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COMPARISON OF PROJECT MANAGEMENT AND LEAN CONSTRUCTION IN A REAL ROAD PROJECT

Keywords: *Lean Construction, Road project, Last Planner System, Percent Plan Complete, Root Cause of Delay, Total project duration*

Abstract

Project Management, PM, refers to the practice of planning, executing and controlling certain tasks to achieve specific goals at the specified time. Applications of this methodology (such as the Gantt chart) are commonly used in construction road projects. In order to increase productivity and reduce project costs, alternative management approaches (such as the Lean Construction, LC) can be followed. In this approach, the lean manufacturing principles are applied to achieve a delivering value with less waste (or in other words, with lower construction time). The aim of this study is to compare the traditional PM and the LC for the construction process of an actual road built in Cairo (Egypt) between the cities of Cairo and Alexandria. In this study, the analysis of certain parameters (such as the percent plan complete, root cause of delays or the total project duration) will be analysed for different construction scenarios. The results of the paper illustrate the advantages of using LC over the traditional PM approach in road projects.

1. INTRODUCTION

Based on Project Management Body Of Knowledge, PMBOK (Rose, 2013), project time management includes the processes to plan and control the total project duration. On the one hand, these processes are as follows: 1) Plan schedule management. 2) Define activities. 3) Sequence activities. 4) Estimate activity resources. 5) Estimate activity durations. 6) Develop schedule. Finaly, controlling the main process is Control schedule.

Toyota Production System (TPS) invented the lean concept and named it Lean Production LP and then it was adapted and applied as Lean Construction. This concept focuses on removing the wastes to meet the customers’ requirements (Sarhan, *et al.*, 2017). This study presents a comparison between the PM Approach and LC with focusing on their impact on time schedule. This comparison will be applied through a simulation model on a real highway construction project, a connection between the centre of the city and the beginning of the main Cairo-Alexandria highway.

The paper is organised as follows: In the first section, a review of previous studies on Project Management approach and Lean Construction is presented with the aim of the main principles and tools of each approach. In the second section, a case study where the different management approaches are compared and presented. In the third section, the results of this comparison are presented. In the fourth section, the results are shown. In the fifth and sixth sections the results are concluded and analysed using some correlations.

2. LITERATURE REVIEW

In this section, a review of previous studies on PM Approach and LC. This state of the art provides useful insights for the comparison of the two approaches.

2.1 Project Management Approach

Project Management Body of Knowledge (Rose, 2013) is focused on the Project Time Management. These areas are: 1) Project Integration Management. 2) Project Scope Management. 3) Project Time Management. 4) Project Cost Management. 5) Project Quality Management. 6) Project Human Resources Management. 7) Project Communications Management. 8) Project Risk Management. 9) Project Procurement Management. 10) Project Stakeholder Management.

According to PMBOK (Rose, 2013), Project Time Management includes the “processes”, or principles to plan and control the total duration of the projects. These principles are as follows: 1) Plan Schedule Management; used to create the policies, procedures and documentation for planning, developing, managing and controlling the total project schedule. 2) Define Activities; determining and gathering all the activities that will be composed of sub-activities on the project. 3) Sequence Activities; defined as determining the predecessor (previous activity) and the successor (following activity) for each activity. 4) Estimate Activity Resources; estimating the resources for every activity that will be implemented in the required project. 5) Estimate Activity Durations; estimating the duration of each activity based on its requirements. 6) Develop Schedule; analysing, resources, durations and constraints of each activity to determine the total duration of the project. 7) Control Schedule; used to control the duration of the activities. It is used to update the project schedule based on the real situation.

According to the PMBOK, (Rose, 2013), some of the most common PM’s tools are as follows: 1) Decomposition; means the breakdown of activities into sub-activities. 2) Procedure Diagramming Method; is a technique where the activities “are represented by nodes”. With the following relationships: a) Finish to Start; the successor activity will start after the finishing of the predecessor one. b) Start to Start; the successor activity will start after the starting of the predecessor one. c) Finish to Finish; the successor activity will finish after the finishing of the predecessor one. d) Start to Finish; the successor activity will finish after the starting of the predecessor one. 3) Leads and Lags; a) Leads; the successor activity will begin *before* finishing the predecessor by two weeks. b) Lags; the successor activity will begin *after* the finishing the predecessor by two weeks. 4) Critical Path Method (CPM); used to estimate the minimum project duration. Any delay in the activities conducted under this path could affect the pace of progress of the whole project. For example, if there is a building project has a foundation activity on CPM; so by delaying this activity for one month, it will delay whole project by at least one month. 5) Critical Chain Method (CCM); allows the project engineers to add buffers on the project activities. This occurs due to the limited amount of resources or the risk that might come up during any stage of the project. For example, if there is a building project has a foundation activity on CPM; the project may be delayed due to the bad weather and lack of labour, so extra days may be added to cope with these delays. 6) Crashing the schedule; used to minimize the project duration by adding more resources or working overtimes. This technique is usually implemented on the activities on the CPM. 7) Fast tracking; similar to the previous process, however this is implemented by working on two activities in parallel. For example for this in road projects, is to start working on excavation for sub-base activity before completing the shop drawings.

Aziz and Abdel-Hakam, (2016) focused on determining and collecting the reasons of delays concerning the previous studies, by using PM Approach. These studies were implemented on different types of construction projects from different countries. Based on Aziz and Abdel-Hakam, (2016), there are some reasons behind the delays, which were observed in a construction road project, which used Project Management Approach. This project had a plan duration of 18 months but was delayed for 12 additional months, due to a number of 293 reasons that were identified by the authors. The main reasons are as follows: 1) Failure of an electrical public cable in the construction site. 2) Working on the extension of international cables. 3) Delays that occurred due to the January 25th revolution[1].

2.2 Lean Construction

Lean Construction is a new technique (was formed in 1997 by Lean Construction Institute) focus on the elimination of the project wastes, leading to

[1] January 25th revolution took place in Egypt in 2011. Accordingly, many sectors were impacted by the events of the uprising, which lasted 18 days until the toppling of the president.

its continuous improvement. These wastes have their impacts on both the schedule and cost. Lean concept is focused on the five principles presented in Figure 1, according to many scholars (Mohammed and Khodier, 2017; Sarhan, *et al.*, 2017; Rodewohl, 2014). These principles are as follows: 1) Value; understand the customers' needs. 2) Value Stream; by making current state mapping, then the wastes (Non-Adding Value activities, not essential) will be identified and finally the future state mapping will be produced after making the modifications. 3) Flow; removing the wastes from the activities. 4) Pull Production; not delivering the material until the exact time when they are needed. 5) Perfection; continuous improvement of the last four steps.

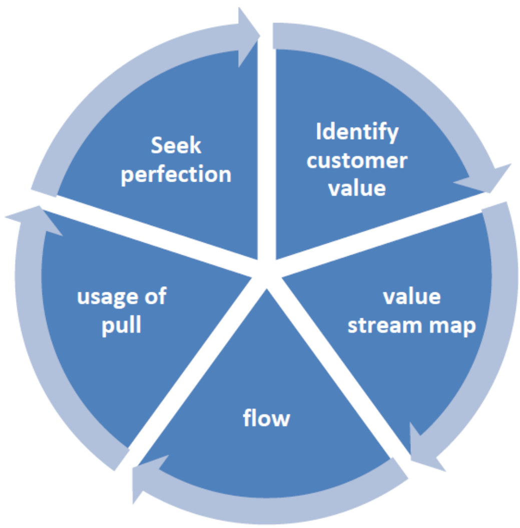

Fig. 1. Lean concept Principles

Source: EXAMINING THE ROLE OF LEAN MANAGEMENT IN LEADING ARCHITECTURE RENOVATION PROJECTS, Conference: ArchCairo7 Building Innovatively Interactive Cities, 2017.

