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PRINCIPLES AND PRESCRIPTIONS FOR THE DEVELOPMENT AND IMPLEMENTATION OF PERFORMANCE DASHBOARDS

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ABSTRACT

Lean Production implementation in construction creates additional demands for Performance Measurement Systems (PMS), beyond what is typically suggested in general performance measurement literature. A PMS can support the implementation of Lean Production by evaluating the impacts of changes and providing information to guide organizations through this process. Some companies have adopted additional metrics during Lean implementation, but often limited to indicators related to the Last Planner System. Most companies still use traditional production control metrics, like cost, time deviation and project progress. There are opportunities for enhance performance measurement in Lean implementation programs, especially by incorporating leading indicators related to fundamental concepts and principles, such as pull production, work-in-progress, and continuous flow. Performance dashboards play a key role in achieving those objectives, facilitating information distribution across managerial levels, enhancing stakeholder communication, and encouraging participation. The main outcome of this investigation is a set of design principles (i.e. general recommendations that support decision-making in the design of a solution) and design prescriptions (i.e. suggested course of action for a given circumstance to achieve a certain effect) to guide the development and implementation of performance dashboards. This research is based on two empirical studies conducted in construction companies implementing lean production.

KEYWORDS

Dashboard, Performance Measurement, Indicator, Metric, Visual Management.

INTRODUCTION

The implementation of the Lean Production philosophy in construction creates additional demands for Performance Measurement Systems (PMS), in relation to what is suggested in general literature on performance measurement (PM) (Maskel, 1991). In fact, the literature suggests that the development of a PMS can play a major role in the introduction of any new managerial approaches, such as the Lean philosophy (Sarhan and Fox, 2013). PMS can support the implementation of Lean concepts and principles, by evaluating the impact of changes (Zanon et al., 2020) and providing information to guide organizations through this implementation process (Teh and Pang, 1999). A well-balanced PMS that contains a combination of leading and lagging indicators can contribute to cultural changes, reinforcing desired behaviours, values, and beliefs (Bourne et al., 2000; Naslund and Norrman, 2019). It also connects continuous improvement initiatives to strategic objectives, indicating

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opportunities for improvement or the need for changes (Kennerley and Neely, 2003). Most importantly, PMS can be used to highlight intermediate benefits, such as increased management capacity, reduced work-in-progress (WIP), faster identification of problems and a greater willingness to change (Crawford and Cox, 1990). It is important to highlight these improvements in order to maintain the motivation and support of different stakeholders in the change process, as some goals normally established in these programs, such as improving costs and time performance, require a long time to be achieved.

In general, construction companies face many problems related to PM: (1) most metrics are focused on results, being ineffective to support real-time decisions (Sarhan and Fox, 2013) (2) some PMS contain too many metrics, mostly focused on supporting rather than critical processes (Costa and Formoso, 2004); (3) the conception of PMS is often limited to the selection of isolated metrics (Beatham et al., 2004); and (4) PMS are poorly integrated into continuous improvement initiatives (Kennerley and Neely, 2003). Moreover, the inappropriate use of PMS is a critical factor in the failure of Lean implementation programmes in construction (Sarhan and Fox, 2013). Some still use traditional production control metrics, such as cost and time deviation, which are strongly based on the thermostat model; in that context control means to meet a predefined standard by correcting deviations, without putting much effort into identifying and eliminating the root causes of these deviations (Koskela and Howell, 2002). By contrast, PM in Lean Production systems should point out different types of problems and support a deep understanding of the main problems (Koskela and Howell, 2002), which can be considered as sources of creative tension for continuous improvement (Spear and Bowen, 1999). Moreover, PMS should provide information that will be used as a reference for improving and learning (Pavlov and Bourne, 2011).

Some companies often adopt additional metrics during the implementation of Lean Construction, but these are often limited to indicators related to the Last Planner System (LPS) (España et al., 2012; Sacks et al., 2017), such as PPC, effectiveness in constraint removal, and causes for the non-completion of plans. Therefore, there are opportunities for improving PM in Lean implementation programs, especially by using some leading indicators related to fundamental concepts and principles, such as pull production, WIP, and continuous flow. Performance Dashboards (PDs) also play a key role in the achievement of those objectives as they create information fields that support the distribution of information among different managerial levels (Waal and Counet, 2008), improve communication between stakeholders (Bititci et al., 2016), and foster people's participation (Greif, 1991). Through the combined analysis of indicators, PDs make it possible to carry out more consistent evaluations and scenario projections (Pauwels et al., 2009).

