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AN INTEGRATED FACILITY MANAGEMENT SYSTEM SUPPORTED IN VDC AND LEAN

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ABSTRACT

The operational costs during the maintenance phase can account for 15% to 70% of a facility's total life cycle expenses, depending upon the type and size of the project. This paper explores the integration of Virtual Design and Construction (VDC) and Lean methodologies, offering practical solutions to optimize the maintenance operations of an engineering laboratory. A comprehensive literature review was conducted to identify common challenges in facility management and assess existing methods and technologies to address these issues. This research introduces the concepts of VDC and Lean within maintenance management, proposing an Integrated Facility Management System (IFMS) that applies these frameworks to the operations and maintenance (O&M) processes. The IFMS aims to harmonize the facility's physical structure, organizational dynamics, and procedural workflows, providing a practical roadmap for facility managers and maintenance professionals. Implemented in an engineering laboratory in Lima, Peru, the IFMS has significantly improved maintenance efficiency. The results include a fivefold reduction in the average time required for corrective maintenance and a 50% decrease in the incidence of such maintenance tasks. Finally, applying VDC and Lean principles to the maintenance phase can yield substantial operational benefits, as evidenced by the data from the implemented IFMS.

KEYWORDS

Facility Management, VDC, Lean, Value stream, Integrated Project Delivery (IPD), BIM.

INTRODUCTION

Despite their innovation, flexibility, and cost limitations, construction products are inherently complex (Nam & Tatum, 1988). This complexity manifests in the organization, the product, and the process. Construction projects involve numerous stakeholders with diverse objectives and interests, leading to fragmentation issues among professionals and organizations (Esa et al., 2014). Moreover, construction products are characterized by many interdependent elements, equipment, and intricate systems that constitute a building (Nam & Tatum, 1988). They are part of a challenging, lengthy supply chain involving numerous internal and external suppliers (Ashworth & Perera, 2015). Some authors correlate this complexity to the construction's heterogeneity and project-based nature (Gálvez-Martos et al., 2018). As a result, construction is ranked the second-lowest sector in adopting information technology (Agarwal et al., 2016).

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On the other hand, the project maintenance phase represents 15% to 70% of a facility's life cost cycle, depending upon the type and size of the project. Furthermore, corrective maintenance corresponds to this cost more significantly (65% to 85%)(Janjalkar et al., 2023). The consequences of deficient building maintenance entail risks to its users' safety and maintenance cost uncertainty (Shou et al., 2020). These maintenance costs are proportional to the downtime (DT) of the system or an asset. The DT is when equipment/system is down until it returns to normal working conditions. The increase in DT is due to non-value-added (NVA) activities or wastes in maintenance operations (Mostafa et al., 2015).

This research presents a background study on the challenges and problems faced by maintenance management and the methods and technologies proposed for their solution. Moreover, Virtual Design and Construction, Integrated Project Delivery, and Lean concepts are introduced. The hypothesis is that implementing these concepts in the maintenance stage generates substantial operation benefits. Finally, an Integrated Facility Management System (IFMS) is proposed based on VDC and Lean.

BACKGROUND

FACILITY MANAGEMENT

The concept of Facility Management (or Facilities Management) has been around for more than 50 years. According to the International Facility Management Association and ISO 41011:2017, it is "an organizational function that integrates people, places, and processes within the built environment to improve people's quality of life and productivity of the core business" (ISO, 2017). Facility management began as a simple sanitary and cleaning service during the 1970s. Since then, it has constantly been evolving into what is known today as the occupational profession, with millions worldwide involved in managing organizations, their facilities, and services (Drion et al., 2012).

LEAN

Lean management principles are a philosophy that draws on the lessons learned from how Toyota does things. This principle helps an organization manage its operations more efficiently (Liker, 2004). The lean philosophy provides waste minimization methods while creating value for the stakeholders (Denzer et al., 2015). Several studies focus on the effect of lean techniques on maintenance efficiency. These tools are 5S; 5Whys, Total Production Management (TPM), Kaizen, Poka-Yoke, Kanban, Process Mapping (PM), Computerized Maintenance Management System (CMMS)/Computer-Aided Maintenance Management (CAMM), Just In Time, Failure Mode and Effect Analysis (FMEA), standardization of procedures, Value Stream Mapping (VSM) (Dragone et al., 2021). However, VSM is the most frequently applied lean technique for understanding the maintenance process by representing material and information flows (Shou et al., 2020).

