Lean Construction versus Project Management in road projects: Scheduling comparison

DoctoralThesis

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Dedication

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Abstract

Lean Construction is regarded as an innovative approach of management for various types of projects in the field of construction. As much as it is currently applied in some countries, its expansion is inevitable, for better overall results are obtained and the projects' objectives are met more precisely. Despite the fact that Lean Construction offers solutions to many problems occurring under the traditional management approach known as the Project Management (PM), the scope of its application is not as promising. Countries where Lean Construction is minimally applied include the United States of America and the United Kingdom besides other countries in Europe and Latin America. However, it is still not applied to a more exhaustive extent in these countries and is completely missing in many others around the world.

This study primarily focuses on the application of Lean Construction to Infrastructure, specifically road projects; investigating Lean Construction solutions to the time wastes. Through conducting a case study research, this work focuses on investigating the impact of applying Last Planner System as a Lean Construction tool on the elimination of Non-Value Added (NVA) activities, that is, wastes in a highway project in Cairo, Egypt. This study includes a State of Art on both Project Management approach and Lean Construction.

The study applies a comparative approach between the application of Project Management approach and Lean Construction in road projects. Hence, the researcher conducted different simulations of the studied road project, taking into account the two approaches (Project Management and Lean Construction), then obtaining the simulations results. Two parameters are used as comparison criteria: Percentage Plan Complete (PPC) and Percentage Activity Waste (PAW). The later (PAW) is a new parameter introduced by the researcher to investigate its results before/after applying the Lean Construction tools.

Findings of the study support the research hypothesis that the application of Lean Construction approach to road projects enhances productivity through eliminating time-related wastes and decreasing the project duration. This research supports the argument that road projects can benefit greatly from the application of Lean Construction instead of the traditional approach.

Resumen

Lean Construction es considerado como un enfoque innovador para la gestión de diversos tipos de proyectos en el campo de la construcción. Por más que se aplique actualmente en algunos países, su expansión es inevitable, ya que se obtienen mejores resultados generales y los objetivos de los proyectos se cumplen con mayor precisión. A pesar del hecho de que Lean Construction ofrece soluciones a muchos problemas que ocurren bajo el enfoque de administración tradicional conocido como Gestión de Proyectos (Project Management, PM), el alcance de su aplicación no es tan prometedor. Los países en los que se aplica mínimamente el Lean Construction son los Estados Unidos de América y el Reino Unido, además de otros países de Europa y América Latina. Sin embargo, todavía no se aplica de manera más exhaustiva en estos países y está completamente ausente en muchos otros en todo el mundo.

Este estudio se centra principalmente en la aplicación de el Lean Construction a Infraestructura, específicamente en proyectos viales; Investigando soluciones de Lean Construction para los desperdicios del tiempo. A través de la realización de una investigación de estudio de caso, este trabajo se enfoca en investigar el impacto de la aplicación del Sistema Last Planner como una herramienta Lean Construction en la eliminación de actividades sin valor agregado (NVA), es decir, desechos en un proyecto vial en El Cairo, Egipto. Este estudio incluye un estado del arte tanto en el enfoque de gestión tradicional de proyectos Project Management como en Lean Construction.

El estudio se aplica a un enfoque comparativo entre la aplicación del enfoque de el Project Management y el Lean Construction en proyectos viales. Por lo tanto, el investigador realizó diferentes simulaciones del proyecto de carretera estudiado, teniendo en cuenta los dos enfoques (Project Management y Lean Construction), y luego obtuvo los resultados de las simulaciones. Se utilizan dos parámetros como criterios de comparación: Plan de porcentaje completado (PPC) y Porcentaje de residuos de actividad (PAW). El último (PAW) es un nuevo parámetro introducido por el investigador para investigar sus resultados antes / después de aplicar las herramientas de el Lean Construction.

Los hallazgos del estudio apoyan la hipótesis de la investigación de que la aplicación del enfoque de Lean Construction a los proyectos viales aumenta la productividad al eliminar los desechos relacionados con el tiempo y disminuir la duración del proyecto. Esta investigación apoya el argumento de que los proyectos viales pueden mejorarse en gran medida con la aplicación de el Lean Construction en lugar del enfoque tradicional el Project Management.

CHAPTER 1 INTRODUCTION

1.1 Justification of Research and the Research Problem

Lean Construction is regarded as an innovative approach of management for various types of projects in the field of construction. As much as it is currently applied in some countries, its expansion is inevitable, for better overall results are obtained and the projects' objectives are met more precisely. Countries where Lean Construction is minimally applied include the United States of America and the United Kingdom besides other countries in Europe and Latin America [245], [35]. However, it is still not applied to a more exhaustive extent in these countries and is completely missing in many others around the world. It is worth mentioning that including the Lean approach in the construction field is relatively recent, as it began in the 90s providing opportunities for improvements in projects' management. Despite the fact that Lean Construction offers solutions to many problems in the traditional management approach known as the Project Management (PM), the scope of its application is not as promising [139].

Having been applied in some instances and not in many others, it is interesting to investigate the reasons behind the lack of its spread. Scholars found that there are challenges that stand in the way of applying Lean Construction. Lack of awareness about the existence of this approach as well as lack of knowledge of how to properly apply it come at the top of the list of obstacles that hinder the application of Lean Construction. One reason that causes lack of awareness is the non-existent interest to change; owners, contractors and decision makers in construction projects reject the application of new approaches for fear of taking risks by trying innovative solutions [35].