According to Sarhan, *et al.*, (2017) and Mihic, Sertic and Zavrski, (2014) the main Lean Construction tools are as follows: 1) Last Planner System. 2) Integrated Project Delivery System. 3) Total Productive Maintenance. 4) Just In Time. 5) Five Why's. 6) 5S. 7) Value Stream Mapping.

2.2.1 Last Planner System (LPS)

Last Planner System is a planning, monitoring and controlling system used to achieve Lean Construction targets by reducing wastes, increasing productivity and improving the workflow reliability, (Porwall, 2010; Jang and Kim, 2007; Sarhan, *et al.*, 2017; Issa, 2013).

According to Last Planner System is composed of four steps which should be applied to be successfully implemented, (Hamzeh, Zankoul and El Sakka, 2016;

Hamzeh, 2009; Jang and Kim, 2007; Porwall, 2010) as follows: 1) Master scheduling; creating the milestones. 2) Phase scheduling; determining the activities that should be done. 3) Look-ahead planning; breaking down the activities, determining and identifying the wastes and assigning the responsibilities to finish the activities. Look-ahead planning has three steps as follows: 1) 6 to 3 weeks before the activity's execution week; the tasks were taken from the phase scheduling and inserted into the look-ahead planning. The general wastes (such as the information of design and types of materials) will be removed. During this step, the tasks are broken down. 2) 2 weeks before the activity's execution week; tasks are continuously broken down and more specific wastes, related to specific wastes of task (the necessary requirements for the tasks such as more details about materials and resources), are identified and removed. 3) 1 week before the activity's execution week; in this stage the process of *pulling* and *screening* are implemented. *Pulling* is referring to determine the tasks that SHOULD be made ready depending on the actual site demand. S*creening* is referring to determine the actions required to remove different type of constraints. 4) Weekly work plan/Commitment plan (the activity's execution week); refers to the execution week in which the Percentage Plan Complete should be calculated.

Porwal, (2010) stated that LPS is a collaborative technique because Last Planner System is a collaborative technique; because it gathers the last planners in a bigger team work to finalize the work. Figure 2 shows the Last Planner System's main components. First, the project objective is determined and identified, then by providing more information the milestones of the project are inserted. Last Planners will determine which tasks SHOULD be done (*Pulling* process) during the six weeks look-ahead planning while trying to expect and eliminate the wastes that could occur. Before the execution week the Last Planners will identify which activities that CAN be done; these activities are not free from wastes/constraints but they can be done based on the pull scheduling principle. Some of these activities are free from wastes/constraints and in this case are regarded as activities, which WILL be done. During the execution week, Percentage Plan Complete of the activities that are done, referred to as DID, will be determined and calculated; Percentage Plan Complete is the actual number of finished tasks divided by the expected number of finished tasks. Regarding the activities that are not finished, the concept of five Why's is applied to determine the cause and the effect of the problem. It is used to Define, Measure, Analyse, Improve and Control (DMAIC) the activities. For example in building projects, painting wall activity was not finished on time. The process DMAIC will be implemented: Define: due to the painting material travelled late; Measure: determine the time duration of this delay; Analyse: expect the affection on the whole duration of the project; Improve: solve the reasons with the material supplier (the main cause of the delay); Control: try to prevent this reason being repeated again.

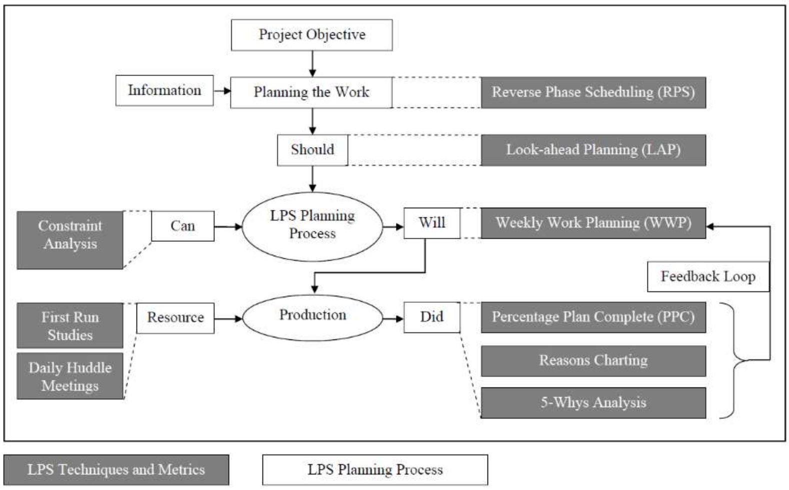

Fig. 2. Last Planner System

Source: LAST PLANNER SYSTEM – AREAS OF APPLICATION AND IMPLEMENTATION CHALLENGES, Institute of Engineering and Science, 2010.

Porwal, (2010) listed the benefits and barriers for Last Planner System. First, the benefits are as follows: 1) Increase in Reliability. 2) Improvement in time to deliver the project. 3) Increase in labour Productivity. 4) Increase in Safety. 5) Increase in Quality. 6) Continuous improvement in time, quality and cost. While some of the barriers that face Last Planner System are as follows: 1) Human nature do not like to change. 2) Negative attitude toward the new technique. 3) Lack of experience and training. 4) Lack of leadership. 5) Lack of support from stakeholders. 6) Applying Last Planner System in late project's state. 7) Lack of collaboration.

2.2.2 Integrated Project Delivery (IPD)

The American Institute of Architects (AIA) defined Integrated Project Delivery as: "a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction."[2] (Mihic, Sertic and Zavrski, 2014).

[2] Mihic, M., Sertic, J. and Zavrski, I., 2014. Integrated project delivery as integration between solution development and solution implementation. *Procedia-Social and Behavioral Sciences*, *119*, pp.557-565.

The American Institute of Architects (AIA) made a comparison between traditional and integrated design processes based on the collaborations of the stakeholders. Figures 3 and 4 shows that almost all the main stakeholders are involved in the early stage of the project which increases the probability of identifying and removing the wastes. In contrast, this does not occur in the traditional design process, (Mihic, Sertic and Zavrski, 2014).

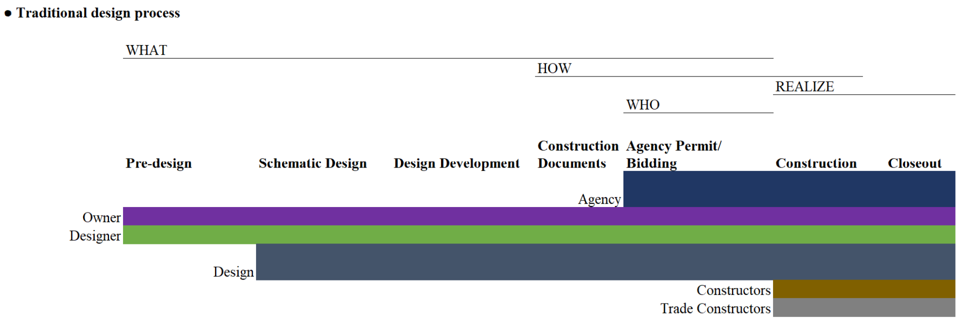

Fig. 3. Traditional design processes

Source: Integrated project delivery as integration between solution development and solution implementation, 27th IPMA World Congress, 2014.

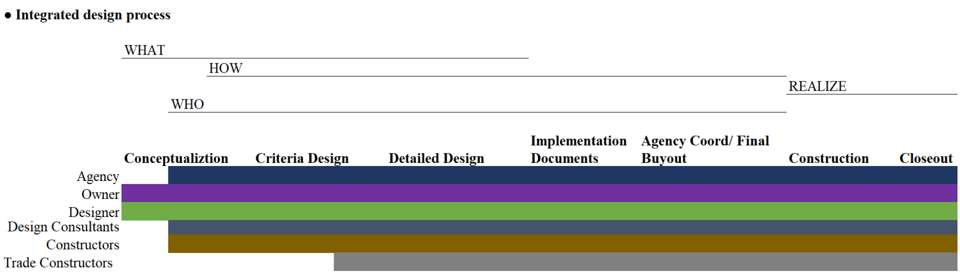

Fig. 4. Integrated design processes

Source: Integrated project delivery as integration between solution development and solution implementation, 27th IPMA World Congress, 2014.