VIRTUAL DESIGN AND CONSTRUCTION (VDC)

Virtual Design and Construction is a management methodology that integrates product, process, and organization models (Kunz & Fischer, 2004). The latter is one of his most significant contributions since his approach focuses on integrating a specific work team to achieve the proposed and, ultimately, the client's objectives. Since then, it has evolved into what is known today, with its main components: Client Objective, Project Objective, Integrated Concurrent Engineering (ICE), Building Information Modeling (BIM), and Project Production Management (PPM). The VDC literature shows various implementations in the design and construction phases, with outstanding results in achieving the client's objectives (Balcazar et al., 2023; Barcena et al., 2023; Bustamante et al., 2023; Del Savio et al., 2022; Majumdar et al., 2022; Palpan et al., 2022; Quinteros et al., 2023; Salazar et al., 2023; Tuesta et al., 2022). These results were obtained for projects in the design and construction phase. However, applying the same rationale for maintenance management implies measuring the production objective with some recurrence and not necessarily fixing it in a project timeframe.

INTEGRATED PROJECT DELIVERY (IPD)

Integrated Project Delivery (IPD) is a delivery model based on the collaboration between the project stakeholders in the construction industry (Aslesem et al., 2018). IPD was initially developed to confront the challenges of increased project complexity, high fragmentation levels in the construction industry, and inadequate communication among stakeholders (Ahmed et al., 2021). A multiparty agreement and the involvement of key stakeholders at an early design stage characterize this delivery system. The emphasis is on relationships, collaboration, and pursuing mutual goals. This implies sharing the risks and rewards of the project as an incentive to achieve this mutual goal (Teng et al., 2017; Durdyev et al., 2019).

METHODOLOGY

This paper aims to conduct an explanatory investigation into implementing an integrated facility management system supported by Virtual Design and Construction (VDC) methodology and Lean concepts.

It is hypothesized that integrating VDC and Lean concepts could help fulfill the client's objectives during the building maintenance phase. Based on this premise, a bibliographic review was carried out in indexed databases, such as Scopus, Mendeley, and Web of Science, as well as regulations and standards of good practice, using the following keywords: "Facility Management," "Virtual Design and Construction," “Lean Maintenance” and "Information System."

The methodology follows the Value Stream Mapping method. First, it identifies the target process to improve. Then, the baseline or current state of the value stream map is constructed based on semi-structured interviews with laboratory personnel in charge (identifying the waste). Next, a future value stream map for maintenance supported by the VDC, IPD and Lean is proposed. Finally, a working plan is developed based on that optimized process (Martonen & Baglee, 2019).

RESULTS AND DISCUSSIONS

PROJECT INTRODUCTION

The facility studied in this article is the Laboratories of the Civil Engineering Department (Figure 1) at the Universidad de Lima, located in Lima, Perú (Figure 1). When the Civil Engineering Program began in 2017, the need arose to implement laboratories to provide (i.) technical and academic support to the subjects taught, (ii.) research support, and (iii.) support for the construction industry. In this sense, the direction of the Civil Engineering Department defined a gradual procedure for implementing the laboratories to meet those goals. The following laboratories were identified and implemented: Laboratory of Materials, Soils, Rocks, Topography, Geomatics, Structures, Environmental Engineering, Pavements, Sanitary Engineering, Hydraulics, and Hydrology. The results obtained in this chapter reflect the method proposed to implement the IFMS under a VDC and Lean approaches applied to the Operation and Maintenance stage.

Figure 1: Overall view of the Laboratories of the Civil Engineering Department of Universidad de Lima.

PROBLEMATIC ANALYSIS BASED ON PRIMARY INFORMATION

It was employed semi-structured interviews with stakeholders responsible for equipment maintenance in the laboratory. These interviews facilitated the definition of objectives, identification of critical equipment, mapping of the equipment maintenance process, identification of problems or sources of variability, and proposal of improvements in the maintenance process. The results of these interviews are presented below.

One hundred percent (100%) of the interviewed managers agreed that the value of the investment made in implementing the laboratories is measured in the degree of use of the equipment in academic courses, research, and industry support.

The laboratory managers pointed out 11 critical pieces of equipment, presented in Table 1, organized by the laboratory disciplines. A piece of equipment is considered vital when it meets the following requirements: (1) its operation is essential due to its high demand, (2) its maintenance is complex and laborious or with much variability in the correction period, or (3) that it does not have a replacement available in the local market.

Table 1. Key equipment.

Laboratory	Key Equipment Name
Materials	Uniaxial Compression Machine (Automax) and Multi-testing Machine (600 KN)
Geotechnics	Triaxial Soil System and Direct Cutting Equipment
Pavements	Hamburg Wheel and Servo-Hydraulic Universal Testing Equipment
Structures	Single-ended Hydraulic Actuator
	Uniaxial Compression Machine (3000 KN)
Sanitary, Hydraulic, and Hydrology Engineering	Compact Fluid Mechanics Basic module (HM250) and Flow and Sediment Transport Channel
Environmental	Spectrophotometer Infrared (FTIR)

Based on the interviews, it was mapped the current maintenance process for the laboratories using the Business Process Model and Notation (BPMN) standard. This process is shown in Figure 2. The stakeholders are the laboratory team, civil engineer career team, maintenance team, buy area, and maintenance suppliers.