This study primarily focuses on the application of Lean Construction to Infrastructure, specifically road projects. The reason for choosing to focus on road projects goes back to their sensitive nature. That is, road projects are regarded as the foundation on which cities are constructed, which makes it a crucial category to start with when applying the Lean approach. According to scholars [111], [223] using the traditional Project Management approach in road projects results in many wastes, most importantly time and cost related wastes. Hence, the study investigates Lean Construction solutions to the time wastes. Because of the significance of road projects and the advantages provided by Lean Construction, the study endeavours to support the argument that road projects can benefit greatly from the application of Lean Construction instead of the traditional approach.

Delays in the scheduled durations of road projects were found to be common when applying the traditional management approach [223]. Based on personal observation of a road project, applying the traditional Project Management approach resulted in time wastes that can be grouped in three categories. These categories are: inspection delays that are caused by factors such as absent or occupied consultants, lack of materials when needed due to not delivering on time, and lack of machinery maintenance which in many instances lead to the breakdown of the equipment on site.

Having observed such problems, the application of Lean Construction to road projects becomes inevitable to face time related wastes. Elimination of wastes is a concept that lies in the core of the Lean Construction by providing various tools to get rid of the different wastes categories. Addressing the aforementioned wastes, Lean Construction provides three tools: Last Planner System (LPS), Just In Time (JIT) and Total Productive Maintenance (TPM), which are discussed in details later [51], [209], [57].

1.2 Objectives

1.2.1 General objectives

As previously mentioned, the main objective of the proposed research is to investigate the application of Lean Construction approach to infrastructure projects with a specific focus on road projects.

The majority of road projects in the world in general and in Egypt in specific are developed using the Project Management concept as the default approach. As noted in the above-mentioned section, the downsides of this approach affect the overall quality and delivery of the projects because of the wastes produced during the process. Hence, Lean Construction, with the advantageous tools it provides, is put forward as a preferable approach to apply to road projects.

Through conducting case study research, this study focuses on investigating the impact of applying Last Planner System as a Lean Construction tool on the elimination of Non-Value Added (NVA) activities, that is, wastes in a highway project in Cairo, Egypt. Non-Value Added (NVA) activities mainly refer to the aforementioned three categories of wastes: inspection delays (such as absent or occupied consultants), lack of materials when needed (due to not delivering on time for example), and lack of machinery maintenance (causing problems such as the breakdown of the equipment on site). During the period from 16th of July until 15th of August 2016, the PhD candidate studied a highway project in Egypt -Dahshour's Connection Highway- aiming at investigating how road projects work under the traditional Project Management approach.

1.2.2 Specific objectives

1) Applying Project Management (PM) into the simulation modelling of the case study:
    a) Making a conceptual model for Work Breakdown Structure (WBS); one of the most important tools for Project Management (PM) approach. This tool is used to decompose the milestones of the project to activities.
    b) Making numerical simulations to determine the impact of the percentage of time wasted during the project activities on the productivity percentage and activities duration. The percentage of time wasted refers to time wastes percentage during each activity divided by the total time of this activity (without the wasted time). The productivity percentage refers to percentage of the actual productivity during a week divided by the productivity planned for the same week. The main idea of using the percentage of time wasted is to demonstrate how the existence of wasted time while applying the Project Management approach negatively affects the productivity percentage and activities duration. Accordingly, the calculations in this simulation reflect the actual observations on site as recorded from the case study of the highway.
2) Applying Lean Construction (LC) into the simulation modelling of the case study:
    a) Making a conceptual model for Weekly Work Planning (WWP). Weekly Work Planning (WWP) is used to determine the percentage of time wasted for the activities that took place in the week before. It is also named “Commitment planning”; engineers have to respond to the question of what will be done next. This is considered short-term planning (weekly planning). Last Planner System (LPS), the Lean tool under which Weekly Work Planning (WWP) falls, aims to protect projects from variabilities. Last Planner System (LPS) is also used to determine the reason behind the failure to execute the required activities. Weekly Work Planning (WWP) is specifically used to determine the breakdown of the activities and identify their wastes.
    c) Making numerical simulations to determine the impact of the percentage of time wasted on productivity percentage and activities duration when these parameters’ values change (by eliminating wastes as explained below) and measuring the results

of these variables. The percentage of time wasted refers to the percentage of wasted time during each activity divided by the total time of this activity (without the wasted time). The productivity percentage refers to percentage of the actual productivity during a week divided by the productivity planned for the same week. The main idea of using the percentage of time wasted is to demonstrate how the elimination of wasted time while applying the Lean Construction (LC) positively affects the productivity percentage and total project duration.

3) Analysing the results.

1.3 Research process

The PhD thesis is divided into four parts as shown in Figure 1-1. The first part is the case study conducted: includes studying and observing a road project. From the site observation the problems are observed and identified. The second part includes reviewing previous studies on the two approaches - Project Management and Lean Construction - in general and how they are applied to road projects in specific. The third part is mainly concerned with conducting different simulations of the studied road project, taking into account the two approaches (Project Management and Lean Construction), then obtaining the simulations results. The last part includes the comparative analysis between the application of Project Management and Lean Construction to road projects, and putting forward recommendations for the industry and suggestions for future researches.