The research question that guided this investigation is "How to develop and implement PDs as a visual management device that supports Lean implementation in construction companies?". This investigation is focused on the performance of construction production systems which can be assessed considering different dimensions: efficiency, lead-time, quality, safety, environmental impact, etc. The main outcome of this investigation is a set of design principles and prescriptions that can provide guidance for the development and implementation of PDs. This study is part of a doctoral research study that aimed to propose a prescriptive knowledge framework that consists of a set of preliminary propositions for design principles and prescriptions for the development of PMS to support the implementation of the Lean philosophy in construction companies (Barth, 2023).

PERFORMANCE DASHBOARDS

The purpose of a PMS is to quantify the efficiency and effectiveness of the actions established (Neely et al., 2005). This objective can be analyzed in relation to the achievement of corporate strategies, in relation to improvement programs, or in terms of local improvements (Bourne et al., 2000). Besides, a PMS has the purpose of supporting decision-making and fostering learning and continuous improvement (Franco-Santos et al., 2007). In addition, PMS can contribute to increase process transparency, a core Lean principle, by making visible some invisible process attributes.

PDs are visual management artefacts that bring together important information to support the achievement of one or more objectives, consolidated and organized in a single interface, so that the information can be combined and quickly analysed by users (Yigitbasioglu and Velcu, 2012; Vilarinho et al., 2018). Visual devices are considered as a means for improving the performance of production systems (Valente et al., 2019), but it is through their effective use that this mechanism can achieve its full potential (Parry and Turner, 2006). As a visual device that supports PMS (Bititci et al., 2016; Eckerson, 2011), a PD has the functions of: (i) support decision-making process (DeBusk et al., 2003; Sarikaya et al., 2019); (ii) allow monitoring of projects toward goals and strategies (DeBusk et al., 2003; Cahyadi and Prananto, 2015); (iii) promote a flow of information supporting communication within the company (Pauwels et al., 2009; Vázquez-Ingelmo et al., 2020); (iv) facilitate prioritization (Yigitbasioglu and Velcu, 2012); (v) support improvement and learning (Parry and Turner, 2006; Cahyadi and Prananto, 2015; Vilarinho et al., 2018); and (vi) encourage the delivery of consistent information (Pauwels et al 2009; Yigitbasioglu and Velcu, 2012).

Like any visual management device, the development of a PD includes a visual and a non-visual portion (Nicolini, 2007). Developing a visual management system involves much more than just designing the device itself (Valente et al., 2019). Some authors use the image of an iceberg to illustrate that the visual device itself (PD) is the small portion of ice that arises above water, while most of the work remains submerged (Eckerson, 2011; Valente et al., 2019). In fact, Valente et al. (2019) suggests that the development of a visual management practice should start by the analysing of the process (identifying main problems, potential causes, and who is involved), then identify users' needs (which information is relevant and what is the purpose of the tool), integrate the visual device into the process or routine (whether it is necessary to perform coordination tasks and promote collaboration), and conclude by defining the attributes of the visual device (the only stage that involves visual work).

Knowing those attributes helps to design visual devices that are in line with the needs of users and the company (Cahyadi and Prananto, 2015). In terms of visual elements, PDs should communicate ideas clearly and effectively. The use of colours, signs, symbols, and graphs can support prioritisation, alerting the user to what needs more attention (Yigitbasioglu and Velcu, 2012). Visual elements should draw the user's attention to the content of the data, avoiding redundant or unnecessary information. Dynamic PDs can be used to show different levels of data granularity for users at different hierarchical levels (Cahyadi and Prananto, 2015). Lower-level PDs should provide additional information (details, views, and perspectives) that enable users to understand problems in more detail (Eckerson, 2011).

Regarding non-visual elements, it is important to devise a database that allows data to be properly organised in order to keep a historical report on the company (Cahyadi and Prananto, 2015). PDs must be integrated with this database so that users can access the information when necessary (Yigitbasioglu and Velcu, 2012). One important concern is the IT system to be used (Cahyadi and Prananto, 2015). Business Intelligence (BI) systems are often used to detail information and analyse scenarios (Eckerson, 2011). However, the wrong use of IT can lead to a loss of focus on what is most important and hinder the use of PDs (Nicolini, 2007).

