Gutiérrez Alvarez, A.R., Nuñez Quispe, R.R., Ccoyllar Escobar, I.M., Melgar Morales M.A., Arteaga Linares F.M. & Manrique Pacheco D.A. (2025). Structural template and formatting instructions for IGLC33 papers. In O. Seppänen, L. Koskela & K. Murata (Eds.), *Proceedings of the 33rd Annual Conference of the International Group for Lean Construction* (IGLC33) (pp. 622–633). https://doi.org/10.24928/2025/0287

IMPLEMENTATION OF VDC IN THE CONSTRUCTION STAGE OF A HOSPITAL: A CASE STUDY

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ABSTRACT

The construction industry faces a number of challenges, including cost increases, schedule delays, and dissatisfied customers. The Virtual Design and Construction (VDC) methodology has emerged as a response to this. However, there is a research gap on the applications and results of VDC specifically in hospital projects. This study focuses on how the implementation of VDC influenced the results of the hospital project in the construction phase and its monitoring through metrics, using on-site observations, document analysis, and unstructured interviews as sources of evidence. Among the results, a 22% reduction in the time for dismantling the tower crane was achieved, a 24% reduction in the time for constructing the structural shell, and a saving of 25,000-man hours in the formwork, steel, and concrete items. In addition, the safety goal of zero accidents was met.

KEYWORDS

Hospital, Virtual Design and Construction, VDC, productivity, case study

INTRODUCTION

The construction sector has a great importance in the world economy being 13% to the global GDP (McKinsey Global Institute, 2017), however, despite its importance, challenges such as low productivity (Del Savio et al., 2022), inadequate planning (Gómez & Morales, 2016), limited collaboration and supply chain fragmentation (Schöttle et al., 2014) remain unresolved. Between 1995 and 2014, labor productivity in the construction industry grew by only 1% per year, compared to 3.6% in manufacturing (McKinsey Global Institute, 2017). This lag is due to the lack of innovation in the industry (Del Savio et al., 2022). In response, new methodologies have been adopted such as the VDC framework which integrates project production management (PPM) and Building Information Modeling (BIM) concepts through collaborative Integrated Concurrent Engineering (ICE) sessions to meet client and project objectives (Kunz and Fischer, 2012). Although VDC has been applied in various building projects, there is a lack

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of research in Peru on its application and results in hospital projects, which are complex projects because they require a greater amount of materials, and deliveries often double in hospital projects compared to traditional housing construction (Fredriksson et al., 2024). The study answers three research questions regarding the application of VDC in the Huarmey hospital project: (1) What were the results and how were they achieved by implementing VDC in the project; (2) What good practices were identified during the implementation of VDC in the project; and (3) What were the lessons learned from the implementation of VDC?

LITERATURE REVIEW

VIRTUAL DESIGN AND CONSTRUCTION

VDC is a project management methodology developed at the Center for Integrated Facilities Engineering (CIFE) at Stanford University (Kunz and Fischer, 2012). It is based on the integration of product, organization, and process (POP) models to improve project planning, design, construction, and operation through clear objectives, collaboration, production management, and digital technologies (Del Savio et al., 2022). The main components of VDC are BIM, Project Production Management (PPM), and ICE. The pillar of PPM is to find systematic methods to analyze process behavior and design actions that reduce internal variability, thus achieving a better project production system (Shenoy & Zabelle, 2016). The BIM pillar is a comprehensive methodology that encompasses all information required for the design, construction and management of a building (Luth G., 2024). It supports product design and not only creating virtual models of the building but also on conveying information through 3D/4D models, training modellers, advising the client and measuring the cost and impact of the project (Del Savio et al., 2022). Finally, the ICE pillar is a collaborative approach that integrates interdependent tasks through intense coordination (Del Savio et al., 2022; Kunz and Fischer, 2012) that improves coordination and reduces development times by optimizing multidisciplinary teamwork (Cacherre et al., 2003). It provides a framework for integrating VDC components with evaluated metrics for product, organization and process (Kunz and Fischer, 2020). These 3 pillars work together to achieve client and project objectives.