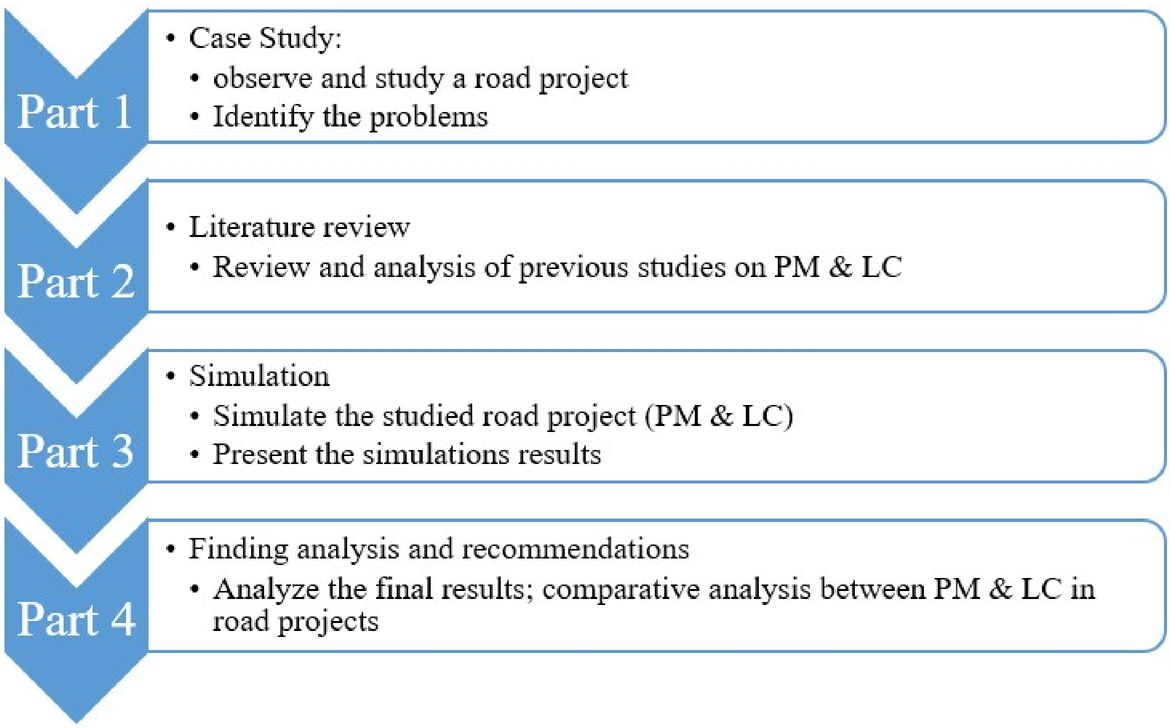


Figure 1- 1: PhD thesis structure

1.4 Research hypothesis

Based on the reviewed literature, this study hypothesizes that the application of Lean Construction approach to road projects enhances productivity through eliminating time-related wastes and decreasing the project duration. Accordingly and in light of the aforementioned objectives, this research targets investigating the following research hypothesis:

- RH: The application of Lean Construction approach to road projects enhances productivity through eliminating time-related wastes and decreasing the project duration.

1.5 Research methodology

The study's empirical work is done through conducting case study research through observing and studying a highway project in Cairo, Egypt. The main aim is to explore the main focus of the study; the impact of applying last planner system as a Lean Construction tool on the elimination of Non-Value Added (NVA) activities, that is, wastes in a highway project in Cairo, Egypt. In that sense the case study serves as a demonstration of the weaknesses of applying the Project Management approach in road projects.

Accordingly, during the period from the 16th of July until the 15th of August 2016, the PhD candidate studied a highway project in Egypt -Dahshour's Connection Highway- aiming at investigating how road projects work under the traditional Project Management approach. Exploring the downsides and their potential impact on road projects was the main aim guiding the case study, in order to emphasize and investigate the degree of importance of Lean Construction (LC) application in road projects.

Numerical simulations are carried out using the software Simio. The main aim of applying these simulations is conducting a comparative analysis between using Project Management (PM) and Lean Construction (LC) approaches in road projects. Hence, three simulations were conducted as follows:

- Simulation PM-EW (Project Management Expected Wastes): Inserting the maximum number of assumed wastes for each sub-activity in the studied project using random functions (personal assumption based on site observations).
- Simulation PM-OW (Project Management Observed Wastes): Different values for time wastes are introduced using random functions based on observations on site.

- Simulation LC (Lean Construction): Same as the previous Simulation, different values for time wastes using random functions based on site observations.

The three simulations are explained in details in the Methodology chapter.

1.6 Document structure

This PhD thesis proposal is divided into six chapters as follows:

- Chapter 1: Introduction; as demonstrated, includes the justification of the research, explanation of the research problem and how it is addressed. This chapter also includes the general objectives, which focus on the application of Lean Construction in road projects. This is followed by the specific objectives, which focus on the numerical simulations done to demonstrate the comparison between the results when applying Lean Construction versus Project Management approach into the simulation modelling. Then, the study's main research question and the explanation of the studied road project are demonstrated by determining the project's location, characteristics and activities.
- Chapter 2: Literature review on Project Management (PM) approach; reviewing previous studies on Project Management (PM) approach. The chapter begins by explaining the concept of Project Management (PM) approach, listing its main knowledge areas and the project management process groups. Additionally, the status of the construction projects nowadays is overviewed in an attempt to demonstrate the downsides of applying Project Management. The next section sheds light specifically on the concept and tools of three knowledge areas relevant to the study. Lastly, previous studies on road projects applying the Project Management (PM) approach are reviewed.
- Chapter 3: Literature review on Lean Construction (LC); reviewing previous studies on Lean Construction (LC). This chapter starts by overviewing the history of the Lean concept and the reasons behind its invention to provide context. This is followed by determining the principles of Lean Construction. A comparison between the two management approaches, Lean Construction and Project Management is then demonstrated. Then a focus on the Lean perspective on construction projects activities is developed followed by presenting the main Lean Construction tools. Emphasis is then done on two specific Lean Construction tools because of their relevance to this study; Last Planner System and Integrated Project Delivery System. In order to present an exhaustive overview, the barriers as well as benefits of Lean Construction are then

presented, followed by reviewing previous studies on road projects applying Lean Construction.