Although PDs have become popular as management tools, the literature does not reflect this trend. Various publications aimed at professionals, such as articles in the business press (Miller and Cioffi, 2004) and textbooks (e.g., Eckerson, 2011 and Few, 2006) discuss the format for visualising information on PDs, how to monitor and measure business with PDs and how PDs should be designed. However, only a few studies on the use of PDs to support PM can be found in academic journals (e.g. Bititci et al., 2016; Cahyadi and Prananto, 2015; Pauwels et al., 2009; Vilarinho et al., 2018; Yigitbasioglu and Velcu, 2012), and even fewer studies related to construction companies. Only 5 papers discussing PDs have been found in the IGLC proceedings (Barth & Formoso, 2008; Wong et al., 2009; Bølviken et al., 2017; Amaral et al., 2020; Amaral et al., 2022), and only three of them deal directly with the development of PDs.

RESEARCH METHOD

Design Science Research (DSR) was the methodological approach adopted in this investigation. This approach has a prescriptive character, and consists of developing solution concepts, called "artefacts", to solve classes of problems (van Aken, 2004; Holmstrom and Ketokivi, 2009). The artefact proposed in this research consists of a set of *preliminary propositions for design principles and prescriptions* for the development and implementation of PDs. This research has explored the development of PMS to support Lean implementation programs, considering production management in construction companies as the application context. A *design prescription* can be defined as a suggested course of action for a given circumstance to achieve a certain effect (Ropohl, 1997), while *design principles* are categories of prescriptions, i.e., general recommendations that support decision-making in the design of a solution or artefact (Vaishnavi and Kuechler, 2007). The artefact was developed as the result of two empirical studies, through collaborative work with two companies. Therefore, the research method can be positioned as *action design research*, i.e., design, implementation, and evaluation of an artefact collaboratively with potential users (Sein et al., 2011).

The two companies (Company A and B) were chosen because both had been involved in long-term programmes for implementing Lean concepts and practices in production management and also due to their interest in improving their PMS. Company A, founded in 1922, is one of Brazil's largest retailers, specialised in the sale of apparel, and acts as a client for commercial building projects. Annually, this company has 40 to 60 small-sized, fast projects, most of them refurbishments. Company B, founded in 1965, is a large firm that develops and builds residential building projects for lower-, middle-, and upper middle-class markets in Chile. Power BI was the IT platform chosen by Company A to support PM and the use of PDs, while Company B managed their metrics by using MS Excel.

The two empirical studies were divided into three stages: understanding the problem in its context; developing and implementing the PMS; and analysing and evaluating the PMS. There were some iterations between those stages, as in any DSR project. Besides understanding the real problem, the first stage had the objective of raising awareness and formalise a plan to develop a PMS to support the Lean improvement programme. Development and implementation stage was made up of several cycles for the creation of the artefact: planning, action (gradual implementation of the artefact), evaluation and reflection, which are typical of the iterative cycles of action design research (Holmstrom and Ketokivi, 2009). In practice, there was no separation between development and implementation. Rather, there was an initial emphasis on the development (construction) of the PMS when it was being conceived. When the team felt that the prototype was ready to be tested, the emphasis shifted to action, evaluation, and reflection. What divided the development from the implementation was the decision by each of the companies to allocate an internal team in charge of implementing the PMS. The "analysis and evaluation" stage was carried out individually for each company, considering the prototype implemented.

At the beginning of each empirical study, a working group, named "PMS Group" was created, to support the development of this research. This group was made up of representatives from different departments of the organization and the first author of this paper. There were meetings every other week during the development of each empirical study. Occasionally, other company representatives were invited to support the discussion on specific topics.

The set of requirements for PMS proposed by Barth and Formoso (2021) was used as the basis for the development of the PMS Group's work. It began with the development of **maps of objectives and strategic actions** for the Lean implementation program in each company, with the aim of explaining and prioritizing implementation actions in the development of the PMS. From the elaboration of those maps, the PMS Group proceeded with defining the elements of PMS, which encompass not only the indicators themselves, but also PDs and cycles of learning and continuous improvement within the PMS. These cycles involve decision-making instances, reports, assigned responsibilities, frequency, and inputs and outputs for each stage. After several discussions among the PMS Group, a proposal of PMS emerged and was presented to representatives of each company. The proposal was refined based on the suggestions made from those professionals and moved on to implementation. The PMS Group continued to refine the PMS proposal along the implementation process.