El Asmar, Hanna and Loh, (2013) presented the concepts of Design Build (DB) and Design Bid Build (DBB). On the one hand, Design Build (DB) refers to having one contractor for both construction and design, while on Design Bid Build (DBB) refers to having two separate contracts for construction and design. Figure 5 summarizes the difference between Design Build (DB), Design Bid Build (DBB) and Integrated Project Delivery (IPD), with a focus on the collaborations factor. For example, Design Bid Build, the contract is signed with the contractor after the work of the design is fully finished (100% finished). In case of Design Build, the contract is signed with the contractor after the 20% of the work of the design is finished. Under the Integrated Project

Delivery approach, all the stakeholders collaborate before the start of the design stage.

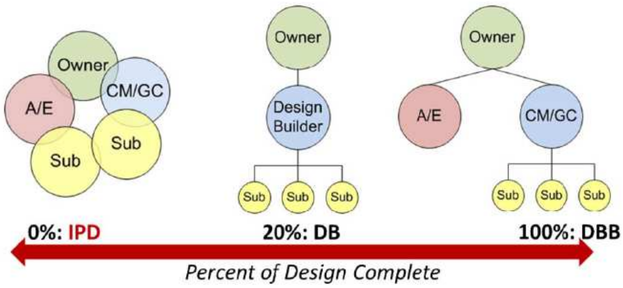

Fig. 5. Collaborations in DB, DBB, and IPD

Source: Quantifying Performance for the Integrated Project Delivery System as Compared to Established Delivery Systems, Journal of Construction Engineering and Management, 2013.

El Asmar, Hanna and Loh, (2013) concluded that using Integrated Project Delivery results in higher quality and faster projects without significant extra cost. Azhar *et al.*, (2015) had a general conclusion that using IPD improves project delivery effectiveness. The study also lists some benefits of using Integrated Project Delivery are as follows: 1) Early involvement of all stakeholders and close collaboration. 2) Sharing risks and profit. 3) Trust and mutual respect.

Mihic, Sertic, and Zavrski, (2014) identified the main barrier that faces the use of IPD in the Croatian construction sector; there are no laws that explain if using IPD is legal or not. However, Public Procurement Act (2005) does not forbid the use of IPD by private investors in contrast to the public investors.

2.2.3 Total Productive Maintenance (TPM)

Singh *et al.*, (2012) explained the reason of using Total Productive Maintenance because it focuses on the maintenance and reparation of the equipment to prevent their failure. The author stated that Total Productive Maintenance is a maintenance approach that focuses on improving the effectiveness of the machines and preventing their breakdowns. Total Productive Maintenance has one foundation, which is 5S, and eight pillars, Figure 6 (5S is a Lean tool refers to Sorting, Setting in order, Shinning, Standardizing and Sustaining, which is a housekeeping method).

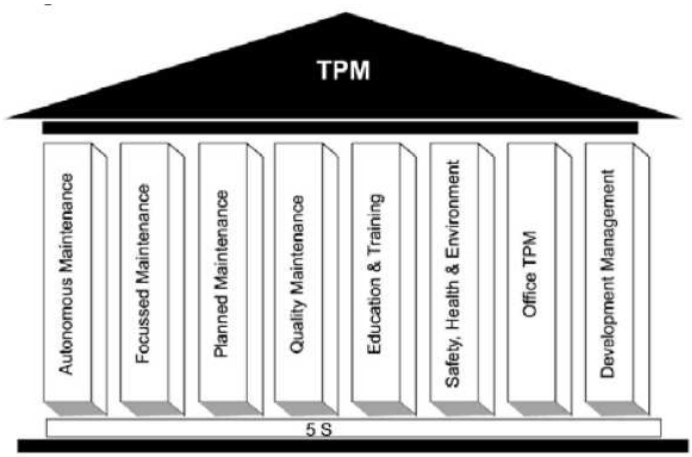

Fig. 6. TPM Pillars

Source: Total productive maintenance (TPM) implementation in a machine shop: A case study, Chemical, Civil and Mechanical Engineering Tracks of 3rd Nirma University International Conference on Engineering, 2012.

Based on the previous studies no barriers have been found, while the benefits that can occur after applying Total Productive Maintenance are as follows, (Eti, Ogaji and Probert, 2004): 1) Increasing the machines effectiveness. 2) Higher levels of quality and safety. 3) Decreasing cost. 4) The labours are motivated to do their tasks.

Singh, *et al.,* (2012) state other benefits after applying Total Productive Maintenance are as follows: 1) Decreasing the activity time. 2) Decreasing machines' breakdown. 3) Increasing performance efficiency for the machines. 4) Increasing the overall equipment effectiveness. 5) Increasing the machine's availability.

2.2.4 Just In Time (JIT)

Just In Time technique is a Pull System technique which refers to delivering the accurate necessary amount of material in the exact time of its need. This tool seeks to minimise or remove the inventories, which leads to minimizing the handling process and increasing labour productivity, (Mohammed and Khodier, 2017).

Like the Total Productive Maintenance tool, there is no determination of barriers for JIT in the previous studies. It is essential to mention that the absence of Just In Time concept could lead to the following consequences (Hosseini, Nikakhtar and Ghoddousi, 2014): 1) Delay in delivering the materials. 2) Decreased labour productivity. 3) Unavailability of the material, which leads to increasing the project durations. 4) The movement of labours increase which tend to make them demotivated. 5) Having unnecessary inventories, which can increase the cost of the project.

2.3 Lean Construction and Project Management Approach Comparison

According to Mohammed and Khodier, (2017) the main differences between Lean Construction and Project Management Approach are as follows: 1) Project Management Approach focuses on the improvement of each activity of the project; while Lean Construction focuses on the improvement of the value of the whole project. 2) Project Management Approach does not focus on reducing the variations; while Lean Construction focuses on reducing the variations at the early stages of the project. 3) Project Management Approach leads to taking action after the problem occurs; while Lean Construction highlights the importance of preventing the occurrence of the wrong actions. 4) Project Management Approach is a push driven method; while Lean Construction is a pull driven method.

3. RESEARCH METHOD

3.1 Project definition

The project analysed in this study is a real highway project. It is located in a new city in Cairo called 6th of October. It is regarded as a connection between the centre of the city and the beginning of the main Cairo-Alexandria highway. The length of the project is 12.812km in each of the two directions. The total width of the project is 17m. The main contractor is one of the biggest public companies in Egypt called Arab Contractors. The working hours of the project during weekdays are scheduled from 08:00 in the morning to 17:00 in the evening including one hour for lunch. It is worth mentioning that the construction sector in Egypt takes one day off as weekend and this project runs during weekdays.

3.2 Data collection

This type of projects – infrastructure projects– depends mainly on the equipment and not on the skill of the labours as the case is in building projects. For this reason, there are many types of machines; each of them has a different use. These machines are shown and defined in Figure 7 and Table 1.

Fig. 7. Road project machines

Source: own research

To collect information about the duration of the sub-activities, site observation was done for 30 days, four hours every day (except Friday which is a weekend). Each sub-activity under each activity was observed and its duration measured. Further, in order to have full data about each sub-activity, information was collected from site engineers orally and through documents such as the shop-drawings and the time schedule of the project.

In order to calculate the duration of each sub-activity, the Value Adding (VA) activities durations were observed, taking into account that each machine has a minimum, a maximum and an average speed. The speed of each machine was determined based on the observation while calculating the duration it took to finish the sub-activity work in a 200 meter section with the different speeds. In case of the Non-Value Adding (NVA) activities, three durations (minimum, maximum and average) were also observed during the manoeuvring of the machine. From the VA and NVA activities duration, the total durations were calculated for each sub-activity. The wasted time was not include in the time durations calculated.

