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A LOGISTIC FRAMEWORK TO ENABLE TAKT TIME PLANNING

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ABSTRACT

Takt Time Planning (TTP) methodology has gained growing popularity in lean construction, with the aim of improving workflow and increasing production stability. Despite the numerous research efforts surrounding TTP, there is a gap in understanding how logistics planning should support TTP in a construction project. This study presents a framework for developing logistics in a construction project that uses TTP as its planning method. The framework consists of four drivers: (a) equipment sizing, (b) layout risk study and analysis, (c) material management, and (d) structuring of daily routes and routines. The results show that the integration of TTP into the logistics framework allowed for the design of the production system to ensure Takt, and to structure a rapid response to the variations found during the LPS control cycles. Hence, the project deadline was reduce by 16.4%, or 4 months.

KEYWORDS

Takt Planning, WorkFlow, Last Planner System, Logistic

INTRODUCTION

In the last decade, it is possible to observe a growing application of the Takt planning method in the lean construction. Among the main benefits achieved with the methodology, we have better team organization, better transparency, reduction of handoffs between sequential teams, reduction of cycle time, increased productivity, reduction of project duration in construction, among others (Yaw et al., 2020; Dlouhy et al., 2019; Binninger et al., 2018; Frandson et al., 2014).

Takt Planning is a structured planning method that brings a perspective of workflow and rhythm to civil construction, since it organizes the sequence of locations that should receive tasks in a construction site and, at the same time, synchronizes the execution of these tasks around a Takt time (Frandson, 2019). Takt time is a unit of time that represents the rate at which a product must be completed to meet customer demand in a specific period of time (Hopp; Spearman, 2004). According to Binninger et al (2018), one of the differentials of Takt Planning, when compared to traditional methods of construction planning, is the fact that services are produced at a constant rate, allowing a reliable pre-planning of activities. Gardarson et al (2019) points out that Takt Planning can be represented as a train with several wagons that move through the areas of a project. In this format, the wagons are different groups of workers who complete a set of tasks before moving to the next area, being followed by another wagon of workers who will complete their respective tasks (Gardarson et al, 2019).

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Vatne and Drevland (2016) signal the important role of logistics for the successful application of Takt. According to Lehtovaara et al. (2019), one of the main barriers to Takt Planning is precisely logistics planning and material control. Tommelein and Emdanat (2022) corroborate this thinking, and suggest a correlation between Takt and logistics planning. If, on the one hand, Takt analysis is an input to logistics planning, on the other hand, logistics can become a bottleneck for the application of Takt, since the dimensioning of transport equipment, the space for storage and movement interference of equipment can make a Takt unfeasible to be applied in a project (Tommelein; Emdanat, 2022).

Recently, Al Barazi et al (2021) demonstrated the potential of simulation methods, such as Agent Based Modeling, for logistics simulation in vertical construction sites, with the goal of fulfilling a hypothetical Takt planning. In this study, it was possible to identify the best number of equipment according to variables such as elevator capacity and speed, storage capacity on site, lunch and snack time, etc. Tetik et al. (2019) set out to analyze the benefits of using appropriate logistics solutions for Takt application in construction. The research focused on the logistics solution of material picking and kitting in Assembly and Logistics Unit (ALU), identifying that the main benefits were related to the reduction of material waste, ability to follow the predetermined Takt sequence, and a better quality of acquisition (Tetik et al., 2019).

While recognizing the significance of logistics in realizing the expected advantages of Takt planning, there is a lack of practical research that illustrates how to establish logistics in a project to fulfil predetermined Takt time. Hence, it is crucial to devise a Takt planning while simultaneously designing and executing logistics strategies for the construction site. The purpose of this article, therefore, is to demonstrate the utilization of a logistics framework to fulfil Takt planning through a case study.

METHOD

The research is positioned as Design Science Research, in which innovative constructions (or artifacts) are developed, designed to solve classes of problems encountered in the real world and, at the same time, make theoretical contributions (Lukka, 2003). The artifact proposed in the present study is a logistics framework motivated by the systematics of Takt time planning. In this type of study, the starting point for conducting the research is the knowledge of a set of practical problems (Van Aken, 2004), in this case, the design and execution of logistics strategies that guarantee the transformation of the construction site to comply with the Takt time requirements.

