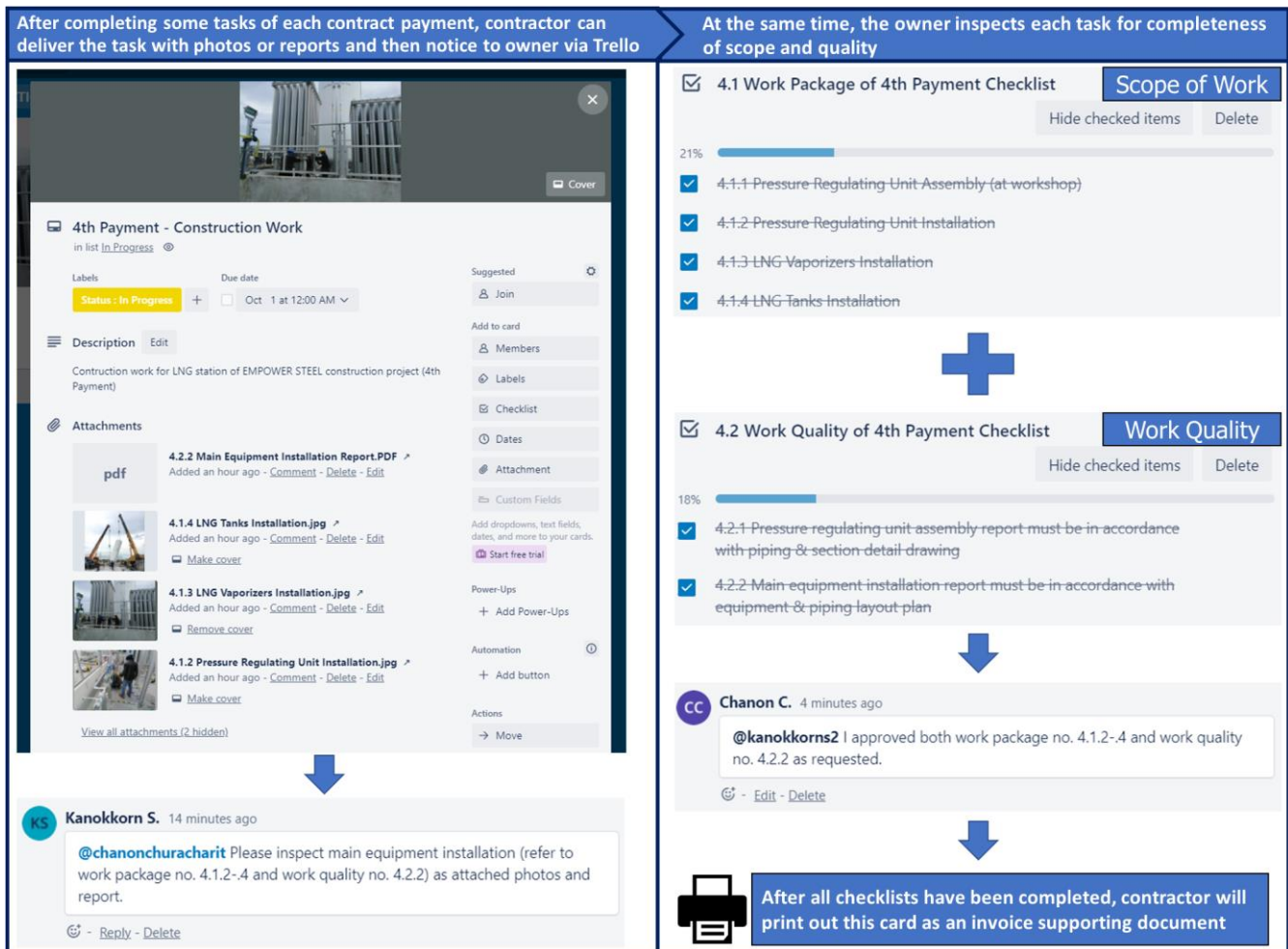


(b)

Fig. 18. Real-time resource tracking by Bluetooth Beacons displayed on the Sitearound: (a) Daily status of project resources, and (b) Manpower histogram.



(a)



(b)

Fig. 19. Real-time controlling the work quality using the Trello software: (a) Lists and cards for controlling the work quality, and (b) Inspection process.