Recent literature reports successful VDC applications. Chocano et al. (2024) optimized the design stage of two multifamily buildings, reducing design time and improving technical file delivery by 25%. In mining, Araujo et al. (2023) proposed a VDC framework that cut diamond drilling time by 10%. Tuesta et al. (2022) applied VDC with prefabricated reinforcement cages in an 870-meter bridge, reducing assembly time by 31% and achieving a 100% buildable design.

METHODOLOGY

This study adopts a case study approach, following the methodology proposed by Yin (2014), which is well-suited to investigating contemporary phenomena in their real-life context. In this case, the implementation of the VDC methodology during the construction phase is analyzed. Multiple sources of evidence were used for data collection, as suggested by Yin (2014), including on-site observations, document analysis, and unstructured interviews. Observations were made during implementation (observations were recorded in detailed field notes); the documents analyzed contained metrics established according to the three main pillars of the VDC methodology such as ICE, BIM and PPM and these documents correspond to the progress reports issued by the project control area and the monthly records issued every 6 weeks by the production area; and the unstructured interviews were conducted with project participants from the project control, production, planning, quality, safety and administration areas.

The data analysis includes: (1) the identification of the project context; (2) the client's time, safety and cost requirements; (3) information on the implementation of VDC and the analysis of production objectives and controllable factors at the stage.

CASE STUDY

Located at km 293 of the Panamericana Norte on the coast of Ancash, the Huarmey Hospital project is built by COSAPI in the Santo Domingo settlement, covering an area of 12,000 square meters. Financed via the "Works for Taxes" mechanism by PRONIS, the project has a budget of S/188 million covering construction, equipment, and furniture. It includes a lot of facilities for a Category II-1 hospital. This study focuses on the results achieved through VDC implementation during its construction phase.

RESULTS AND DISCUSSIONS

CLIENT AND PROJECT OBJECTIVES

One of the objectives of COSAPI's direct client was to deliver the project on the promised date. Therefore, a highly reliable construction was established as the project objective, reducing the construction time by 6.30%. In addition, the client emphasized the importance of maintaining a safe work environment, establishing a goal of zero accidents throughout the execution of the project. To drive the achievement of target values for each metric and ensure the proper implementation of VDC, the methodology was applied at both the corporate and project levels. At the corporate level, training sessions and programs were conducted to teach how to implement VDC and ensure its ongoing monitoring. At the project level, ICE sessions were held at the beginning of the project, where VDC was comprehensively explained. During these sessions, the project framework was developed in collaboration with each area, objectives and metrics were defined with their input, and the tracking methodology was established. A strong emphasis was placed on fostering a culture of collaboration and continuous improvement throughout the implementation process.

PPM

Regarding the PPM component, this section presents and analyzes the three production objectives and the four metrics associated with controllable factors. To ensure compliance, various production control tools were used, such as Lookahead, Takt-Time Planning, Pull Planning, root cause analysis, workflow management, sectorization, balance chart, overall activity level assessment and Value Stream Mapping.

These strategies were implemented through specific ICE sessions, which addressed key activities such as constraint release, identification and mitigation of bottlenecks, optimization of production processes and increase of effective work. Thanks to this structured planning, a reliable and continuous workflow was established, thus improving stability and predictability in project execution.

Production Target: Approval of medical equipment files

In Table 1, the production target, its controllable factors, and their respective metrics, formula and target values are shown.

Figure 1 shows that, at the beginning, the number of approved files exceeded the number of planned files; however, over time, this trend was reversed. Initially, the approval process with PRONIS and supervision was carried out through traditional, non-collaborative management, resulting in approval times of 2 to 3 months. This delay impacted procurement and installation timelines and, in many cases, affected the pre-installation required in their final environment.

Table 1: Details of production target: approval of medical equipment files.

Production target				Controllable Factor		
Description	**Why?**	**Metric**	**Target Value**	**Description**	**Metric**	**Target Value**
Approval of medical equipment sheets	Ensure the procurement of medical equipment	Number of medical equipment approved / Total number of medical equipment	≥ 80 %	ICE medical equipment sessions	1 weekly	≥1

The use of VDC was key to mitigating these delays. Since the contractor identified medical equipment procurement management as a critical risk based on lessons learned from previous hospital projects, a proactive strategy was adopted. ICE sessions were implemented to integrate procurement discussions, allowing real-time resolution of queries and direct assignment of responsibility. This collaborative approach facilitated more informed decision making, improving coordination among stakeholders and allowing the contractor to proactively alert the client of delays in approving critical equipment. As a result, the application of VDC helped reduce uncertainty, streamline the approval process, and minimize disruptions to key project milestones.