The framework was developed during a case study about a housing project with 23 residential towers in 5-storey structural bricklaying, totaling 1180 apartments, divided into 3 distinct contracts (Figure 1).

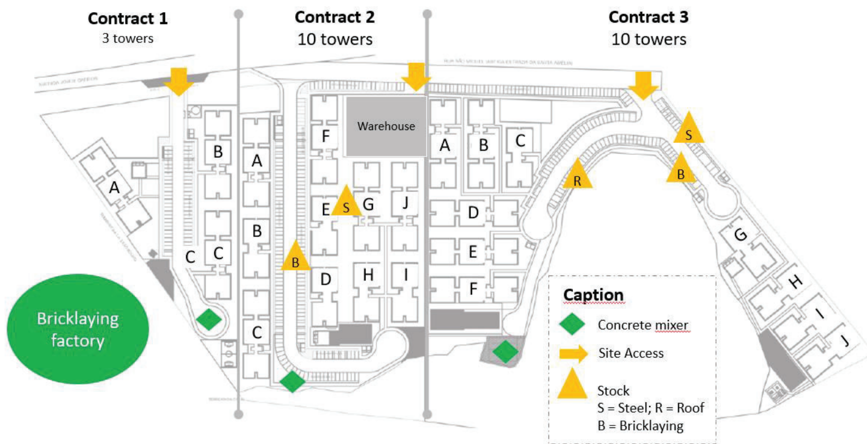


Figure 1: Location of the towers and construction site facilities

The contractor of this project was interested in implementing Lean practices, hiring a consulting company for this purpose (implementation period from September 2021 to February 2022, total of 6 months). At the time of the diagnosis carried out by the consulting company in September 2021, only masonry structural walls and structured concrete slab activities had started, and the project still had 15 months left until its completion (September 2021 to October 2022). Due to the project being divided into 3 contracts with the same due date, during the diagnosis phase there was a scenario of a large amount of work in progress, since all 23 towers had initiated structural activities, but none of them had advanced to the 5th floor. In this regard, the deadline, inicially October 2022, pointed to a 5-month delay trend, going until March 2023.

Thus, in addition to Last Planner System routines, we proposed the deployment of a TTP and a logistics system that would allow the project to be delivered on time. The biggest challenge in this project was to scale the logistics system, as well as to be able to maintain the Takt of the productive activities, since the construction site had approximately 75,000 m², 800 employees during its peak of execution and a complex system of material and transport centers, as shown in Figure .

This research presents three distinct steps: (a) definition of Takt and structuring of the logistics system; (b) development of logistics strategies; and (c) evaluation of the logistic system implemented. The development of these steps is described in detail below. As sources of evidence it is possible to highlight: (i) participant observation of the authors of this paper at the construction site and at LPS meetings, acting as project consultants; (ii) reports on the status of the consulting project, periodically developed during the consulting; (iii) result and process indicators applied during the consulting period until the end of the construction project; and (iv) logistics checklist (Fireman et al, 2023).

DEFINITION OF TAKT AND LOGISTICS FRAMEWORK

Takt definition was carried out according to Equation 1 , in which we used 80% of practicability, because the construction site presents horizontal characteristics and external activities, which were very affected by climatic conditions. The available time, number of repetitions and number of activities vary according to activity groups, called "trains" in the case study, and assumptions of initial projects. It is important to point out that although the praticability factor is sometimes implicit in the calculation of available time in the literature, here we prefer to use it explicitly.

$$Takt = \frac{available\ time\ *\ 80\%\ practicability}{(repetitions + number\ of\ activities - 1)} \qquad \text{Equation 1}$$