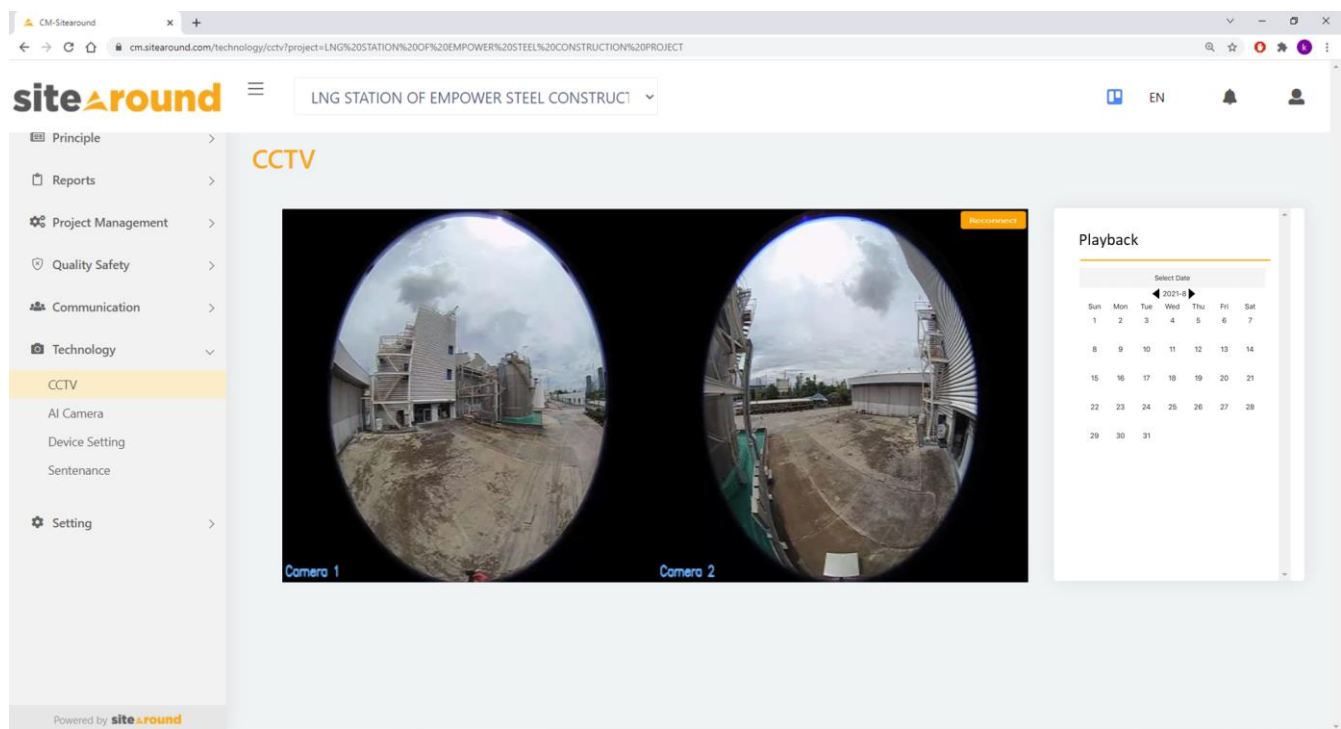
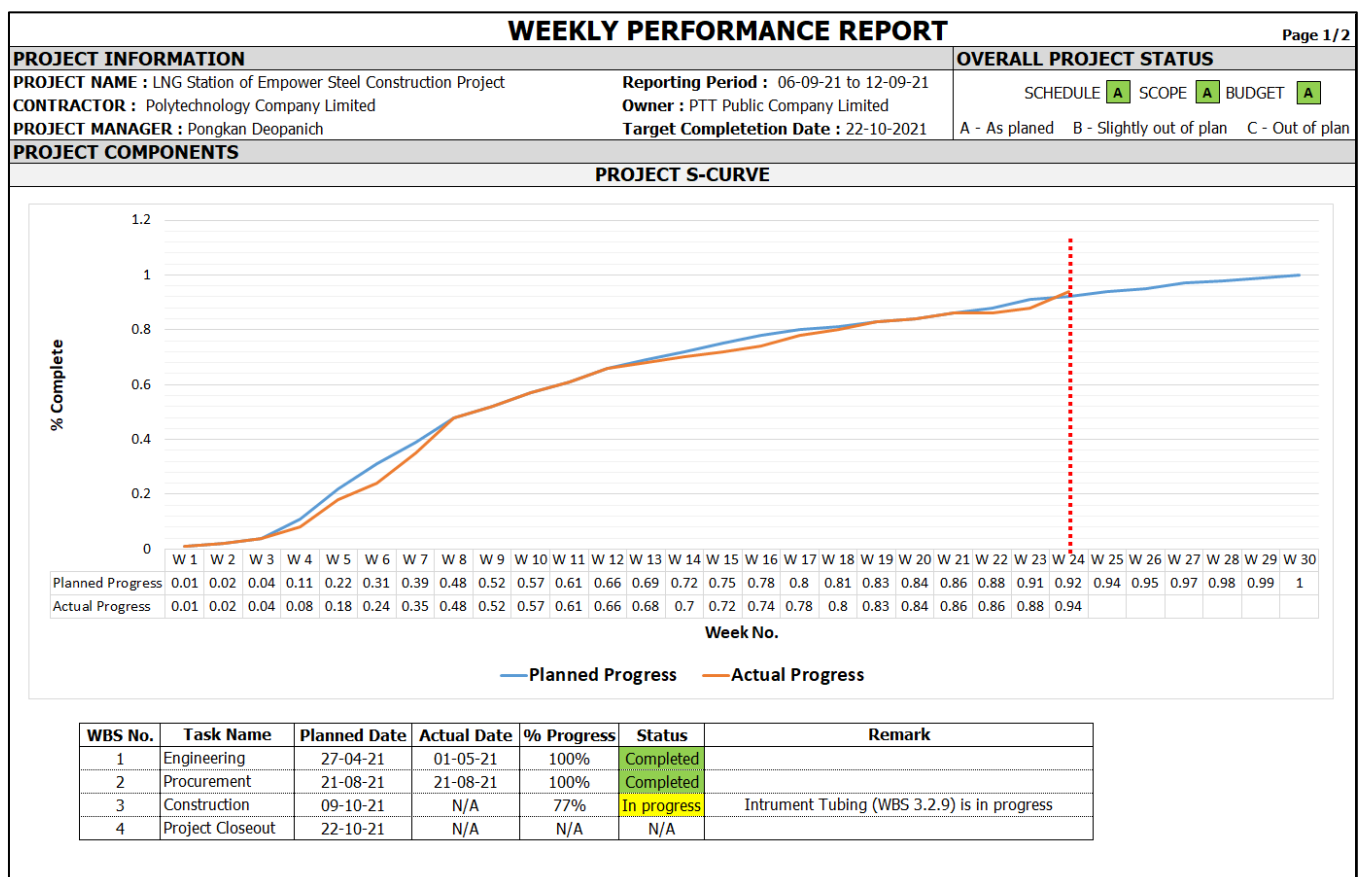