During the site visits, eight wastes that occurred in one month were observed. More details about these wastes are shown and explained in Table 2. This table further demonstrates the Lean tools that are used in the simulation to eliminate the identified wastes. Similar to the observation of the durations of each sub-activities, each time waste was observed during each sub-activity. Two of these eight wastes (W4 and W8) are calculated per meter not per occurrence as other wastes; the reason for this is because these two wastes depend on the material quantity.

In case of W1, this mainly refers to the time unnecessarily wasted during the inspection of an activity. For example, in several instances, an activity finishes and the work process was frozen while waiting for the consultant to inspect the finished activity. During the observation this happened and the consultant did not show up that day which led to the following activity being postponed till the next day after inspection. Figure 8 shows an example of delayed work; the equipment stopped waiting for the inspection. One way to overcome this obstacle/cause of waste is by allowing the equipment to work in another section until the finished area is inspected.

Fig. 8. Waiting for inspecting the finished activity

Source: own research

In the second waste W2, problems that occurred and could be resolved using the JIT concept are demonstrated in Figure 9, where the paving finisher is shown waiting for the asphalt trucks which arrived late. The perfect occurrence is to deliver the material exactly on time, neither late nor early. For W3, which displays shortage of machine gas due to lack of maintenance; however by applying maintenance and repair this problem can be eliminated. For W4, this waste mainly refers to the long distance between the loading and unloading areas.

Fig. 9. Paving finisher waiting the asphalt trucks

Source: own research

W5, which is the equipment stopped for mechanical problems, is similar to W3 because they occurred due to lack of maintenance and repair, as shown in Figure 10. If there was continuous maintenance of machines, this would not have been the case. In addition, regarding W6, as shown in Figure 11, double drum rollers, which is the equipment, used to mash the surface of asphalt layers uses water on the drum during rolling. This equipment ran out of water in the middle of work activity and the water sprinkle was used to refill it. The mechanical section should check on the water in the double drum rollers to prevent this waste of time and cost.

Fig. 10. Waiting for mechanical problems

Fig. 11. Double drum rollers filling with water

Source: own research

Regarding W7, sometimes the paving finisher had to make two trips to pave the road with asphalt because of the lack of compatibility between the width of the road and that of the paving finisher; that is, the road's width is too big for the paving finisher to pave in one trip. This type of waste causes can be addressed by increasing the width of the pavement, during the paving process the width of the paving finisher ranges from 3meters to 6meters. Regarding W8, in addition to the mentioned causes of waste, sometimes the asphalt truck's driver suddenly drops a significant amount of asphalt leading to a time gap between the moment when the asphalt was dropped and the time needed by the paving finisher to pave it.

Table 1. Resource for each sub-activity

Activity	Sub-activity	Resource
Sub-base layer works	Unloading	Aggregate truck
	Levelling	Grader
	Sprinkle	Water sprinkle
	Compact	Single drum roller
1st aggregate layer works	Unloading	Aggregate truck
	Levelling	Grader
	Sprinkle	Water sprinkle
	Compact	Single drum roller
2nd aggregate layer works	Unloading	Aggregate truck
	Levelling	Grader
	Sprinkle	Water sprinkle
	Compact	Single drum roller
1st Asphalt layer works	MC Sprinkle (referring to Medium Curing)	MC sprinkle
	Putting first asphalt layer	Asphalt truck + Paving finisher
	Compact	Double drum roller
2nd Asphalt layer works	RC Sprinkle (referring to Rapid Curing)	RC sprinkle
	Putting second asphalt layer	Asphalt truck + Paving finisher
	Compact	Double drum roller

Source: own research

Table 2. Wastes explanation and modification

Wastes	Explanation	Waste modified (using Lean tools)
W1	The work of the activity was finished but could not start the following activity (dependencies) because the consultant should inspect the finished one first.	Increase the coordination and communication between project parties. Apply Integrated Project Delivery System (IPD).
W2	The asphalt trucks were delivering	Deliver the material on

Wastes	Explanation	Waste modified (using Lean tools)
	early which led to wait on site or the paving finisher was waiting for the asphalt trucks arriving late.	time. Apply Just In Time (JIT).
W3	The machine had shortage of gas, which led to a waste of time.	Make maintenance and repair. Apply Total Productive Maintenance (TPM).
W4 (Per meter)	Transport the aggregate to the working area. For distance more than 5Km far.	Increase the coordination and communication between project parties. Apply Integrated Project Delivery System (IPD).
W5	The equipment stopped for mechanical problems.	Make maintenance and repair. Apply Total Productive Maintenance (TPM).
W6	Double drum rollers ran out of water.	Make maintenance and repair. Apply Total Productive Maintenance (TPM).
W7	Paving finisher had to make two trips to pave the road with asphalt because of the width of the road.	Increase the coordination and communication between project parties. Apply Integrated Project Delivery System (IPD).
W8 (Per meter)	The asphalt truck was waiting until the paving finisher pave the asphalt dropped down on it.	Increase the coordination and communication between project parties. Apply Integrated Project Delivery System (IPD).

Source: own research

3.3 Objective of the simulations:

In the beginning, the simulation is carried out using the software Simio[3]. The target of this simulation is to apply Project Management approach and Lean Construction on the studied project to produce results that are accurate enough to resemble reality.

[3] Simio is a simulation modelling software.

Pilot model: Simple structure (Figure 12)

- Simulation PM-OW (Project Management with Observed Wastes), Table 4: Different values for time activities and *observed* wastes duration will be used as input: using a random function based on observed information (different triangular laws ±20%, ±10%, ±5% and 0%).
- Simulation PM-EW (Project Management with Expected Wastes), Table 5: Different values for time activities and *expected* wastes duration will be used as input: using a random function based on observed information (different triangular laws ±20%, ±10%, ±5% and 0%). The observed durations are the 0%.
- Simulation LC (Lean Construction): Different values for time activities will be used as input: using a random function based on observed information (different triangular laws ±20%, ±10% and ±5%). Based on literature (Porwall, 2010; Jang & Kim, 2007; Sarhan, *et al.*, 2017; Issa, 2013; Mihic, *et al.*, 2014; El Asmar *et al.*, 2013; Azhar *et al.*, 2015; Singh *et al.*, 2012; Eti, *et al.*, 2004; Mohammed & Khodier, 2017; Hosseini, *et al.*, 2014), wastes are eliminated from this simulation.

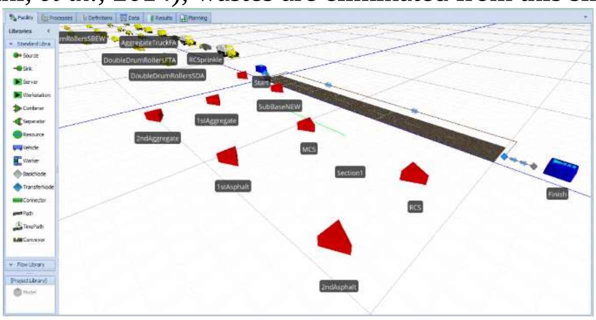

Fig. 12. Pilot simulation

Source: own research

The three equations below are used as inputs inserted into the software to get from them the outputs for Productivity of each activity (as occurred in the project), Root Cause of Delay (RCD) and Percent Plan Complete (PPC).

$$\text{Productivity of activity i per week (As occurred) } \textit{in simio simulation } [\frac{\text{m2}}{\text{week}}] = \left(\frac{\text{Total quantity of activity i [m2]}}{\frac{\text{Total Time for activity i [hour]} *}{\text{Number used in the activity i}} + \text{Total waste time in activity i [hours]}} \right) * 7 \frac{hours}{day} * 6\ days/week$$

$$\text{RCD\%} = \frac{\text{Waste time ONLY during an activity} * 100}{\text{Total time of a activity WITHOUT WASTE TIME}}$$

$$\text{PPC\%} = \frac{\text{Occurred productivity on week (Productivity per week) (for each activity)} * 100}{\text{Planned productivity on week zero (Expected productivity per week) (for each activity)}}$$

3.4 Model explanation (Simulations LC and PM):

The three simulations (two using PM approach and one using LC) will each apply following steps; there are eight activities (Categorized as entities in Simio): Sub-Base Layer (filling with material from the site and from outside the site), First Aggregate Layer, Second Aggregate Layer, MC sprinkle (referring to Medium Curing), First Asphalt Layer, RC Sprinkle (referring to Rapid Curing) and Second Asphalt Layer. The study focuses on one section of the project (as a pilot). This section will have its sub-activities (Categorized as tasks in Simio), for example, having four sub-activities, Unloading, Levelling, Sprinkle and Compact. Every sub-activity will require a number of resources (for example, Aggregate Trucks will be used in Unloading).