- Chapter 4: Methodology; detailed explanation of the conducted case study including information about the simulations applied and the inputs data. At the beginning details about the studied road project are presented in order to provide the necessary context; the location, scheduled duration, project length, and more information related to the project. The main activities of the project and the obstacles observed during the site visits are demonstrated. The next section includes the information related to the conducted simulations. Under this section, the justifications of applying the different simulations in the study are discussed, their assumptions, the parameters used and identification of the inputs in each simulation.
- Chapter 5: Results analysis; the results of the numerical simulations for each activity of the studied road project are presented. Then, in light of the researcher's own observations and the previous studies, analysis of these results is illustrated.
- Chapter 6: Conclusion; responding to the study's main research question based on the findings analysis. Further, in this chapter the study's limitations are presented as well as recommendations to the construction industry and suggestions for future research.

*C*HAPTER 2 PROJECT MANAGEMENT (PM) APPROACH

2.1 Introduction

In this chapter, an overview of previous studies on the Project Management (PM) approach and how it is applied in different construction projects is demonstrated. The chapter begins by explaining the PM as the traditional approach and its main pillars in general by presenting the PM process groups and knowledge areas. In this section, an explanation of the problems that face the construction industry in light of the PM application is presented. Besides, subsections that focus on explaining the knowledge areas relevant to this study and its main tools are developed. In the section that follows, details of the Project Management (PM) approach application on general projects sectors is analysed. Last but most important to this study is the section where analysis of the application of PM approach in road projects is demonstrated. The chapter is then brought to an end with the conclusion where the main highlights are emphasized.

2.2 Project Management approach concept

Any construction project can be identified as successful mainly through achieving improvements in the main criteria; related to cost, time and quality, in addition to effectively meeting the stakeholders' requirements. Hence, turning material at hand into the required output and finalizing the project with the identified benefits (reducing cost, meeting stakeholders' requirements, etc.) come at the top of the list to attain successful project management. It is essential to note that the project management success is not the same as the project success; as the first means the success of the "iron triangle" (which refers to cost, time and quality) and the second refers to the success of delivering the final result of the project. Corrective project planning, hiring workers with adequate skills set, and availability of materials and equipment are identified as important factors in order to have a successful project [171], [144], [169], [167], [255], [188], [122], [43], [279], [168], [8], [198], [90], [89], [55], [229], [178], [254], [189], [154], [184], [237], [69], [98], [177], [141], [128], [134], [295], [160], [246], [10], [11], [14], [61], [97], [120], [130], [135], [195], [182], [228], [231] [276].

The Project Management Institute (PMI) is a non-profit institute with a main mission to set the requirements and procedures for managing construction projects using the PM approach. The PMI published the Project Management Body Of Knowledge (PMBOK) guide for the Project Management (PM) approach. The first copy was published in 1996, providing guidelines of how to attain project and project management success. This guide defines the project as a temporary attempt of a process to deliver a unique result of a product, as it has a specific beginning and end. The PMBOK GUIDE defines project management as phases designed to manage the project by using the necessary knowledge and tools to meet the project's targets; the project's success criteria. There are forty-seven project management procedures categorized under ten knowledge areas and five project management phases. The five project management phases and knowledge areas are [169], [188], [122], [43], [279], [8], [198], [55], [229], [178], [177], [128], [246], [233], [134], [135]:

(1) Initiating; this entails the identification and definition of the project.
(2) Planning; under this process phase occurs the planning of all the knowledge areas, which takes place before starting the execution stage.
(3) Executing; is the execution process; the transformation of the customer's imagination to real.
(4) Monitoring and controlling; this phase controls the knowledge areas and tracks any changes that occur.
(5) Closing; this is the finalizing process of the project.

While knowledge areas are:

(1) Project Integration Management; includes the track to determine how to define, execute, manage, control and close the project.
(2) Project Scope Management; is used to include all the data to finish the project exactly as the customer wants and expects.
(3) Project Time Management; is used to develop and control the project schedule.
(4) Project Cost Management; is used to develop and control the project budget.
(5) Project Quality Management; refers to the quality policies and objectives for the project.
(6) Project Human Resource Management; includes the identification, organization and management of the team members, workers and human resources of the project.
(7) Project Communication Management; is used to include the information about the communication process between the stakeholders in the project.
(8) Project Risk Management; refers to the identification, ranking, controlling the risks in the project.
(9) Project Procurement Management; includes the procedures needed to track the relationships with the organizations outside the project, which may include sub-

contractors, suppliers or any other organization that delivers products to the construction project.

(10) Project Stakeholder Management; includes the identification of any stakeholder who can affect the project directly or indirectly. It includes also the controlling process with the stakeholders.

This study is mainly concerned with two knowledge areas: project time management and project risk management. As a matter of fact, the two areas are correlated; where risk management has a significant impact on time management [263], [127] [151], [23], [164], [287]. For instance, an error in the design phases if not detected early as a part of risk management can reflect during implementation causing postponements in time schedules and hence impacting the ability to maintain effective time management [164]. Lean Construction identifies projects' risks under the category of time wastes as discussed in further details in the chapter on Lean Construction [127].