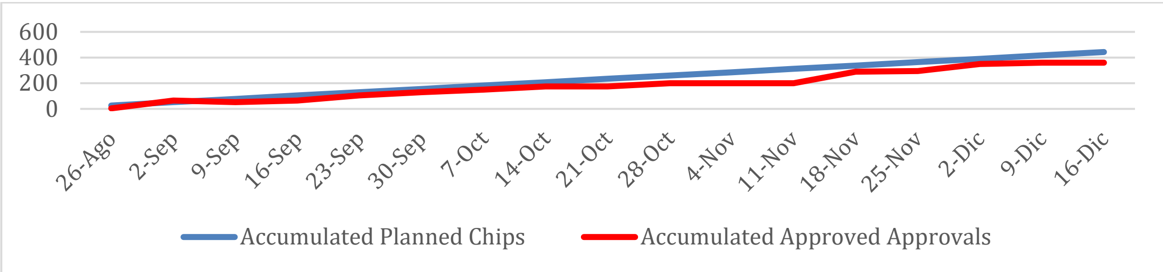


Figure 1: Metric evolution of production target: percentage of approved medical equipment files.

Production Target: Variability of activities

In Table 2, the production target, its controllable factors, and their respective metrics, formula and target values are shown.

Table 2: Details of production target: variability of activities.

Production target				Controllable Factor		
Description	**Why?**	**Metric**	**Target Value**	**Description**	**Metric**	**Target Value**
Variability of activities	Ensure the completion of scheduled activities	Activities completed / Scheduled activities	≥ 85 %	Review by the production area of completed and incomplete activities.	1 weekly	≥1
				Analysis and identification of the causes of non-compliance	1 weekly	≥1

Figure 2 shows a general trend of improvement in compliance with programmed activities. At the beginning of the project, significant fluctuations were observed. However, as it progressed, key measures were implemented that stabilized and increased compliance, exceeding the target. This improvement in the PPC was due to the reduction of variability through more rigorous monitoring and control of controllable factors, systematic analysis of the causes of non-compliance, and greater involvement of group leaders and subcontractors in weekly planning. In addition, the timely release of constraints was optimized through ICE sessions, which improved the reliability of the weekly plan.

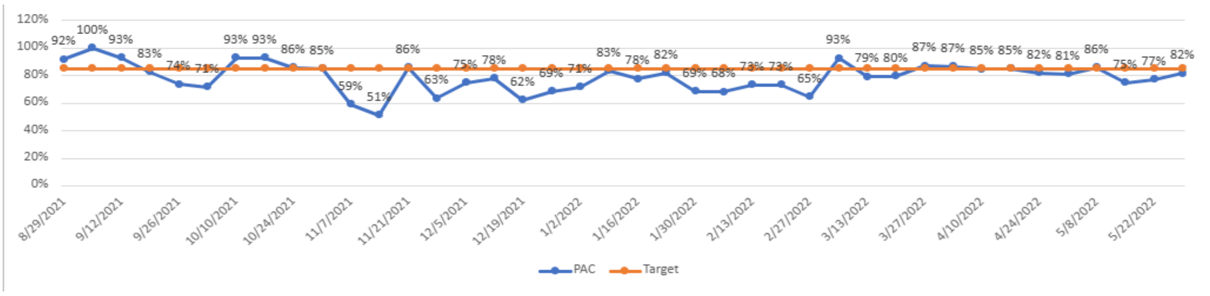


Figure 2: Metric evolution of production target: Percentage of Activities Completed (PAC).

Production Target: Subcontractor safety performance chart

Table 3 shows the production target, its controllable factors and their respective metrics and target values.

Table 3: Details of production target: subcontractor safety performance chart.