In both empirical studies, the PDs were partially implemented due to time and human resource constraints on the part of the companies. At Company B, the **planning** and **operational PDs** were tested, but the proposed **tactical** and **strategic PDs** were presented to the company representatives in a mock-up format. At Company A, the **planning PD** was tested, and the **operational** and **tactical PDs** proposals were delivered in mock-up format. Strategic **PD** was not part of the research at Company A.

Multiple sources of evidence were used, including participant observation (LPS meetings, PMS Group meetings, and meetings with professionals from the companies studied), direct observation during visits to construction sites, individual and group interviews, document analysis, analysis of existing software tools and existing company databases. Table 1 summarises the time spent in each source of evidence for different research stages.

Table 1: Summary of hours spent in each source of evidence for different research stages.

Stage	Source of Evidence	Company A	Company B
Understanding	Participant observation	23,8hr	26,5hr
	Direct observation	6,0hr	13,5hr
	Individual and group interviews	12,5hr	5,0hr
Development and implementation	Participant observation	61,5hr	106,5hr
	Individual and group interviews	2,0hr	-
Analysis and evaluation	Participant observation	15,8hr	1,5hr
	Individual and group interviews	-	6,3hr
Total		121,5hr	159,3hr

RESULTS

MAPS FOR THE LEAN IMPLEMENTATION PROGRAM

The PMS Group developed maps of goals and strategic actions for the Lean implementation program, in the short, medium, and long term (Figure 1). Intermediate goals were defined based on long-term strategic goals, which were the point of departure to establish actions connected to the Lean implementation program. Those actions were distributed across seven managerial processes: (1) production, (2) quality, (3) design and BIM, (4) people, (5) costs, (6) supply chain, and (7) performance measurement and learning.

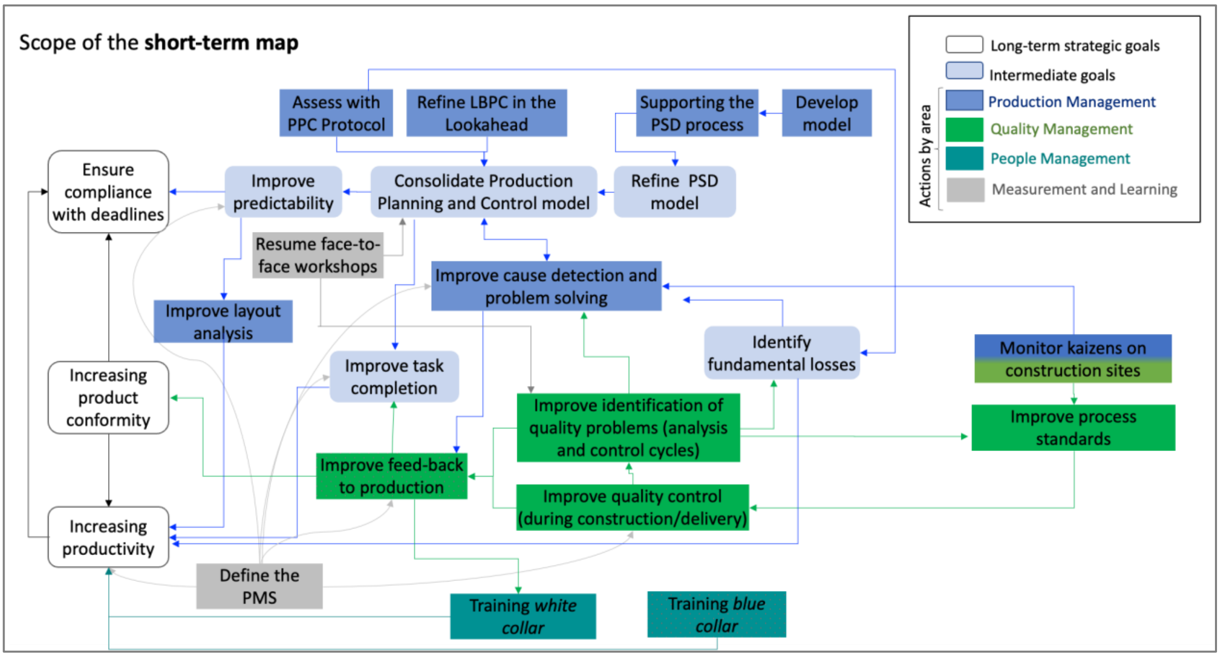


Figure 1: Example map of goals and strategic actions for the Lean program.