To define the Takt, a mapping of the construction sequence was designed, and we identified the existence of 17 internal and 9 external activities for each Takt area. However, at that time, there were still restrictions with long lead time that had not been hired, for example the ceramics tiles, which would take 180 days, and the materials for gas system installation that had a lead time of 90 days. Due to these factors and prerequisites, such as safety buffer and executive sequence restrictions between internal and external activities, the Takt application strategy for the entire construction site was divided into groups of activities, creating 5 trains, as described below and outlined in Figure 3:

a) masonry structural walls and structured concrete slab activities had already started and had no initial prerequisite, thus, their Takt was calculated separately;
b) train 1 corresponds to electrical and plumbing installation activities, waterproofing and cementitious floor underlayment, without time restrictions, but not yet started;
c) train 2 corresponds to gas system installation and gypsum coating activities (due to gas lead time this activity train would have less time available than train 1);
d) train 3 corresponds from ceramic tiles activities until the end of internal activities (it would also have less available time than train 2 due to ceramic tiles lead time);
e) train 4 corresponds to façade activities, which can only start when the first roof top structure of the towers is completed;
f) train 5 corresponds to façade activities after the first window installation (internal activity), and must be completed one month before the end of the work.
g)

	Takt Area	**Repetitions**	**Number of Activities**	**Lead time (days)**	**Available time (days)**	**Takt (days)**
masonry structural walls	Apartments	69	1		204	2,37
structured concrete slab	Apartments	82	1		210	2,05
Train 1	Flooring		3		283	1,94
Train 2	Flooring	115	2	90	224	1,54
Train 3	Flooring		10	180	220	1,42
Train 4	façade modules	59	5		219	2,78
Train 5	façade modules		4		170	2,19

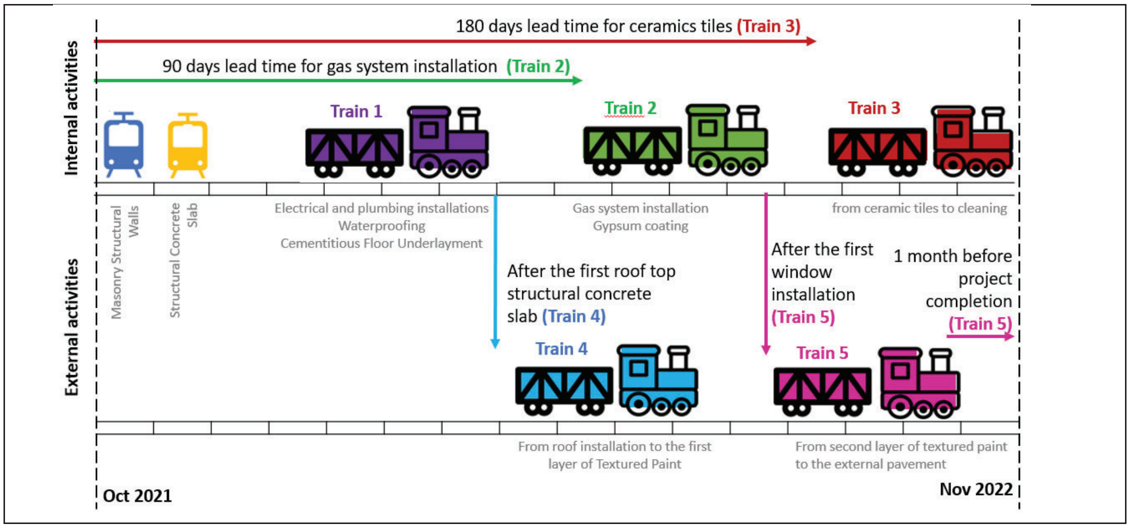


Figure 2: Takt Calculation table

Soon after the definition of the planned Takt, it was necessary to establish logistical planning and control that would allow to meet the TTP. Thus, the framework presented in Figure 3 was proposed, containing four drivers: (a) equipment sizing; (b) layout potential risk study and analysis; (c) material management; and (d) structuring of daily routes and routines. Evaluation of these drives is presented in Fireman et al (2023). In this article, we will present the use of this framework as a logistic strategies structurer carried out in the analyzed case.