Production target				Controllable Factor		
Descriptio n	Why?	Metric	Target Value	Description	Metric	Target Value
Subcontractor safety performance chart	Ensuring compliance with subcontractor safety standards	Points obtained / Possible points	≥ 85 %	Conduct safety walks	1 weekly	≥1

Figure 3 shows the evaluation of subcontractor safety performance and an upward trend, consistently exceeding the 85% target. Success is attributed to going beyond legal compliance and in response to this the visual tool “safety activity chart” was implemented, as shown in Figure 4, which assesses six key performance factors, arising from an ICE session, with the aim of fostering a safety culture among all subcontractors throughout the project.

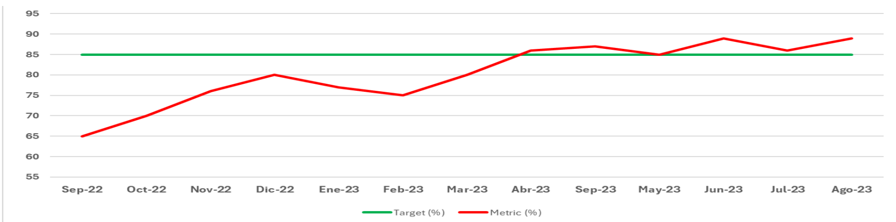
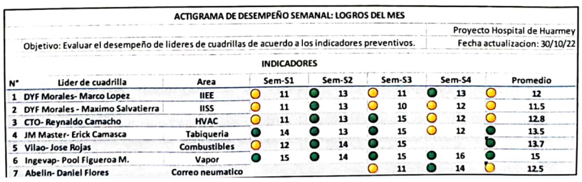


Figure 3: Metric evolution of production target: evaluation of subcontractors’ safety performance.



ACTIGRAMA DE DESEMPEÑO SEMANAL: LOGROS DEL MES

Objetivo: Evaluar el desempeño de lideres de cuadrillas de acuerdo a los indicadores preventivos.

Proyecto Hospital de Huarmey

Fecha actualizacion: 30/10/22

INDICADORES

N°	Lider de cuadrilla	Area	Sem-S1	Sem-S2	Sem-S3	Sem-S4	Promedio
1	DYF Morales- Marco Lopez	IIEE	11	13	11	13	12
2	DYF Morales - Maximo Salvatierra	IISS	11	13	10	12	11.5
3	CTO- Reynaldo Camacho	HVAC	11	13	15	12	12.8
4	JM Master- Erick Camasca	Tabiqueria	14	13	15	12	13.5
5	Vilao- Jose Rojas	Combustibles	12	14	15		13.7
6	Ingevap- Pool Figueroa M.	Vapor	15	14	15	16	15
7	Abelin- Daniel Flores	Correo neumatico			11	14	12.5

Figure 4: Safety activity chart on one work front.

Visible leadership activities were implemented in the field, including inspections, training, recreational activities and visual dashboards to improve performance in the six key factors. Outstanding subcontractors received awards, incentivizing continuous improvement and compliance with safety standards. In addition, ICE sessions introduced the use of QR codes in work areas to identify hazards and control measures, which facilitated the validation of Safe Work Analysis (SWAs) and reduced the time required to prepare and validate SWAs by 30%.

BIM

Regarding the BIM component, 1 production metric and 2 controllable factors were defined that seek to contribute to the fulfillment of the project and client objectives. In this section, the unique BIM production metric and its controllable factors are explained in detail to explain their positive correlation with the metric. The tools used to support the fulfillment of these metrics were Revit (BIM Model), Revizto (Interference Review Software) and additionally, a PDF file was created containing real-time drone images, which was shared with COSAPI management, the supervisor, the client, and other stakeholders. This tool was also used in Look Ahead sessions and planning meetings, facilitating monitoring and decision-making based on up-to-date project data.

Production Target: Number of days in advance for the delivery of BIM sketches

In Table 4, the production target, its controllable factors, and their respective metrics, formula and target values are shown.

Table 4: Details of production target: number of days in advance delivery of BIM Sketches.