INCLUSION OF NEW INDICATORS

In an effort to assess the performance of production management, considering some core Lean principles, the PMS Group suggested the inclusion of new indicators. Adherence to planned batches, cycle time and tagging differentiated work packages (e.g. rework, non-planned work packages, etc.) were proposed to monitor WIP. Indicators were also proposed to assess the status of production, based on a tool named production status matrix, and to monitor the rhythm of activities being carried out (control of batch completion rhythm) (Barth and Formoso, 2021), as well as metrics for projecting the conclusion of the construction stage.

The planned batch adherence graph compares the planned start and finish of each batch with the actual start and finish. This graph also makes a projection of the expected start and finish dates on the basis of the data obtained on the same batch, allowing improvement actions to be taken in time to change unwanted results. The cycle time graph complements this information, in which variations can be monitored. Tagging differentiated work packages graph is a stratification of the work packages planned and executed in the short-term plan, which are labelled according to their nature (informal activities, rework activities, percentage of backlog activities that are executed, etc.). A high volume of informal work indicates that part of the workforce capacity is being planned informally and may be being used to execute activities that do not add value.

The development and implementation of these indicators was carried out in collaboration with its representatives of each company, in pilot projects. During those pilot projects, the need to develop a database to organize the information generated by the PMS was identified. The PMS Group was in charge of developing a database by using MS Excel spreadsheets, seeking to automate data collection based on existing controls. It is important to emphasise that most of the indicators proposed in this research work can be obtained from a small number of control tools, as there was a concern with limiting the data collection effort. Adherence to planned batches, cycle time, control of batch completion rhythm, project completion projection can be obtained from the status control matrix. Differentiated work packages can be identified in short-term plans.

Performance Dashboards

Based on the definition of new indicators and the construction of the database, each PMS Group devised a set of **planning PDs**, which evolved throughout discussions with representatives of different areas of the company. PDs were developed for the operational, tactical, and strategic levels. Moreover, some specific PDs were developed according to requirements of each company. Company A, for instance, chose to use a PD that grouped together short- and medium-term SLP indicators, while Company B chose to use a PD for each planning horizon. In Company B, in addition to the typical LPS indicators, the medium-term PD had a strong emphasis on location-based planning and control (LBPC) indicators (adherence to planned batches and cycle time). Due to space limitations, only operational and tactical PDs developed for Company B are presented in this paper. A complete description of all PDs is presented in Barth (2023).

The **operational PD** (Figure 2) groups together the indicators of one project divided into five zones: cost, labour efficiency, quality, project deadline and planning. A second interface of the operational PD also contains graphs of LBPC indicators for some processes considered critical to the projects. Moreover, the **production status matrix** is presented as part of the operational PD in company B (Figure 3), where it is possible to monitor fully completed batches, WIP, rework and interrupted work.