Figure 3: Logistic Framework

EQUIPMENT DRIVER

Since demand sizing is done by input, a total of 48 inputs were studied. This was carried out through the Takt area, considering the storage of input in batches and the number of batches that can be transported by equipment (Figure 4). Thus, as an example, for each apartment unit, 73 sqm of ceramic tiles is required. These are transported in boxes, which can store 2,12 sqm of ceramic tiles each. Each pallet can carry 32 boxes and only 5 pallets can be transported by each truck, due to volume and weight restrictions. At the end, as shown in Figure 5, 197 ceramic tiles travels are required to supply the 1,180 apartments (Takt areas).

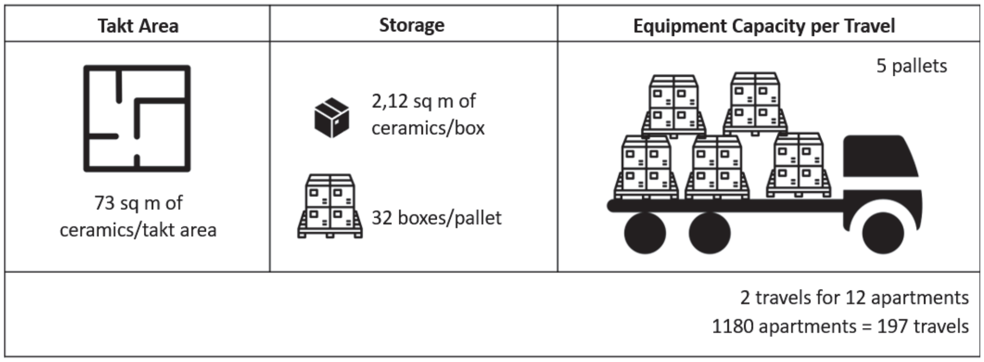


Figure 4: Example of quantification of materials by input and Takt area

For the equipment to meet the TTP, it was necessary to size the number of travels per type of equipment per input, characterizing the necessary demand. Soon after, this demand was compared with the current capacity of the equipment on site (data collected daily during the project). Table 1 presents the comparison between demand and capacity of critical equipment. Since demand is bigger than capacity, it was necessary to exchange supply equipment for input, and a fuel supply pump was allocated on site to reduce the set-up time of such equipment.

Table 1: demand versus capacity of critical equipment

Equipment	Demand (peak)	Capacity (peak)
Munk	73 trips per day	73 trips per day
Backhoe loader	62 trips per day	57 trips per day

LAYOUT DRIVER

To evaluate potential logistics risks, a layout study was carried out in an analogical manner, where in which each frame represented a period of time and a specific train. Thus, every 3 months it was highlighted in the frame where each of the 5 trains plus the masonry structural walls and structured concrete slab activities would be located. In this way, it was possible to evaluate risks of crossing different workflows, storage locations closest to the towers in construction and pre-assembly locations, such as cutting and folding steel rebars and concrete mixer. Figure 5 shows this layout analyses. Vertically, we have the different trains in different colors, and horizontally each column corresponds to 3 months of the project.