The total time will be identified and added for each sub-activity. Additionally, every sub-activity will have its waste (wastes are W1, W2, W3, … W8) and these wastes will be categorized under a group named as Root Cause of Delays (RCDs).

First, eight entities are created representing the eight activities, and then the pilot section will be added to the model. The section will contain 18 sub-activities; every sub-activity will use mainly one type of machinery. Finally at the end of each week, two expressions will be calculated (PPC and RCD) based on their equations, while at the end of the simulation the final duration of each activity will be estimated.

Table 3 presents a list of assumptions for the three simulations. Tables 4 and 5 present the types of wastes that were observed/expected while working on every sub-activity. While Table 6, shows the number of times each waste occurred and the percentages of its occurrence. In simulation PM-OW, the percentages are the observed number of occurrence over the maximum number of occurrence. While in simulation PM-EW, the percentage of occurrence of each waste is assumed to be 100%. The last simulation (LC), these percentages went down to zero for all wastes; after applying the modifications presented in Table 2, these wastes were eliminated.

Table 3. List of assumptions

#	Assumptions
1.	The road will be divided into sections (each section has the same length).
2.	Each section is composed by different layers each one is carried out into different activity and one is built after the previous one is completed. Every activity is introduced into the simulation as entity.
3.	Working in sub-activities are sequenced (e.g: in activity sub-base, if sub-activity unloading in section 12 finishes, aggregate truck will start working in section 13 on sub-activity unloading, and so on)
4.	Sub-activities of each activity are modelled as tasks.
5.	*Every activity will have its value of PPC and RCD*
6.	*Every group of machinery has the same characteristics (e.g.: working time, equipment number, waste times).*
7.	*Every machinery will work in each one sub-activity (except putting asphalt layers).*
8.	*Total time, QSiRate and wastes are defined randomly.*
9.	*Triangular random expressions.*
10.	*The values of the total time and wastes time are obtained from observation.*
11.	*The wastes are simulated as delayed times among activities.*
12.	*No overlapping between any two sub-activities.*

Source: own research

Table 4. Wastes occurrence during every sub-activity (Observed)

Activity	***Sub-activity***	***Pebbles wastes (As occurred in the site visiting)***
Sub-base layer works (Each layer)	*Aggregate truck*	*W4*
	Grader	*W1, W5*
	Water sprinkle	*W1*
	Single drum roller	*W1*
1st aggregate layer works (Each layer)	*Aggregate truck*	*W4*
	Grader	*W1, W5*
	Water sprinkle	*W1*

Activity	*Sub-activity*	*Pebbles wastes (As occurred in the site visiting)*
	Single drum roller	*W1*
2nd aggregate layer works	*Aggregate truck*	*W4*
	Grader	*W1, W5*
	Water sprinkle	*W1*
	Single drum roller	*W1*
MC	*MC sprinkle*	*W1*
1st Asphalt layer works	*Asphalt truck*	*W2, W3, W7, W8*
	Paving finisher	
	Double drum roller	*W2, W3, W6*
RC	*RC sprinkle*	*W1*
2nd Asphalt layer works	*Asphalt truck*	*W2, W3, W7, W8*
	Paving finisher	
	Double drum roller	*W2, W3, W6*

Source: own research

Table 5. Maximum wastes occurrence during every sub-activity (Expected)

Activity	Sub-activity	Pebbles wastes (As occurred in the site visiting)
Sub-base layer works (Each layer)	Aggregate truck	W4
	Grader	W1, W3, W5
	Water sprinkle	W1, W3, W5
	Single drum roller	W1, W3, W5
1st aggregate layer works (Each layer)	Aggregate truck	W4
	Grader	W1, W3, W5
	Water sprinkle	W1, W3, W5
	Single drum roller	W1, W3, W5
2nd aggregate layer works	Aggregate truck	W4
	Grader	W1, W3, W5
	Water	W1, W3, W5

Activity	Sub-activity	Pebbles wastes (As occurred in the site visiting)
	sprinkle	
	Single drum roller	W1, W3, W5
MC	MC sprinkle	W1, W3, W5
1st Asphalt layer works	Asphalt truck	W1, W2, W3, W5, W7, W8
	Paving finisher	
	Double drum roller	W1, W2, W3, W5, W6
RC	RC sprinkle	W1, W3, W5
2nd Asphalt layer works	Asphalt truck	W1, W2, W3, W5, W7, W8
	Paving finisher	
	Double drum roller	W1, W2, W3, W5, W6

Source: own research

Table 6. Wastes Information for simulations PM & LC

Waste	# of occur. (Observed)	Max. # of occur. (Expected)	% of occur. (Priority) Simulation LC	% of occur. (Priority) Simulation PM OW	% of occur. (Priority) Simulation PM EW
W1	35	39	0%	89.74%	100 %
W2	4	4	0%	100.00%	100 %
W3	4	39	0%	10.26%	100 %
W4	11	11	0%	100.00%	100 %
W5	11	39	0%	28.21%	100 %

Waste	# of occur. (Observed)	Max. # of occur. (Expected)	% of occur. (Priority) Simulation LC	% of occur. (Priority) Simulation PM OW	% of occur. (Priority) Simulation PM EW
W6	2	2	0%	100.00%	100 %
W7	2	2	0%	100.00%	100 %
W8	2	2	0%	100.00%	100 %
W9	35	39	0%	89.74%	100 %
W10	4	4	0%	100.00%	100 %

Source: own research

3.4.1 Flow charts:

- <u>*Simulation PM:*</u>
  1- Input data (Waste deviation: +-5%, +-10%, +-20%)
    a. i=1
    b. N=number of waste deviations analysed =3
    c. Do (Waste deviation =i) if i<N+1,
      - Run the model
      - Waste deviation = i+1
      - Go to b
      - Output data (PPC, RCD and total activity duration)

  2- Analysis of the results
- <u>*Simulation LC:*</u>
  1- Input data (Waste deviation: +-5%, +-10%, +-20%)
    a. i=1
    b. N=number of waste deviations analysed =3
    c. Do (Waste deviation =i) if i<N+1,
      - Run the model
      - Waste deviation = i+1

- Go to b
- Output data (PPC, RCD and total activity duration)

2- Analysis of the results

4. RESULTS

This section demonstrates all the results for each simulation of the three simulations (Project Management for Observed Wastes, PM- OW; Project Management for Expected Wastes, PM-EW; Lean Construction, LC). In every simulation, there are four scenarios; scenario ($\pm$20%) will have the duration (Activities and wastes time) deviation by $\pm$20%. This deviation percentage will decrease until it becomes $\pm$0%. Each simulation ran 600 times to increase the accuracy of the results. The results are shown in the Figures from 13 to 24. Figures 13, 14 and 15 are for the below six results on each the three variables PPC, RCD and Ratio Total duration/Planned: 1) PM-OW filling with excavation material, 2) PM-OW filling with outside material, 3) PM-EW filling with excavation material, 4) PM-EW filling with outside material, 5) LC filling with excavation material and 6) LC filling with outside material.