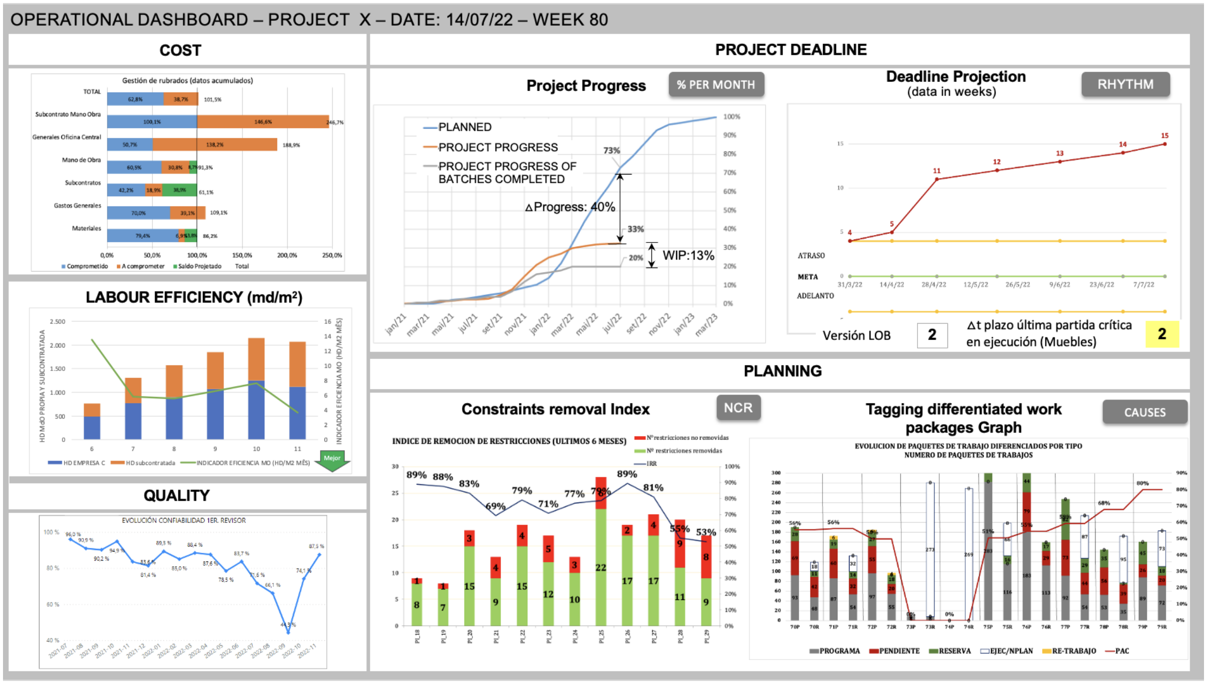
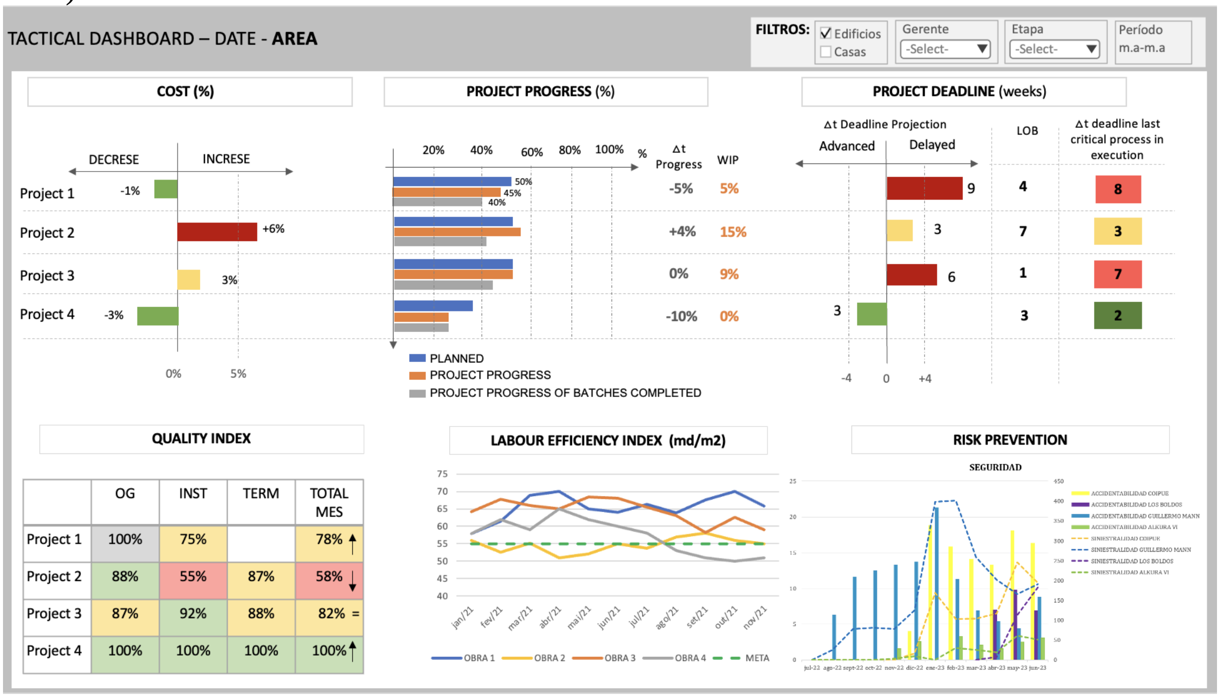


Figure 2: Example of Operational PD for residential building project.