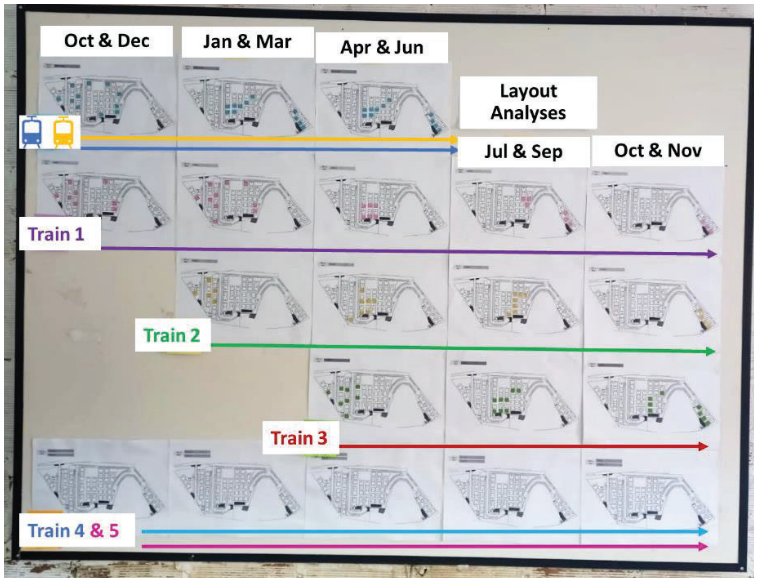


Figure 5: quarterly Layout Study

Then, Figure 6 presents a detailed study for the site's peak working week. It presents, the routes between pre-assemble location (such as cutting and folding steel rebars and concrete mixer) and storage (such as material stocks and warehouses) to workstations. Thus, it was possible to assess the density of workflow and identify the main transportation risks.

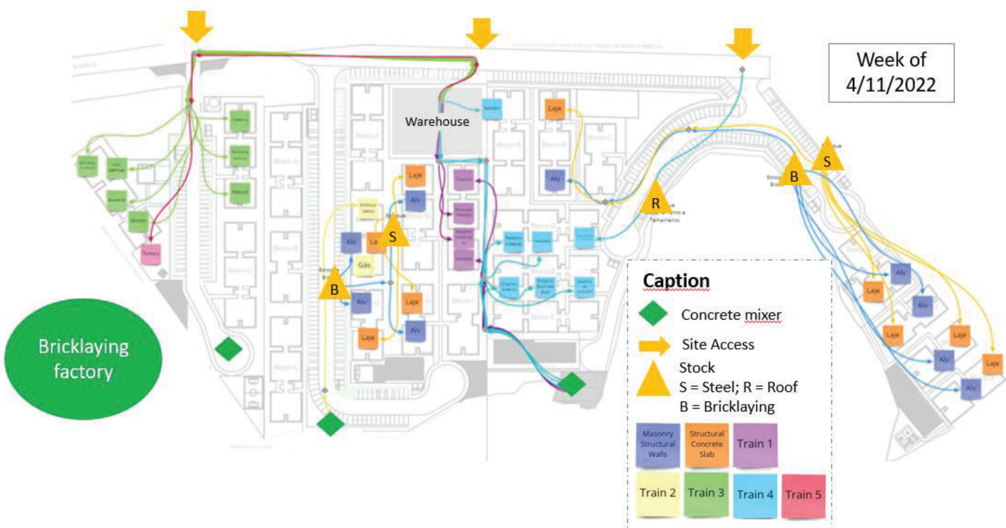


Figure 6: study of routes between production/storage locations and workstations

MATERIAL MANAGEMENT DRIVER

From the tools developed in the layout driver, it was possible to identify different potential risks for material management. The main ones were:

a) assess whether the flow of sand (number of travels per day) would impact the movement of materials at the site, since all concrete was produced at the site in only 3 concrete mixers;

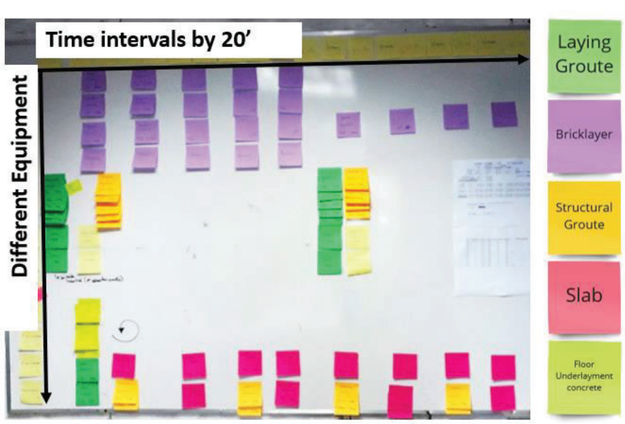
b) define the supply flow of the cementitious floor underlayment, mainly identifying the equipment to be used to avoid possible obstructions to pumps due to density and gravel incorporated into the mixture;
c) definition of evening supplies to avoid route jamming during the teams' working hours;
d) definition of ceramic tiles storage locations at the manufacturer and in front of the towers, since 983 pallets of this input would be needed to build the 1,180 apartments (as discussed in the equipment lever);
e) considering the ceramic tiles to be supply to the floors via a small crane by boxes, since each floor would need 10 pallets, or 320 boxes;
f) considering the installation of the crane in the elevator shaft of the towers in order to vertically supply the apartments;
g) definition of roof tile storage and supply, since it would be necessary to store 5,784 roof tiles for each tower module (the construction project has 59 modules, totaling 341,256 roof tiles for all towers);
h) definition of wood storage and supply for the roof structure, since it would be necessary to receive 4 trucks every 2 weeks (supplier restriction), which could supply the demand of 9 modules.