Figures 16, 17 and 18 are for the below six results on each the three variables PPC, RCD and Ratio Total duration/Planned: 1) PM-OW 1st Aggregate Layers, 2) PM-OW 2nd Aggregate Layers, 3) PM-EW 1st Aggregate Layers, 4) PM-EW 2nd Aggregate Layers, 5) LC 1st Aggregate Layers and 6) LC 2nd Aggregate Layers.

Figures 19, 20 and 21 are for the below six results on each the three variables PPC, RCD and Ratio Total duration/Planned: 1) PM-OW MC, 2) PM-OW 1st Asphalt Layers Layers, 3) PM-EW MC, 4) PM-EW 1st Asphalt Layers, 5) LC MC and 6) LC 1st Asphalt Layers.

Figures 22, 23 and 24 are for the below six results on each the three variables PPC, RCD and Ratio Total duration/Planned: 1) PM-OW RC, 2) PM-OW 2nd Asphalt Layers Layers, 3) PM-EW RC, 4) PM-EW 2nd Asphalt Layers, 5) LC RC and 6) LC 2nd Asphalt Layers

4.1 Results

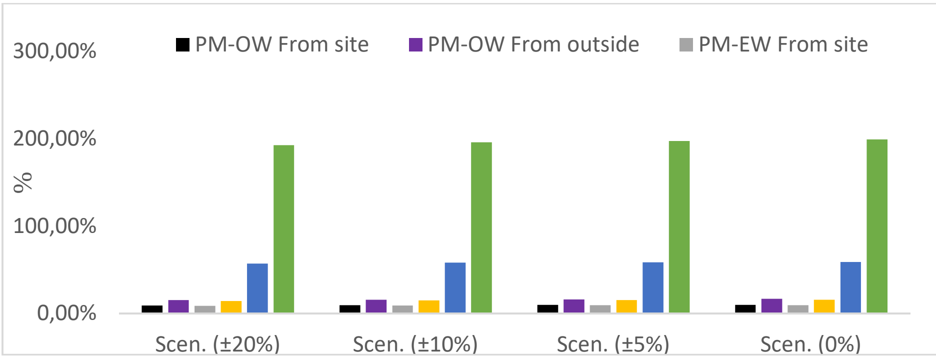

Fig. 13. Sub-base Layers PPC results

Source: own research

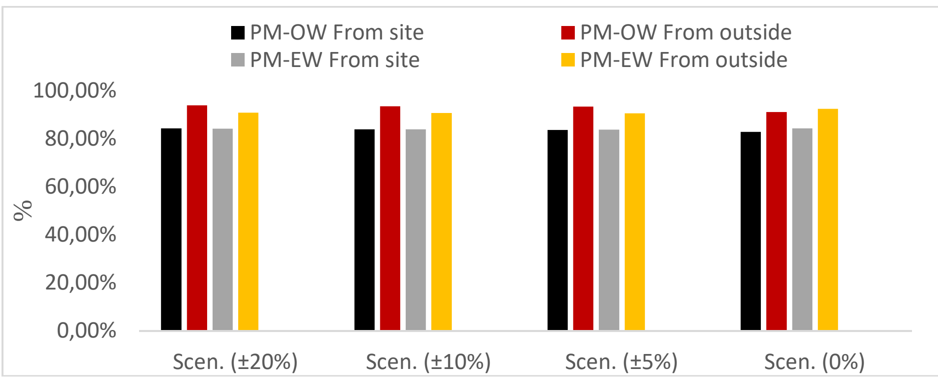

Fig. 14. Sub-base Layers RCD results

Source: own research

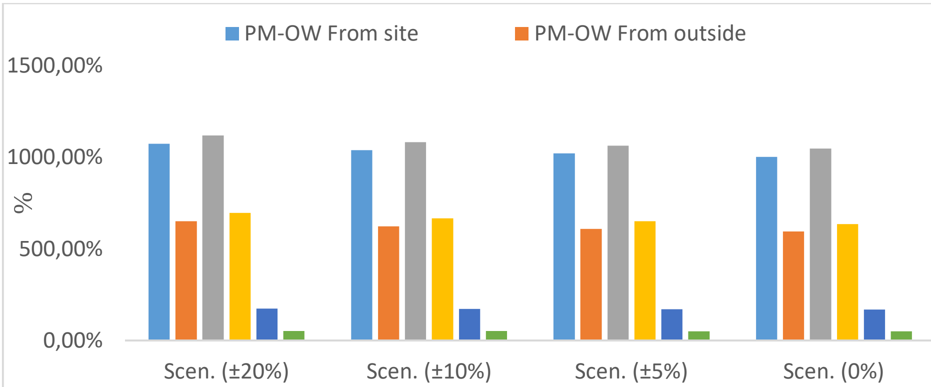

Fig. 15. Sub-base Layers Ratio Total duration/Planned results

Source: own research

4.2 1st and 2nd Aggregate Layers Results

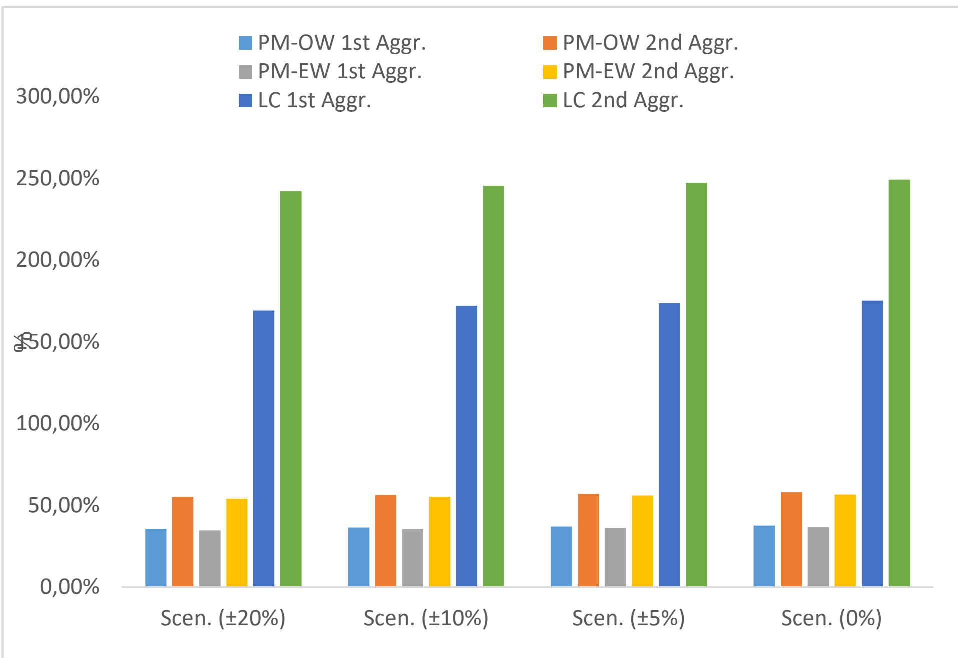

Fig. 16. 1st and 2nd Aggregate Layers PPC results

Source: own research

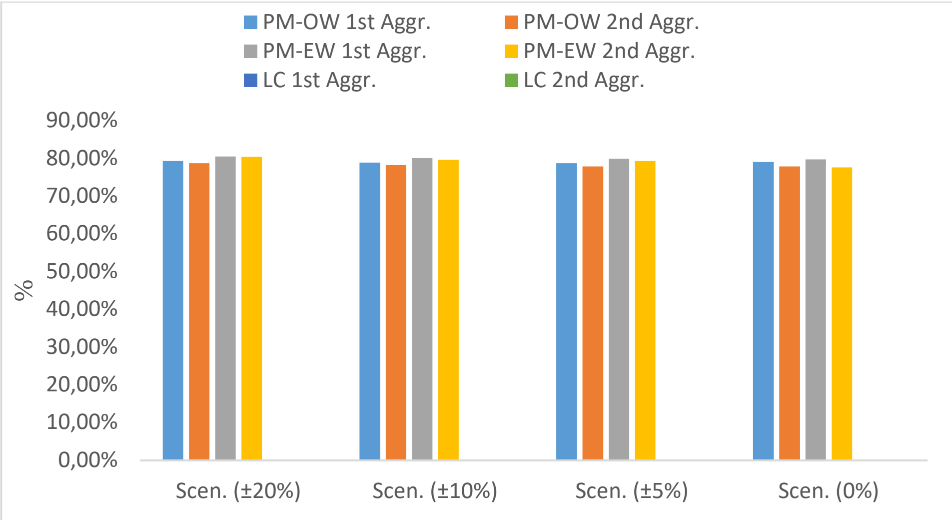

Fig. 17. 1st and 2nd Aggregate Layers RCD results

Source: own research

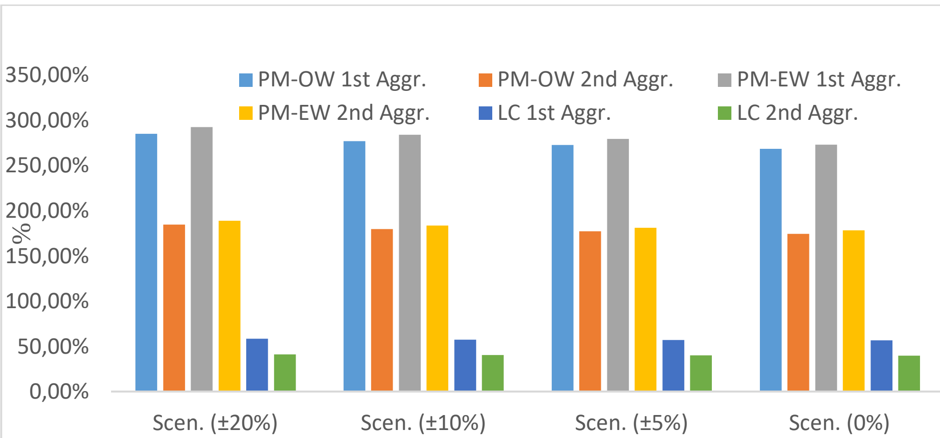

Fig. 18. 1st and 2nd Aggregate Layers Ratio Total duration/Planned results

Source: own research

4.3 MC and 1st Asphalt Results

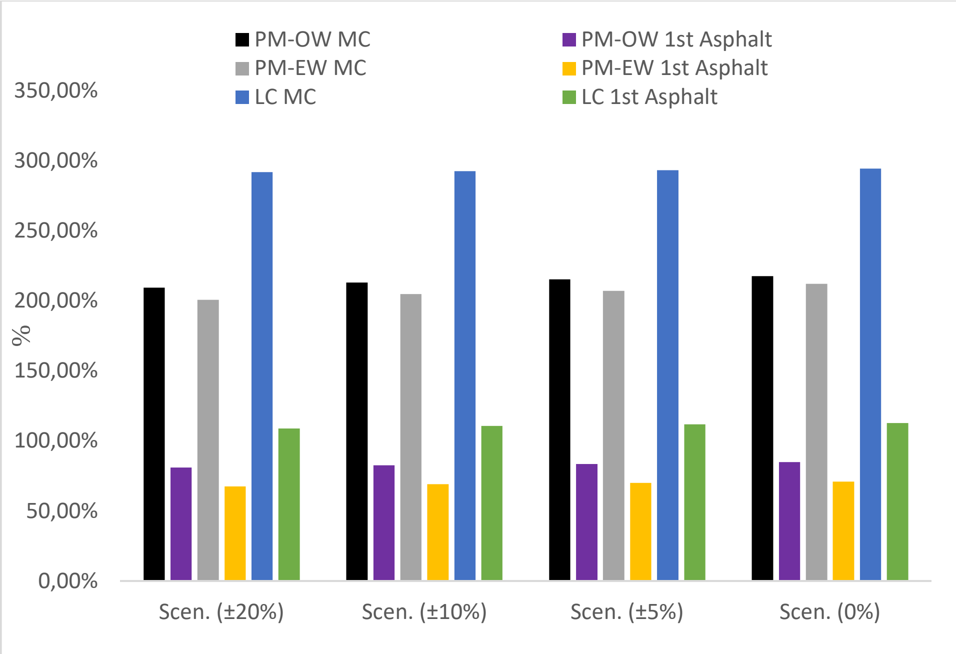

Fig. 19. MC and 1st Asphalt PPC results

Source: own research

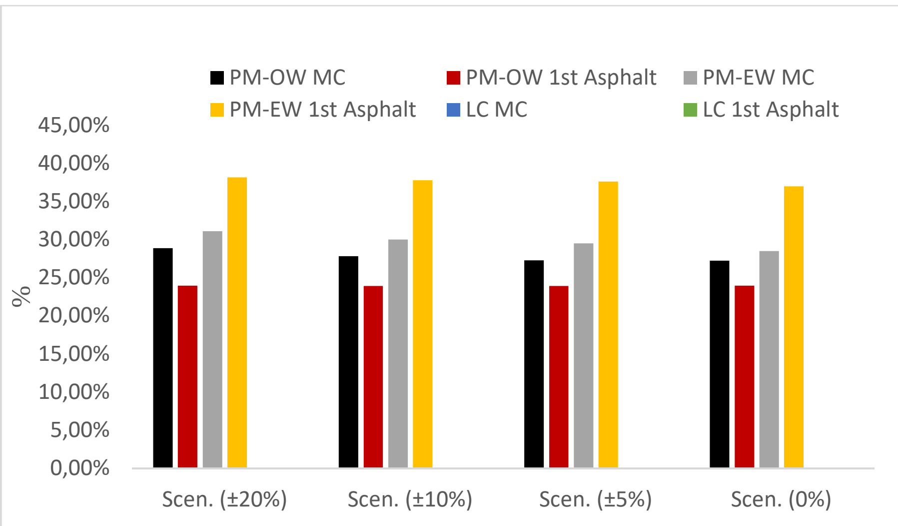

Fig. 20. MC and 1st Asphalt RCD results

Source: own research

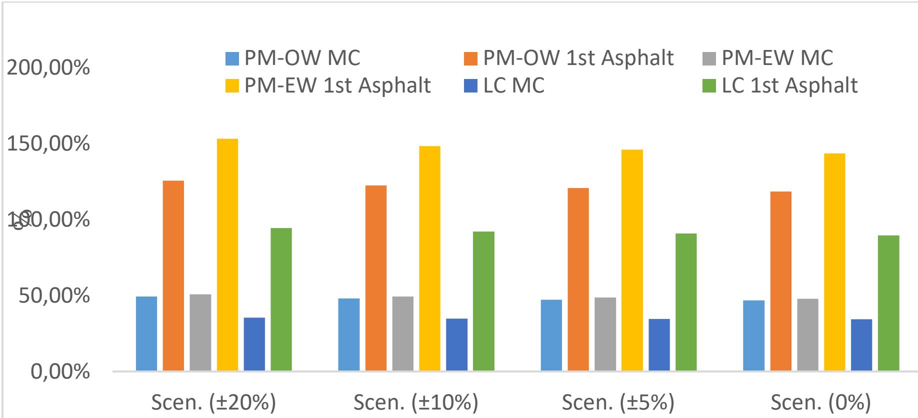

Fig. 21. MC and 1st Asphalt Ratio Total duration/Planned results

Source: own research

4.4 RC and 2nd Asphalt Results