LOCATION HIERARCHY		ACTIVITIES																													
IST LEVEL BATCHES (FLOORS)	2ND LEVEL BATCHES (APARTMENTS)	ACTIVITY 1	ACTIVITY 2	ACTIVITY 3	ACTIVITY 4	ACTIVITY 5	ACTIVITY 6	ACTIVITY 7	ACTIVITY 8	ACTIVITY 9	ACTIVITY 10	ACTIVITY 11	ACTIVITY 12	ACTIVITY 13	ACTIVITY 14	ACTIVITY 15	ACTIVITY 16	ACTIVITY 17	ACTIVITY 18	ACTIVITY 19	ACTIVITY 20	ACTIVITY 21	ACTIVITY 22	ACTIVITY 23	ACTIVITY 24	ACTIVITY 25	ACTIVITY 26	ACTIVITY 27	ACTIVITY 28	ACTIVITY 29	ACTIVITY 30
6	7	T	T	T	T	T	T	T	T	T	T	T																			
	6	T	T	T	T	T	T	T	T	T	T	T																			
	5	T	T	R	T	T	T	T	T	T	T	T		P																	
	4	T	T	T	T	T	T	D	T	T	T	T		P																	
	3	T	T	T	T	T	T	T	T	T	T	T		D																	
	1	T	T	T	T	T	T	T	T	T	T	T		P																	
	2	T	T	T	T	T	T	T	T	T	T	T		P																	
5	7	T	T	T	T	T	T	T	D	T	T	T	D	T	T	D															
	6	T	T	T	T	T	T	T	R	T	T	T	T	T	P	D															
	5	T	T	T	T	T	T	T	T	T	T	T	T	D	T	T	P														
	4	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	P														
	3	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	P														
	1	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	P														
	2	T	T	T	T	T	T	T	T	T	T	T	T	R	T	D	P														

Figure 3: Extract of the Production Status Matrix: part of the operational PD.

The tactical PD (Figure 4) enables comparisons between projects to be made, supporting meetings involving the whole production management staff, in which information is exchanged between site managers from different projects and the top production manager. The **tactical PD** was divided into six areas: cost, project progress, project duration, quality, labour productivity and safety management. The **strategic PD** was divided into four zones: planning (including time deviation, and project progress with and without batch completion), cost (cost deviation), quality conformance, and labour utilisation metrics (outcomes measured by area and monetary units).



	OG	INST	TERM	TOTAL MES
Project 1	100%	75%		78% ↑
Project 2	88%	55%	87%	58% ↓
Project 3	87%	92%	88%	82% =
Project 4	100%	100%	100%	100% ↑

Figure 4: Example of Tactical PD for residential building project.

ESTABLISHMENT OF DECISION-MAKING INSTANCES

Some decision-making formal instances were defined in order to formally define control points and learning cycles for continuous improvement. Those control points must be regarded as moments for analysis and reflection, based on indicators connected via PDs. In fact, some regular meetings that already existed in the companies were adapted to include PD analysis. In Company B, the short-term planning PD was used to discuss the results at the weekly commitment planning meeting, whereas the medium-term planning PD was used in look-ahead meetings every fortnight. The operational PD was connected to a monthly meeting between the Site Manager and the Project Manager, named operational meeting. The tactical PD was used for a monthly meeting between each Project Manager and the company Overall Construction Manager, to present the results of the projects under the responsibility of the former. In addition, a lessons-learned meeting was held three times a year, in which Project Managers presented good practices and improvement opportunities identified in the projects completed during the period.

NON-VISUAL ELEMENTS

For each proposed PD, the PMS Group defined a person in charge for compiling the indicators and generating the reports. This is concern with the non-visual part of the PMS, that is necessary to generate an update version of the visual device (Valente et al., 2019). The flow of information generated by the PDs had to be made clear, to make reliable connections between operational, tactical, and strategic PDs. In this flow, the goals are broken down from the strategic level, through the tactical PD, up to the operational level. This allows a user at the strategic level to access detailed information by using the tactical and operational PDs, when necessary, as suggested by Eckerson (2011) and Cahyadi and Prananto (2015). At the operational level, goals and feedback are also disseminated among the construction site teams. The information generated by PM at the operational level, feeds back into the tactical and strategic levels, creating a bottom-up and top-down flow, as suggested by Bhasin (2012).