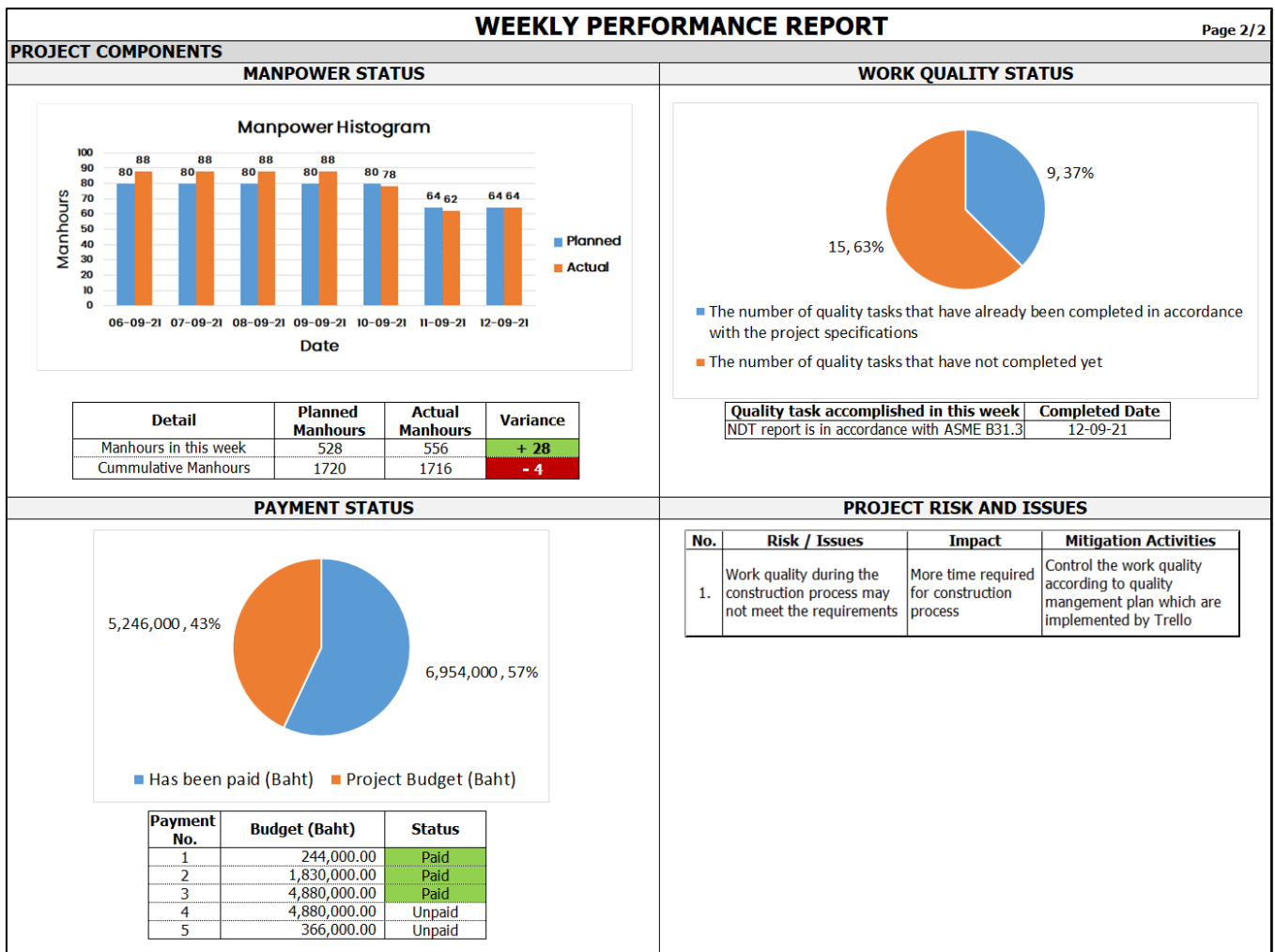