Thus, during LPS meetings, together with the warehouse manager and the logistics manager, the logistics strategies for these materials were discussed and applied on site.

ROUTE & ROUTINES DRIVER

After defining the three previous levers, it was necessary to implement the equipment Kanban and Check in/out tools for structuring of routes and routines. These tools had as input the sizing of daily goals from TTP and the demand for materials, dealt with in previous stages of the framework.

The equipment Kanban had 5 inputs: laying grout, bricklayer, structural grout, input of slab and cementitious floor underlayment. Kanban was partially implemented - it was not used for hands-off management between workstations and pre-assemble location and storages. But, according to Figure 7(a) the demand for each input was analyzed for each supply equipment (vertical) per hour (horizontal). Initially, the construction team had a certain resistance to the implementation of this tool, but eventually it was used for critical analysis of supply, involving the production engineer, the logistic manager and the foreman.

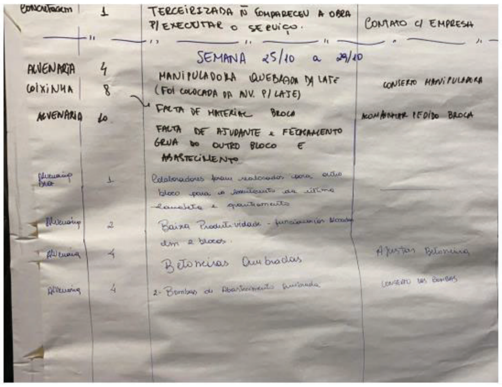


(a) Kanban by equipment (vertical) and time interval (horizontal);

(b) check in/out routine per work front

Figure 7: tools developed for leveraging routes and routine

Check in/out was defined for 13 services (see Figure 7 - b) and played an important role in solving logistical problems at the site. There were a significant number of Reasons for Non-Compliance regarding equipment breakdown and supplies delay. These were reported daily during the Check in/out routine by team leaders. These observations were acted out in daily action plans (see Figure 8a) and helped structuring a fast-problem-solving flow for equipment (see Figure 8b). Because of that, we established more frequent preventive maintenance for certain equipments, such as the external plaster projection pump, shown in Figure8 (b).



(a) notes from check in/out;

(b) evidence of breakage in the external plaster projection pump.

Figure 8: examples of equipment breakdown and help chain management

DISCUSSION

The benefits, as indicated in the literature (Yaw et al., 2020; Dlouhy et al., 2019; Binninger et al., 2018; Frandson et al., 2014), that have been observed with the implementation of the logistics framework are:

a) improved team organization, achieved through the use of layout, material, routes and routines drivers, risk analysis of layout, defining strategies for managing storage and supply of materials, as well as structuring daily production routes and routines.
b) enhanced transparency, facilitated by the visual board implemented in this case study, as in the quarterly layout study (Figure 6), route study (Figure 7), Kanban (Figure 8), and check in/out (Figure 8);
c) increased productivity through the check in/out routine, which facilitated the structuring of a fast-problem-solving action plan for any issues that arose daily.