Production target				Controllable Factor		
Description	**Why?**	**Metric**	**Target Value**	**Description**	**Metric**	**Target Value**
Number of days in advance delivery of BIM sketches	Allows for review, understanding and reduction of any doubts between teams.	Number of days in advance for delivery of sketches	≥ 5 days	Percentage of approved schemes compared to those developed	# Sketches prepared approved / # Sketches prepared	≥80 %
				Updating the BIM model with RFI's	# RFI's updated in the model / # Total RFI's with closed response	≥85 %

In Figure 5, there is an increase in the number of days in advance for delivery of the sketch, which ultimately led to meeting the target value. This is due to compliance with the controllable factors as seen in Figure 10 and Figure 11. The target values were achieved with adequate controllable factors and by promoting ICE sessions to review these results, in which the model and the LOG of pending sketches for approval were reviewed. The results and the compliance trend allowed for continuous progress in on-site production.

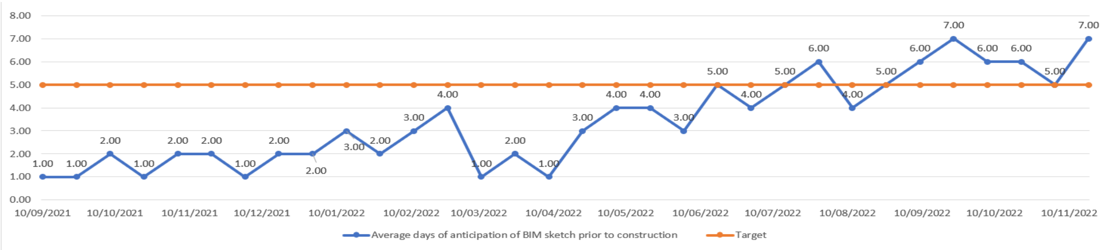


Figure 5: Metric evolution of production target: number of days in advance for the delivery of BIM sketches.

The main objective of establishing this metric was to address the need on site to have these plans available several days in advance, which allows for their review, understanding and resolution of any doubts between teams or interferences. This anticipation helps to promote the flow of information and work, which contributes to the project objective of reducing deadlines. As a crucial example, it allowed for timely sketches of the installation passes and the installations embedded in the slab, thus avoiding inadequate management of these elements that would lead to rework that would negatively affect the project deadlines.

Controllable factor: Percentage of approved schemes compared to those prepared

The first controllable factor, shown in Figure 6, was the percentage of approved schemes compared to the schemes prepared. An upward trend in the metric is observed, managing to exceed the target value of 80% since the end of April.

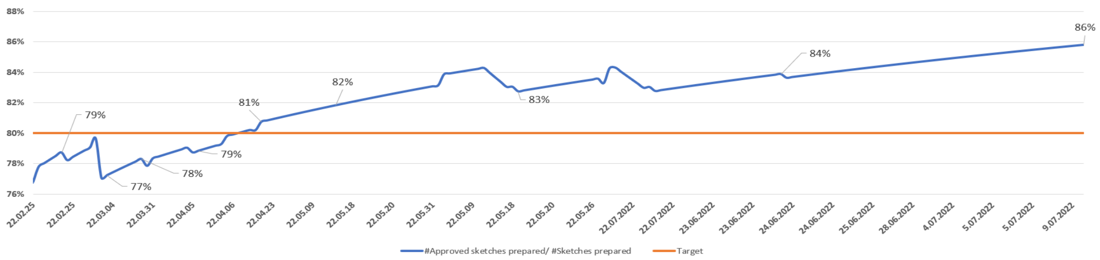


Figure 6: Controllable Factor: Approved BIM schemes.

Measuring this progress was crucial due to the need for each drawing produced to be internally closed as soon as possible in the BIM or Technical Office area before reaching the production area. This internal closure ensures that the drawings are accurate and ready to be used in construction without causing delays.

Controllable factor: Updating the answered RFIs in the BIM model

The second controllable factor, shown in Figure 7, was the update of the BIM model with the responses to the RFIs, which also has an increasing trend.

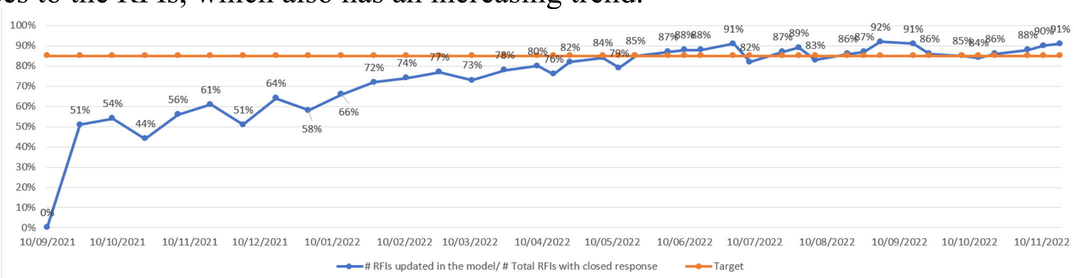


Figure 7: Controllable Factor: BIM RFI updates.