Fig. 20. Real-time construction progress tracking by CCTV cameras displayed on the Sitearound.



(a)



(b)

Fig. 21. Weekly performance report: (a) Page 1 of 2, and (b) Page 2 of 2.

PROJECT HANDOVER CHECKLIST				
Project Title :		LNG Station of Empower Steel Construction Project		
Project Start Date :		1-Apr-21	Completion Date : 22-Oct-21	
Project Budget :		12,200,000 Baht	Version : 0	
Handover Checklist :				
No.	Details	Answer		Additional Comment
1	Equipment are installed and tested	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	—
2	Installation/test reports are submitted	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	—
3	Punch list is corrected	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	—
4	DOEB permission is approved	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	—
5	Commissioning reports are submitted	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	—
6	Final documents are submitted	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	—
7	Operation and maintenance training are provided	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	—
8	All contract payments have been paid	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	—
9	The requirement of the project is fulfilled	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	—
Handover Acknowledge :				
Transferred by :				Date : 26-Oct-21
Received by :				Date : 26-Oct-21

Fig. 22. The project handover checklist.

5. Conclusion and Outlook

In this study, the concept of the PMBOK guideline and PMIS is integrated and adopted to manage LNG construction projects to achieve on-time delivery with uncompromising quality. It can be said that the proposed methodology is very effective, with the number of projects finished on time in 2021 increasing from 75% to 100%, compared to the previous year. According to the findings of the study, enhancing the project management process by using the PMBOK guideline can assist the project team in developing and implementing the project management plan efficiently.

By applying PMIS that combines a CCTV system, a Bluetooth beacon system, project management software, and a cellular network for project monitoring and control, the project team is allowed to view the captured images or video and track the existing manpower and main equipment of the construction site in real-time. It can be used to review project progress and approve submittals online, as well as examine the contractor's work quality and contract payment. When a delay occurs, the project can be caught up promptly with the method mentioned above.

The cost-benefit analysis of the investment in the PMIS equipment to monitor and control the demonstration project shows that the investment cost includes installation costs of CCTV system, Bluetooth Beacon system, network devices, control cabinet for IoT system, and project management software subscription license is 59,700 baht in total. The project's benefits include reducing weekly employment allowances for site inspections and travel expenditures for the vehicle travelling from the company to the site. This equates to an annual savings of 76,800 baht. The project is considered financially viable, with a benefit-cost ratio (BCR) of 1.17, net present value (NPV) of 10,118.18 baht, internal rate of return (IRR) of 16.95%, and an 11-month payback period. This is the result of analyzing the data to determine the project's cost-benefit by establishing the project life of 1 year and a project discount rate of 10% based on the interest rates that commercial banks charge premium retail customers.

In conclusion, the results of this study mainly contribute to the improvement of project management capability in LNG station construction projects to ensure timely completion. Unlike previous papers that attempted to improve project management with only a single project management tool or technique, the approach in this study integrates all important aspects of project management from the PMBOK guideline and the PMIS (including project management software and IoT system) to increase the probability of completing the project within the deadline. To our best knowledge, this approach has never been attempted before in any research paper.

In the future, the company tends to apply the PMIS adopted in this study to more common construction projects. Since the highest risk of this project is a delay in main equipment delivery, RFID might be utilized to locate

and monitor the equipment [23]. It helps to prevent stored equipment at the warehouse from being lost or misplaced before the actual installation. Moreover, other IoT technologies, such as drones for inspecting hazardous construction areas [24], augmented reality (AR) for scheduling and visualizing of project progress [25], and artificial intelligence (AI) cameras for PPE detection to improve workplace safety practices [26], may be used in larger, more complex construction projects to develop a better project management capability.

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