Scholars state that construction projects face many problems and risks during the construction phases [263], [151], [23], [164], [287]. In some cases, the planning phase in the construction project is not realistic; that is too ambitious to be executed. This results in many problems when the execution phase starts while striving to develop the unrealistic set plan. As a result, conflicts between the project's stakeholders arise. This sheds light on how collaboration between the owner and the main contractor acts as a prerequisite for efficient performance during the different phases of the project [263], [151], [23], [164], [287]. Being regarded as a vital concern, collaboration between the different project partners is one of the main issues addressed in this study. The reason is that such complications are potential reasons for having delays in schedules, which increases the total cost of projects and leads to the reduction of activities' quality. In addition, incorrect risks information and poor management are also considered reasons behind cost overrun and schedule delays. Another factor that should be taken into account is the sub-contractor selection criteria; reputation, quality of work and ability to deliver on time should be studied early in the selection process to avoid potential risks. Previous studies state that the increments in projects costs and delays in schedules are common problems in construction projects around the world [263], [151], [176], [23], [164], [287]. As aforementioned, these problems in most instances lead to conflicts between the different project partners which may be resolved only by resorting to international arbitration and thus causing obstacles. One of the most common causes of cost increase and highly important to consider is safety risks; mainly referring to workers' injuries. Unfortunately, this problem is highly common especially in construction projects where workers are in many instances vulnerable to serious injuries [23]. In addition to endangering lives, these injuries can increase the project's cost by as much as 15% as a result of funding the treatment of the injured [23].

For the above-mentioned reasons, the construction industry has a negative reputation when it comes to project success. Nowadays, it is a target for engineers to finish the project without delays and within budget. Some of the reasons that cause delays in the schedule is shortage of information related to estimating the activity resources and duration, breakdown of machines, inefficient selection of sub-contractors and design change by the owner. Despite the fact that researchers focus on the improvement of this issue, the situation is still not good. Generally, changes or variations caused by one or more stakeholders are defined as a deviation from the scope or the schedule. Significant as it is to the success of project management, this study delves into the issue of variations through focusing on tools that could provide solutions to avoid its consequences. The PM approach lacks such tools, and hence this is further developed and discussed in the chapter on Lean Construction. Design changes are identified as one of the most significant risks factors, which might occur due to poor communication and collaboration between stakeholders. It may lead to increases in cost, low quality of the work accomplished, delays in the schedule besides decreasing the motivation of the workers. Accordingly, design changes increase the percentage of the activities reworked. Figure 2-1 shows some reasons of the design changes [115]. These reasons are based on internal criteria and external criteria. Internal criteria related to the use of new technology in the project can be followed by changing in the design for an activity. It is also related to the errors in design and changing in the project's concept. Examples of external criteria include a financial crisis in the project's country, which in turn affects the import of needed material. Also the laws and requirements in each country are external criteria that can cause design changes [192], [79], [71], [255], [231], [179], [21], [169], [4], [69], [184], [283], [292], [239], [220], [271], [18], [84], [200], [183], [237], [123], [285], [247], [160], [276], [14], [291], [19], [124], [197], [150], [122], [295], [273], [195], [43], [264], [126], [258], [11], [115], [185], [38], [114], [267], [189], [113], [22], [10], [58], [154], [182], [289], [17], [266], [178], [90], [30], [74], [75], [174], [44], [83], [99], [270], [168], [60], [177], [7], [229], [290].

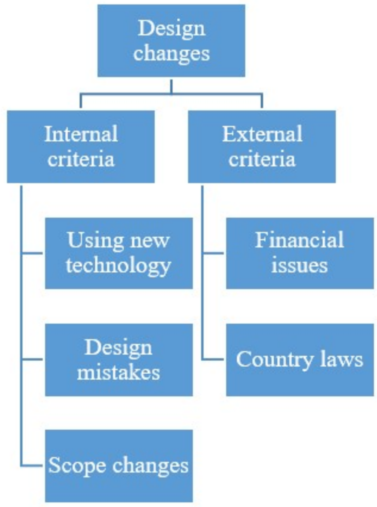


Figure 2- 1: Design changes reasons [115]

The author of this thesis has a professional experience as a site engineer working with the main contractor and hence personally supervised project activities such as reinforcement of steel, dewatering system among others in addition to finishing activities. Having worked in the construction stage of a residential building affiliated to an embassy in Egypt, the researcher has personally witnessed the occurrence of design change in the project leading to erroneous consequences. After pouring concrete for five columns on the ground floor of the building, the owner discovered that the height of the ground floor was not as high as he desired, noting that this step was implemented based on the set design. Consequently, the work for the project stopped completely for about three months due to negotiation meetings between the owner, the consultant and the main contractor attempting to introduce changes to the design to meet the owner's expectations. This project was scheduled to finish in three years but due to many delays and other wastes duration was delayed for three extra years. The main contractor is an international company that ranked in the 13th place as best in the world during this period.

2.3 The main knowledge areas

In the next sections, a detailed explanation of three knowledge areas is presented, (Project Time Management, Project Risk Management and Project Stakeholder Management). The study is specifically concerned with these three knowledge areas since it focuses on providing recommendations for improving the total duration of construction projects. Managing and anticipating risks besides efficient collaboration between stakeholders are variables that relate to time management. Hence, eliminating waste (waste is the result of risks) from the project and emphasizing of the stakeholders responsibility in this task are deemed core issues in this study.