It was essential that these responses be integrated into the BIM model to ensure that the generated sketches contained the most up-to-date information, thus avoiding errors on site. In addition, measuring the updating of the BIM model ensured that the sketches were ready in time for approval by the Technical Office area and their subsequent use in production.

ICE

In this ICE component, 2 production objectives and 2 controllable factor metrics have been established for each of the production objectives, which are described in this section. An ICE Room (Big Room) was implemented to carry out coordination sessions with specialists, supervisors, clients and other key team members. In addition, group leaders were included in these sessions, a practice considered beneficial since they are responsible for directing personnel in the field and achieving the established production objectives.

During the ICE sessions, tools such as 4D schedules, drone photos, and 3D models were used to visualize production in real time and detect future constraints. Sessions dedicated to monitoring and reviewing production goals were held with managers and group leaders, facilitating collaborative decisions to improve results. Sessions were also held with the designers to resolve "Requests for Information" (RFIs). Critical RFIs were responded to informally to avoid disruptions, while less critical RFIs were addressed and formalized during the sessions.

Production Target: Release of incidents

In Table 5, the production target, its controllable factors, and their respective metrics, formula and target values are shown.

Table 5: Details of production target: release of incidents.

Production target				Controllable Factor		
Description	Why?	Metric	Target Value	Description	Metric	Target Value
Release of incidents	Have a highly reliable model for construction	Number of issues solved / Number of issues detected	≥85%	ICE sessions	1 weekly	≥1
				Sending the ICE session agenda 3 days in advance	Number of days in advance	3

Figure 8 shows a general improvement in the percentage of resolved issues. Although there were significant fluctuations initially with many unresolved issues, over time a stabilization and an upward trend were observed, almost approaching the expected target.

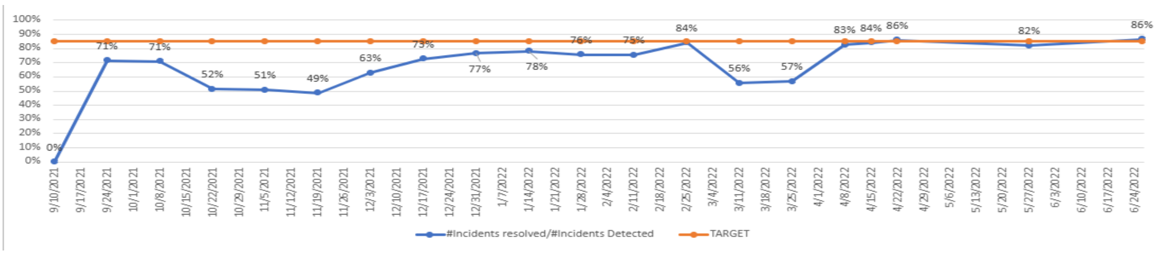


Figure 8: Metric evolution of production target: percentage of issues solved.

The results are due to compliance with controllable factors, such as sending the agenda 3 days in advance, which allowed the team to prepare and foster a more productive dialogue. In addition, the 2-hour duration of the ICE sessions was effective in resolving a significant number of issues through intense collaboration. Another good practice was the shift to a collaborative office which facilitated continuous interaction between team members.

Production Target: Attendance of participants

In Table 6, the production target, its controllable factors, and their respective metrics, formula and target values are shown.

Table 6: Details of production target: attendance of participants.

Production target				Controllable Factor		
Description	**Why?**	**Metric**	**Target Value**	**Description**	**Metric**	**Target Value**
Attendance of participants	Provide timely solutions to detected incidents	Number of participants who attended / Number of participants invited	100%	ICE sessions	1 weekly	≥1
				Sending the ICE session agenda 3 days in advance	Number of days in advance	3

Figure 9 shows the general trend of improvement in the percentage of attendance at ICE sessions during the implementation of VDC in the Project. The importance and contribution of this metric to the objectives set is that it ensures that all key stakeholders are participating and are aware of the problems and solutions, promoting a high level of commitment and collaboration for a rapid resolution of incidents or unforeseen events. An improvement was found, almost reaching the target value because rules were implemented that served as an incentive for those summoned to be present.