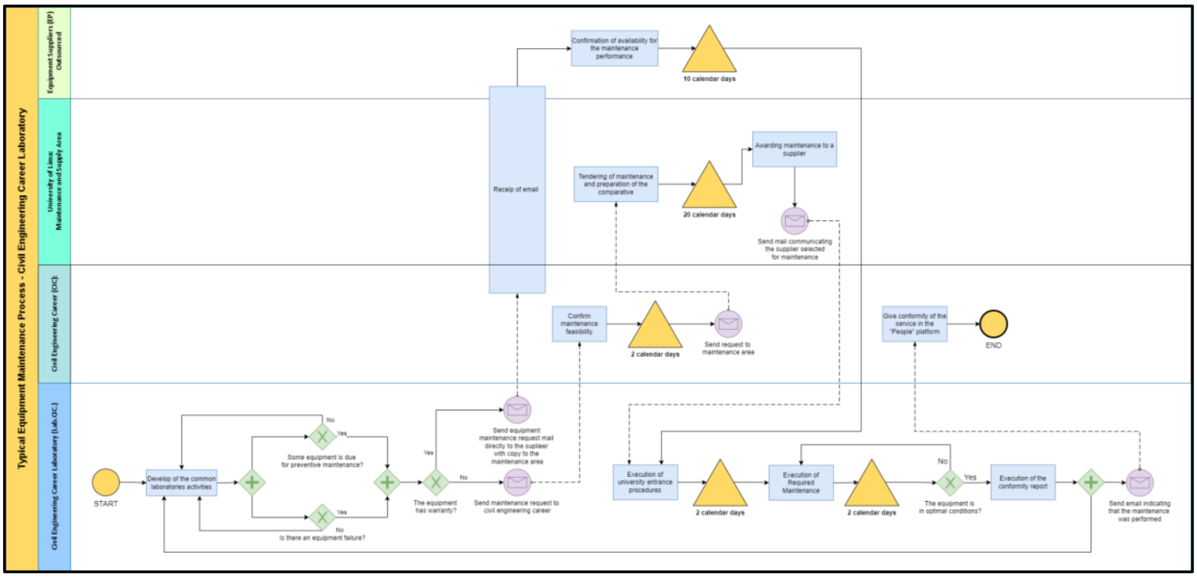

Figure 2 - Current maintenance flow.

The maintenance process is sequential and fragmented. Most communications are made by email. The average duration of the equipment maintenance process depends on two variables: the type of maintenance (corrective or preventive) and an equipment warranty. The equipment inoperability days were increased from 2 days (duration with preventative maintenance and warranty) to 26 days for equipment that did not have a warranty (Table 2). In this sense, strategies are needed to include a more extended warranty.

Table 2. Current maintenance process analysis.

Type of Maintenance	Warranty	Total Process Duration (Days)	Duration of Inoperability (Days)
Preventive Maintenance	Yes	14	2
	No	26	2
Corrective Maintenance	Yes	14	14
	No	26	26

The interviewees identified the main issues with the maintenance process as follows: (1) Latency in communications and deficiencies in following up maintenance requests, (2) variability in the duration of provider selection, (3) the absence of extended warranties, and (4) maintenance information management. Additionally, the laboratory team does not participate in provider procurement. Hence, the duration of the award process and the reliability of the chosen supplier emerge as the primary sources of variability within this process.

The waste analysis and classification were based on the current maintenance flow. In this context, the most impactful wastes are the waiting times and ineffective data management in the entire process. A fragmented approach to maintenance management generates those wastes. The sequential and fragmented process increases communications latency and increments the total cycle time.

As a result, 60% of the interviewed managers reported that some equipment in their laboratory was inoperative due to maintenance, with an average repair time of 130 calendar days for critical equipment (corrective maintenance).

VDC FRAMEWORK ELABORATION

The VDC framework includes explicit specification of client and project objectives and measured performance for the project. This includes specifying a performance objective and a desired performance measured with a specific frequency (Kunz & Fischer, 2020). The proposed VDC framework, presented in Table 3, was based on the stakeholders' interview information and the systematic bibliographic review. Subsequently, the stakeholders validated this framework, and the impact of applying it on the maintenance process was measured. The VDC outputs and production metrics allowed the maintenance process production to be evaluated and compared with a target value.

The client's objective is to guarantee the critical equipment operability in the laboratory. The goal, 95% of operability, was defined considering only one day stop for preventive maintenance per month. It is desired to avoid any equipment inoperability due to corrective maintenance. The project team’s (the maintenance process stakeholders) objective is to develop an integrated facility management system to manage the 11 critical equipment and supply the client maintenance needs.