2.3.1 Project Time Management Concept

According to scholars [189] time schedule is considered the most important factor of the "iron triangle" (time, cost and quality) for identifying successful projects. It is estimated to be used as information by the owner for the future plans. Project Time Management is the knowledge area, which is responsible to estimate, develop and control the schedule of the construction projects. It has seven project management processes. According to scholars [233], [55], [189] these processes are:

(1) Plan schedule management; includes the main information lines about the procedures, executing, managing and controlling of the project schedule.
(2) Define activities; the process of determining and identifying all the activities of the project.
(3) Sequence activities; determines the realistic relationships between the identified activities.
(4) Estimate activity resources; identifies all the resources required to finish each activity. These resources include human, equipment, materials and the suppliers of these materials.
(5) Estimate activity durations; determines the duration to finish each activity. This estimation depends on the previously estimated resources.
(6) Develop schedule; after determining the activities, their sequences, resources and durations. Collect the information together and make the estimated schedule.
(7) Control schedule; uses to manage any changes during the project construction and minimizes the occurrence of the risks and take corrective/preventive actions.

- **Project Time Management Tools**

The tools demonstrated in this section are displayed according to the order of processes in which each tool is used. Project Time Management starts by determining the lines and procedures for the schedule related to a project plan schedule management. Planning of the schedule includes the identification on how the engineers plan, and execute the duration of the project. The schedule of the project updates frequently as the changes take place during the execution of the project. The next process in time management is to determine what the activities are in the required project. The main tool used for the activities is the Work Breakdown Structure (WBS), which is one of the most important tools for Project Management (PM) approach. This tool is used to decompose the project's milestones to activities. The third process determines the relationship between the defined activities and their sequences. This process uses tool Precedence Diagramming Method (PDM). The aim of this tool is determining the detailed relationship between the activities. Figure 2-2 shows the explanation of this tool through demonstrating two main activities in the project (A & B), and four different potential relations between the activities: [261], [300], [233], [91], [180], [52], [32], [55]:

(1) *Finish to Start*; the start of the next activity is after the finish of the first one.
(2) *Start to Start*; the start of the next activity is after the start of the first one.
(3) *Finish to Finish*; the finish of the next activity is after the finish of the first one.
(4) *Start to Finish*; the finish of the next activity is after the start of the first one.

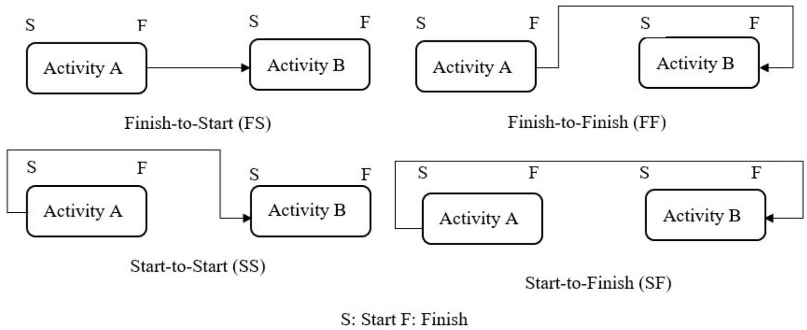


Figure 2- 2: Precedence Diagramming Method (PDM) concept [233]

Which relation is necessary is decided by the project planners during the planning phase depending on the nature of each activity and how it is related to or impact the other. For example, if Activity A is putting the asphalt layer, and Activity B is painting road signs on the ground then the relation clearly needs to be *Finish to Finish.* The reason for choosing this relation is because both activities will be done in parallel and hence saving time.

After determining the relations between the different activities on the project, an estimation of the resources needed for each activity is developed. Based on this process the duration of each activity is also estimated. The stakeholders develop the estimation of each activity duration and resources. The last step in the planning process group is developing and illustrating the schedule of the entire project based on the information collected during the previous processes. Figure 4 shows the tool that is used while developing the schedule of the project. This tool - the Critical Path Method (CPM) – aims at setting expectations of the longest duration some activities may require. Morgan R. Walker and James E. Kelley Jr. developed the Critical Path Method (CPM) during the 1950s. According to scholars [180] this tool is considered the most popular tool used to manage construction projects. As shown in Figure 4, every activity in the project is shown on a square. This square includes data relates to "Early Start", "Early Finish", "Late Start" and "Late Finish". The early values are calculated in forward direction, while the late values are calculated in backward direction. The critical activities, displayed on the critical path, affect the final project duration in case of increase in their duration. This is demonstrated through looking at the difference in the values of the early start and late start, and those of early finish and late finish, which in both cases is zero. This difference between both cases (early and late) is commonly referred to as *float* (check Figure 2-3). Hence the critical path activities reflect the total duration of the project since they maintain a constant time plan as explained.

According to scholars [209], [129], [50], [110], [51] there are disadvantages that emerge when applying the CPM:

(1) CPM focuses on the logical dependencies between the activities and neglects the workflow of the project.
(2) CPM adds time buffers between the activities to cover any constraint that can occur; however, this can increase the number of constraints that interrupt the workflow. Buffers are not needed, and this leads to converting the buffers to wastes.
(3) CPM does not consider the project as workflow process.
(4) CPM has no constraints expectations.

In order to decrease the project's duration, the Critical Path Method (CPM) advices to use crash or fast tracking concepts [261], [55]. Crash is defined as increasing the number of skilled labours on the activities that are on the critical path. However, crashing may be the reason of increasing both the number of risks and the project's cost. While fast tracking is starting the following activity before finishing the previous one. Fast tracking increases the percentage of risks and increases the wastes relate to rework. One of the tools applying fast tracking is Design Build (DB) tool. This tool is most popularly used in construction projects in USA despite its failure to maintain consistent collaboration between the projects' stakeholders, which is core to applying the fast tracking concept with lower risks [81]. This tool makes one contract for both the design and construction stages. This tool is the modification of another traditional tool, which is Design Bid Build (DBB). The traditional tool makes two contracts for the design and construction stages. Design Build (DB) and Design Bid Build (DBB) are considered project delivery systems, two tools are shown in Figure 2-4. Design Bid Build (DBB) is the traditional tool, which depends on making two contracts with the designer and the contractor. While Design Build (DB) depends on making one contract which includes the project's design and construction process, [180], [261], [300], [171], [52], [233], [260], [187], [163], [90], [60], [61], [7], [8], [92], [55].