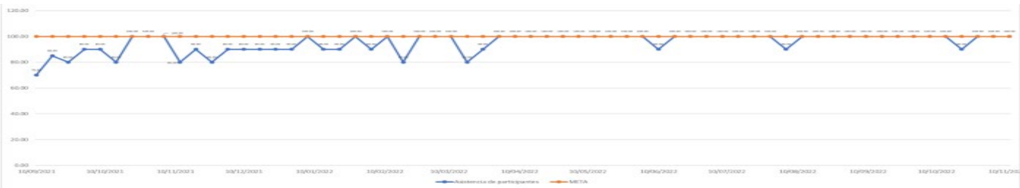


Figure 9: Metric evolution of production target: percentage of key participants attending ICE sessions.

IMPACT OF VDC ON THE PROJECT

Time and Cost

The application of VDC in the project generated significant benefits, mainly in the optimization of the execution time. The 24% reduction in the construction time of the structural hull was calculated by comparing the time scheduled in the initial schedule with the actual time after the implementation of VDC. This optimization saved 25,000 man-hours, equivalent to 30% of the contractual hours allocated for this phase. Also, the tower crane dismantling time was reduced by 22%, comparing the estimated duration in the schedule with the actual duration. Initially scheduled for September 18, 2022, the disassembly was completed on June 30, generating an approximate savings of US$26,870 in associated costs.

In addition, optimization of the structural execution process reduced the use of the safety net from 4.5 months to only 1.5 months. This reduction was determined by comparing the actual time of use with the period estimated in the initial planning, resulting in a savings of approximately US$14,510.

Security

The implementation of VDC transformed safety management in the project from a reactive approach, limited to compliance with legal requirements and reacting after incidents, to a preventive model where clear metrics were established and constantly monitored to meet the goal of zero accidents, providing support for better risk management and better decision making regarding the safety performance of subcontractors and workers in general.

Another key impact was the adoption of a technology-driven approach to solving safety challenges, driven by the BIM pillar. Priority was given to assessing which technological tools could optimize risk management and improve safety on site, which allowed identifying faster and more effective solutions with the available resources through biweekly ICE meetings, contributing to more efficient and proactive risk management.

As a result, COSAPI was recognized by its client for reaching 1.5 million man-hours without accidents, consolidating an environment of safety, excellence and recognition.

CONCLUSIONS

Among the results obtained, a 22% reduction in the time taken to dismantle the tower crane was achieved, a 24% reduction in the time taken to build the structural shell, and a saving of 25,000 man hours in the formwork, steel, and concrete items. In addition, the safety goal of zero accidents was met.

These positive results are due to the ICE Production objectives, which allowed for optimized information flows and extreme collaboration; the PPM Production objectives, which achieved continuous flows of work and information; and the BIM Production objective, which also focused on continuous flows of information and work.

During the implementation of VDC, the following good practices were identified:

- ICE: Use of the ICE Room (Big Room) with 4D programming, drone photos, and 3D models to visualize production in real time and detect future restrictions.
- PPM: Implementation of Lookahead, Takt-Time Planning, Pull Planning, Work Trains, Sectorization, Balance Sheet, General Level of Activities, Value Stream Mapping, Analysis of Causes of Non-Compliance, Application of Constraints, Safety activity charts, and Focus on Procurement of Medical Equipment Sheets as a Production Target.
- BIM: Use of Drones.

Lessons learned from the project include the importance of involving all key stakeholders, including group leaders and subcontractors, in ICE sessions from the beginning to identify constraints. It is also essential to maintain ongoing IT support to improve processes, such as the use of drones and QR codes. Additionally, stakeholders who follow traditional approval methods, like PRONIS, should be included in ICE sessions to streamline procedures and eliminate waiting times. Finally, it is recommended to establish metrics that allow the contractor to alert the client about delays in approvals and to remind them of key dates.

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