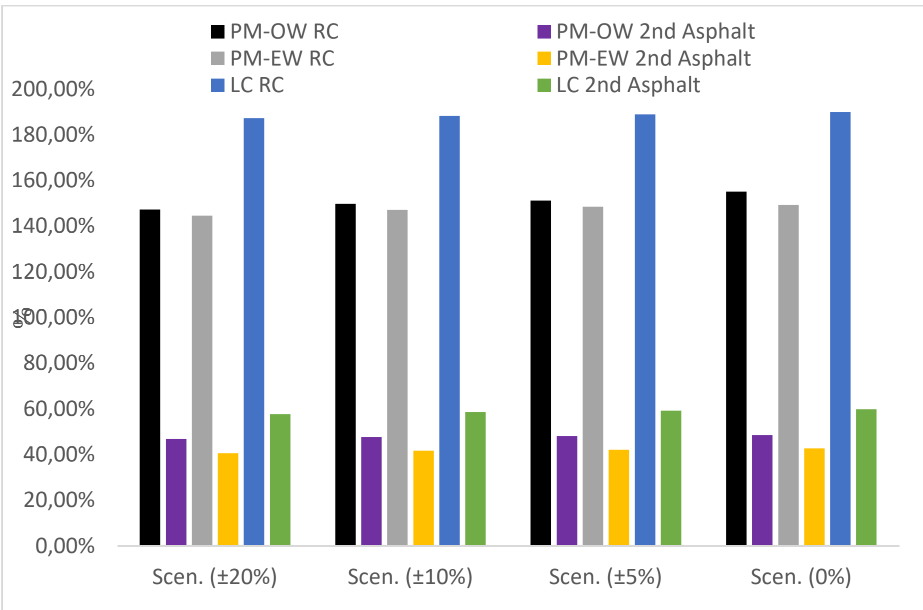

Fig. 22. RC and 2nd Asphalt PPC results

Source: own research

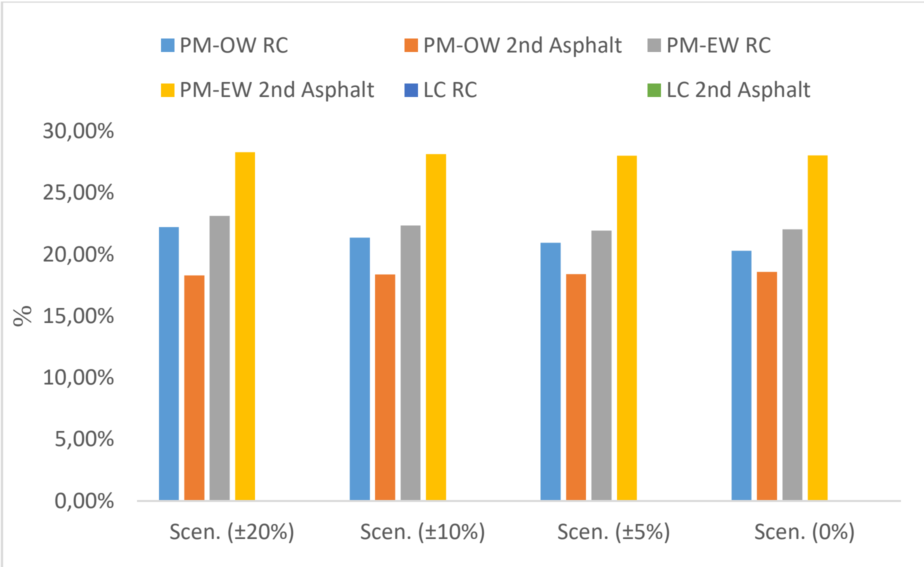

Fig. 23. RC and 2nd Asphalt RCD results

Source: own research

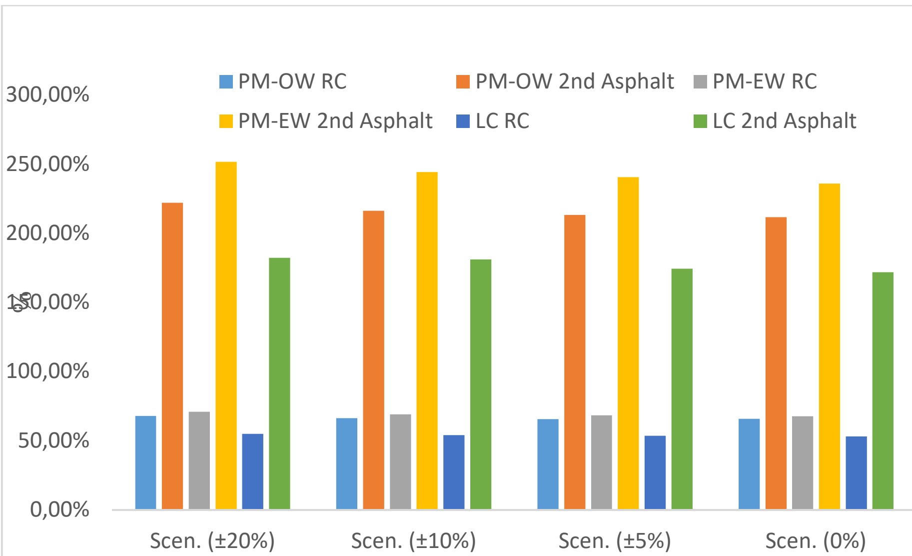

Fig. 24. RC and 2nd Asphalt Ratio Total duration/Planned results

Source: own research

5. RESULTS ANALYSIS

Previous studies prove that the application of Lean Construction in construction projects eliminates wastes/obstacles. This only takes place by using Lean Construction tools with their right requirements. These tools have some challenges or barriers that need to be overcome first. In the previous section, results of modelling a pilot project from the case study were displayed. These results are listed for each activity with four correlations; PPC, RCD, Total Duration for each activity and Ratio between Total Duration Calculated and Total Duration Estimated.

In general, there is a negative correlation between PPC and the other variables; when PPC increases, a decrease in other variables is noted (RCD, Total Duration for each activity and Ratio). Using Lean Construction, results in RCDs' values becoming zero because no waste occurs in any activity. When Lean Construction is applied, the values of PPC reaches more than 100% for all activities except for two; sub-base Layers with filling with materials from site and 2nd Asphalt Layer. The reason for this is that these two activities need more than one resource to finish on the scheduled time or ahead of the schedule date. Regarding the activity of sub-base Layers filling with materials from site, it is expected to be finished in every section in about 9 hours. It is worth noting that the required material quantity of the other sub-base activity (filling with material from outside the site) is 30% of the requirements of one filling material from site, but still it is also expected to be finished in every section in 9 hours.