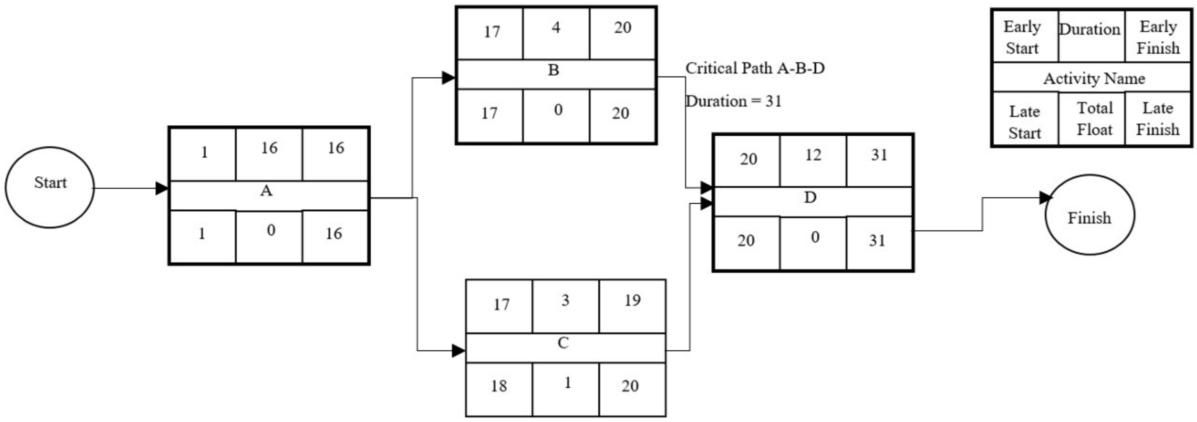


Figure 2- 3: Critical Path Method (CPM) application [233]

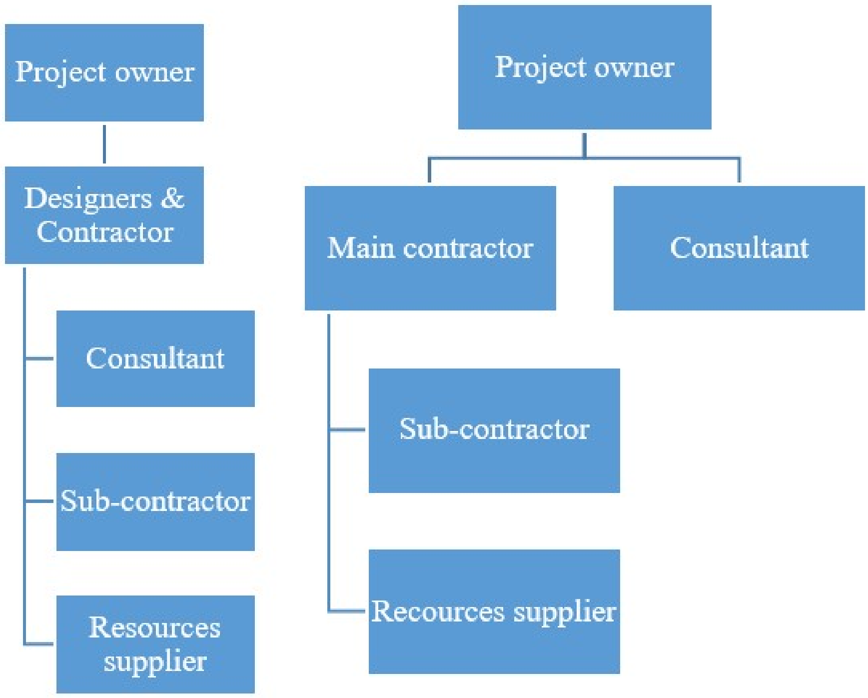


Figure 2- 4: Concepts of Design Build (DB) and Design Bid Build (DBB) [90]

In order to manage the risk of delays in the Critical Path activities, engineers use what is known as buffering; or in other words giving a range of time to activities that might *float* more than one day. This is achieved through either Critical Chain Method (CCM) tool or Critical Chain Buffer management as shown Figure 2-5 [233]. The aim of the CCM tool is mainly to cover for any delay that occurs in any of the Critical Path activities using buffering. Using buffer activities on the non-critical activities. Figure 6 shows two types of buffers (1) Feeding Buffers, which are between the activities that are not on the Critical Path, and (2) Project Buffer, which are before finishing the project that is on the critical path. The Project Buffer is used to manage any delay that takes place on the critical path during any period of the project. Finally, the last process refers to controlling the schedule. This is used to manage, control and update the schedule due to the occurrence of the changes during the construction project, [233], [91], [92].