It was also possible to make progress in sizing the equipment and material to meet the production demand defined by the Takt planning through the equipment and material drivers, which was a barrier described by Lehtovaara et al. (2019). However, logistics strategies such as material picking and kitting in the Assembly and Logistics Unit (ALU), as described by Tetik et al. (2019), could represent an even greater advancement in this driver. Tommelein and Emdanat (2022) have pointed out this synergy between Takt and logistics for the dimensioning of transport equipment, storage space, and interference of equipment movement, which are reflected in the equipment, layout, and materials drivers described in this paper. However, the proposed framework also advances the structuring of routes and routines on the construction site. Therefore, the structured use of these four drivers allowed for the design of the production system to ensure Takt, as pointed out by Tommelein and Emdanat (2022), and a rapid and structured response to the variations found during the LPS control cycles.

Figure 10 presents a comparative analysis of the projected duration. At the time of diagnosis, while there was no prospect of starting any activity other than masonry structural walls and structured concrete slab activities, and without Lean practices implemented, the project duration was 5 months after the contract, totaling 390 days. The actual duration of the project was 326 days, a 16.4% reduction in relation to the projected deadline. In Figure 9, it is possible to identify that if the proposed deadline reduction suggested by TTP was achieved in its entirety, the project end date would be October 2022, according to the contract, representing a potential time reduction of 27.9%. The main roots causes of problems that prevented from the reduction propose by the potential reduction are related to the above-average weather conditions and delays in the supply chain due to lasting COVID-19 effects.

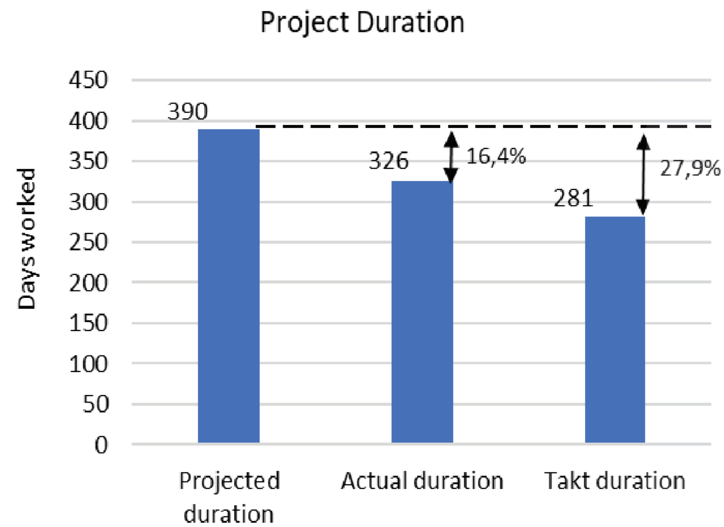


Figure 9: evaluation of the framework drivers

Even with these two roots causes, we understand that the joint application of a logistics framework and TTP contributed to achieve a good performance on the project. But, a limitation of this study is that there is no data to confirm that the 16.4% of reduction was only motivated by the joint application of them.

CONCLUSION

This article fulfills its goal, since it presents the development of logistics strategies considering the drivers of the proposed framework and the TTP. The drivers are: (a) equipment sizing, (b) layout risk study and analysis, (c) material management, and (d) structuring of daily routes and routines. These drivers allow a multivariate analysis with different sources of evidence to identify problems and logistics potential risks, allowing more efficient action plans and acting directly on the root causes. The proposal of this framework can structure both the development and the evaluation of logistics systems to support TTP. In this paper, only the development was explored, but publications focusing on evaluation, such as Fireman et al (2023), can assess the logistics strategies in different contexts, fostering good practices that guarantee Takt enforcement.

Another important paper output was to bring light to some difficulties faced when applying Takt planning. For example, the artifice of creating 5 trains was applied to circumvent some obstacles identified during method application, such as the long lead time restrictions of ceramics tiles and gas system installation or the interference between some internal and external activities, differently from Gardarson et al (2019) approach which these problems did not exist. These obstacles demonstrate that the best time for applying TTP with a focus on the project's macro strategy is before the project begins. If the method it is applied during the project, some services may not act synchronized to a single Takt, and it would be necessary to use more than one train, as present in this paper.

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