Concerning, the case of Second Asphalt Layer activity, despite the material quantity required being more than the first Asphalt Layer's quantity by about 60%, still both activities are expected to finish taking the same duration. For the first Asphalt Layer, using Lean Construction, the values of PPC are almost 100%, which is means that this activity will finish almost on the estimated time and this can be seen in the value of the ratio between Total Duration Calculated and Total Duration Estimated. The values of PPC for MC (referring to Medium Curing) and RC (referring to Rapid Curing) sprinkles are more than 100% for all simulations because the expected duration was very high, while the wastes observed/expected on these two activities were still lower than the expected durations.

6. CONCLUSION

It can be seen from the values of the simulations that the worst simulation is PM-EW, while the best one is LC. As displayed, the duration wastes have been most severe when the Project Management approach was applied in the simulation. One of the main reasons is that this approach does not provide sufficient expectations of the wastes that could potentially occur due to lacking the tools that qualify for such forecasting. On the other, Lean Construction entails tools that when applied leads to time wastes elimination. As demonstrated through the findings of the simulation for instance, Last Planner has been the most effective tool in eliminating time wastes, thanks to six weeks look-ahead tool, which forecasts the potentially occurring wastes in the followings weeks. This emphasizes that forecasting expectations about problems is a highly essential and impactful criterion for the success of road construction projects. This criterion is lacking in the PM approach but when sufficiently implemented through the Lean construction tools, clear enhancements can be achieved.

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