DESIGN PRINCIPLES AND PRESCRIPTIONS

Based on the literature review and the two empirical studies, five design principles and 8 prescriptions for developing and implementing PDs to support production management in construction companies was proposed. Some of the observed practices involved in the implementation of PMSs of the two empirical studies are presented as examples of the application of the set of principles and prescriptions.

Principle 1: Include a set of leading and lagging indicators that complement each other and help overcoming limitations of individual metrics.

Prescription: Use combined controls to anticipate future results. Practice identified: analysis of project progress (lagging indicators) combined with plan reliability (PPC), status of WIP and delivery projections (leading indicators) and rhythm curves.

Principle 2: Promote improvement and learning.

Prescription: Identify emergent connections between indicators as a way of learning. Practice identified: the users of the PD identified that the higher the degree of completeness of batches, the better the quality of the final product, considering that fewer assessment and finishing tasks needs to be carried out.

Principle 3: Support decision-making by providing meaningful and timely feedback to users.

Prescription: Identify the information needs of different stakeholders. The choice of indicators and the way they are displayed depend on the specific needs and knowledge of each user (e.g., managers, workers, and subcontractors). *Practice identified:* PDs were designed to include both the information required by their direct users and the information considered important by those who assess performance at different managerial levels.

Prescription: *Use PDs as visual management devices*. Visual devices must be designed for users and made available so that the necessary information is accessible (Valente et al., 2017). *Practice identified*: the use of dashboards to monitor production status, giving visibility to the situation in each production batch, and at the same time providing data on cycle time, WIP, and task completeness.

Prescription: *Connect PD analyses to a decision-making instance. Practice identified*: PDs need to be connected to formal meetings (e.g. LPS meetings), otherwise they are not systematically used. Note that this is a requirement, but simply connecting PDs to instances of analysis and reflection does not guarantee that they will be used for decision-making. The combination of different design principles is what makes it possible to achieve the desired effects.

Prescription: *Use IT to develop PDs and automate data collection and processing, and define the human resources for implementation.* IT helps to reduce the time and effort needed to collect and process data (Bhasin, 2012), but it is also important to assign tasks to those responsible for conducting this process. *Practice identified:* use of business intelligence software or spreadsheets to introduce automation in the generation of PDs. This prescription was partially implemented in the two empirical studies.

Principle 4: Show production status.

Prescription: Monitor production status by using the status control matrix. Monitoring the system status makes it possible to apply pull production, defined by Hopp and Spearman (1996) as authorising the release of work based on the status of the system, in order to avoid WIP. Practice identified: Use of leading indicators and visual devices (production status matrix) to monitor production status.

Principle 5: Provide information to deal with variability that cannot be removed.

Prescription: Give visibility to processes and results. Construction projects, like other complex systems, are characterised by a high degree of variability that cannot be fully removed (Williams, 1999). The PMS must provide information that makes complexity visible so that people can learn from information about anomalies and informal practices. *Practices identified:* Measurement of informal practices, represented in the differentiated work packages chart at the operational PD; making explicit non-visual work in the process of generating PDs and the staff responsible for that.

Some of the proposed prescriptions are related to the conception of PD, whereas others are concerned with their implementation, such as “identify emergent connections between indicators as a way of learning”, “use PD as visual management devices”, and “connect PD analyses to a decision-making instance”.

CONCLUSIONS

The main outcome of this research work is a set of 5 design principles and 8 prescriptions for the development and implementation of PDs to support production management in construction companies. Those PDs have played an important role in the Lean implementation programs of the companies involved in this research study, as they have made the use of PM more systematic, and introduced a number of metrics related to Lean concepts, which are not usually adopted in construction companies. The implementation of the PDs required explicit planning of the non-visual activities needed to generate the necessary metrics, as well as the establishment of formal meetings for analysis and reflection. The use of these visual management devices made it possible to explore connections between the indicators, resulting in analyses more consistent with the reality of the projects. The use of PDs was promoted by connecting them to decision-making instances (LPS and other formal meetings), which encouraged the frequent updating of the indicators that were part of the PMS. In addition, the PDs made it possible to make the flow of information between the different hierarchical levels transparent.

Further work is necessary in the assessment and refinement of the proposed knowledge framework (design principles, prescriptions, and practices) so that it can be widely used in the implementation of Lean Construction. This is considered the main limitation of the proposed artefact.

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