The operability percentage is the core metric of the maintenance process. Two identified problems were the absence of extended warranties and delays in provider selection. As controllable factors, the IFMS includes process mapping and uses collaborative contracts with an IPD scope for maintenance suppliers. This IPD contract implementation has improved the willingness to collaborate and create an open communication culture, integrated information, collaborative goal definition and decision-making, and early involvement of the key participants (Kahvandi et al., 2017; Aslesem et al., 2018). In this sense, the IFMS aims to consider IPD contracts to create long-term collaborative contracts with the maintenance providers and guarantee preventive maintenance and availability for corrective maintenance. This IFMS/IPD contract shall consider sharing the risks and rewards of the year maintenance budget as an incentive. However, this contract should be considered in the early phases of the design process to align better the process needs.

Weekly meetings with the maintenance stakeholders were considered for the ICE component. The communication latency was one of the main problems identified in the interviews. The ICE sessions generated response latency reductions. Hence, the IFMS proposal shall include ICE sessions weekly to keep updated on the maintenance status of the 11 critical equipment. Some important issues were the maintenance provider selection, the information needed to include on the BIM, and a collaborative contract with the selected supplier with an IPD scope.

Another issue was managing maintenance information. The BIM component allows maintenance information to be managed following the COBie standard. As a controllable factor, the IFMS proposes creating a required information checklist for each project. The information needed for the maintenance team may vary per project and organization. The goal for this component is to include all the required information for maintenance in the BIM with the COBie Standard.

Table 3. Proposed VDC Framework.

VDC Framework				
Client Objectives	Guarantee a 95% operability of the critical equipment. (This means only one day stop for preventive maintenance per month)			
Project Objectives	Develop and implement an Integrated Facility Management System (IFMS), which manages the 11 critical equipment of the laboratories.			
Components	**Item**	**Description**	**Metric**	**Goal**
ICE	Production Metrics	Have 100% compliance with the agenda in the sessions (% Agenda Compliance).	$\%Agenda\ Compliance = \frac{\#Items\ Completed}{\#Items\ Scheduled}\ x\ 100$	100%
	Controllable Factors	Send the Meeting Agenda in advance.	Number of days in advance to send the agenda	2
BIM	Production Metrics	Have 100% equipment operation and maintenance information included in the BIM model (With COBie Standard)	$\%\ \text{O\&M}\ Information\ in\ BIM = \frac{\#Inf.\ Included}{\#Inf.Required}\ x\ 100$	100%
	Controllable Factors	Define the information needed for the maintenance checklist for critical equipment.	Required Information Checklist per essential equipment	1
PPM	Production Metrics	Have 95% monthly operability for the 11 critical equipment	$\%\ \text{Operability} = \frac{\#Operating\ Hours}{\#Total\ Hours}\ x\ 100$	95%
	Controllable Factors	Create the VSM for the current maintenance process and optimize it with IFMS.	# of Process Map developed	1
		Create collaborative contracts with the maintenance suppliers with an IPD scope	$\%\ Critical\ Equipment\ with\ a\ colaborative\ contract\ scope = \frac{\#Equip.with\ Contract}{\#Total\ Critical\ Equip.} x\ 100$	100%

IFMS IMPLEMENTATION AND VALIDATION

The maintenance stakeholders validated the IFMS methodological approach. The approach received a satisfaction level of 73% and suggestions for improvement related to developing specific strategies for each piece of equipment and laboratory. Table 4 shows the results of the three-month early adoptions of the IFMS. It can be observed how the average duration for the corrective maintenance was reduced by five times, and the number of corrective maintenance incidents was reduced by half, validating the IFMS implementation.

Table 4. IFMS implementation results.

Process	Baseline Measurement	Maintenance Process with IFMS	Delta	Target
Average Duration of the Corrective Maintenance Process (Calendar Days)	130	22	108 (5 times less time)	2
Number of Corrective Maintenance Incidents	5	2	3 (Reduced by Half)	0

CONCLUSIONS

The main objective of this research was to propose an Integrated Facility Management System (IFMS) based on the concepts and practices given by the VDC and Lean. The IFMS was built based on information from the maintenance process problem identified through semi-structured interviews. This allowed for understanding, validating, and precisely defining the client and project objectives. Also, the systematic review helped to suggest production metrics and controllable factors that support the implementation of IFMS based on the VDC and Lean principles.

With the early implementation of IFMS, the average duration for corrective maintenance was reduced by fivefold, and the number of corrective maintenance incidents was reduced by half. Moreover, this methodology received the acceptance of 73% of the stakeholders. The next step is developing a relational contract with the maintenance suppliers. This will allow us to improve the operability performance of the critical equipment based on collaborative relations.

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