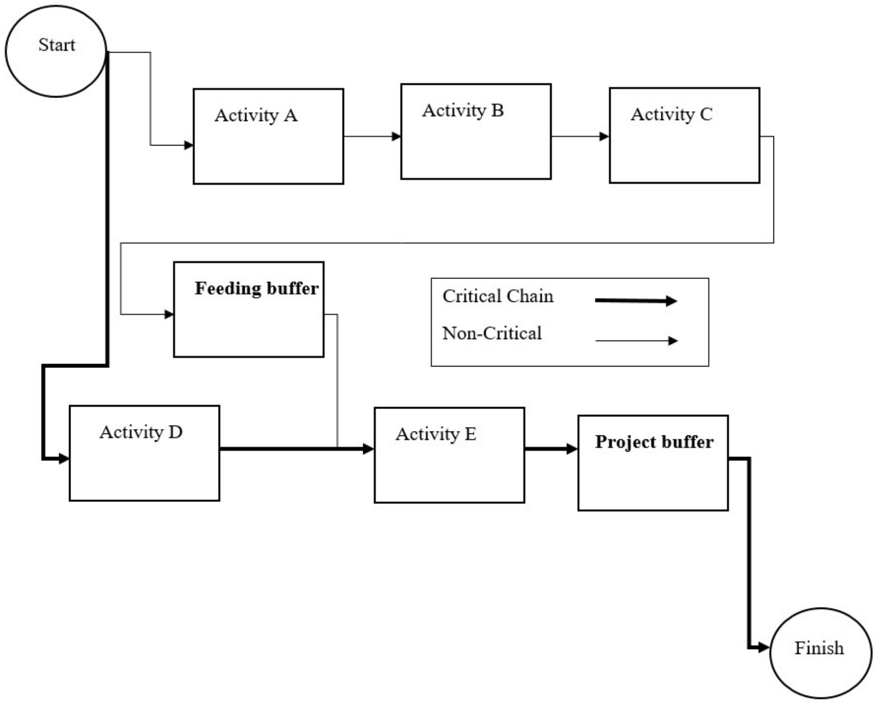


Figure 2- 5: Example of the Critical Chain Method (CCM) application [233]

2.3.2 Project Risk Management Concept

Risk is defined as an action that leads to impacts on the project. Risk may have negative or positive impacts (negative impacts can be the project's wastes result to worker injuries or destruction of any part of entire project) [263], [55], [125], [299], [113], [269], [301], [92], [180], [74], [225], [178], [159], [9], [252], [80]. Construction industry is considered one of the most dangerous industries. Some scholars [233], [271] stated that each risk may have more than one impact on the project. Examples of potential risks include exceeding the project budget, an accident in the project and change in design during the construction phase. As previously mentioned, despite the Critical Path Method (CPM) being a common tool used in construction projects, it fails to consider risks. Meanwhile, there is a Lean tool (Last Planner System) - concerned with project time management like CPM - that takes risks and time wastes into consideration as discussed later in the chapter on Lean Construction. Many scholars [273] stated that the construction project's risks cannot be eliminated,

Project Risk Management is the knowledge area responsible to determine how to react with the risks during the construction projects. This knowledge area is critical during managing any construction project. According to literature [161], [159], [125], [299], [220], [269], [301], [233], [92], [273], [113], [80], [267], [177], [295], [279], [55], [263] the six project management processes are:

(1) Plan risk management; determines the procedures of the risks in the construction project.
(2) Identify risks; lists the existing risks and know their effect on the project, because these risks may have a negative or positive affection.
(3) Perform qualitative risk analysis; determines the priorities of the impact of each identified risk and its occurrence percentages estimates if the risk has a positive or a negative effect on the project.
(4) Perform quantitative risk analysis; identifies the numerical effects of each risk on the project.
(5) Plan risk responses; determines the actions that take with the risks, by focusing on the highest priority risks.
(6) Control risks; is used to update the cost and schedule estimation after the occurrence of the risks.

- **Project Risk Management Tools**

According to [233] Project Risk Management starts by planning and managing the risks' strategies and procedures during a project. The risks can be seen as both threats and opportunities, (risks perceived as threats have a negative effect on the project while those seen as opportunities have a positive effect on it). The next step is identifying the risks and setting expectations of their potential occurrence during the project construction. Stakeholders are the ones in charge of developing risk identification. This step is followed by the following processes: (1) developing the qualitative and (2) quantitative data for the risk analysis. Qualitative risk analysis is used to determine the priority of each identified risk. This is carried out by determining the probability and impact of each risk. During the project meetings, the probability of occurrence of each risk is determined and the impact of each risk in the project is listed. The left column in Table 2-1 - Matrix of Probability and Impact of the risks - is the probability percentages, and the row below addresses the impact percentages. This table includes three risks categories, the dark blue, medium blue and the light blue are used for the highest, the smallest and the category with moderate risk categories. The highest risks category has the highest values of both the probability and impact. The next step is developing the quantitative risk analysis. This process in some instances is not developed as a result of the ignorance of the project's expert with the necessary data and information. In this case – if the quantitative data for the risks is not developed - the reliability of the project's results decreases. Usually, this process is implemented for risks that are deemed significant, that is, have a strong (negative) impact on the project. The main purpose of performing quantitative risk analysis is decreasing uncertainty during the different phases of a construction project. The development of this type of analysis occurs through determining the most likely - high and low - values of the project's estimates of cost and time [233], [271], [267], [125], [113], [161], [263], [225], [80].

Table 2- 1: Matrix of Probability and Impact of the risks [233]

Matris of Probability & Impact										
Probability %	Threats %					Opportunities %				
90%	0.040	0.080	0.150	0.310	0.600	0.600	0.310	0.150	0.080	0.040
70%	0.035	0.070	0.140	0.300	0.500	0.500	0.300	0.140	0.070	0.035
50%	0.030	0.060	0.120	0.240	0.450	0.450	0.240	0.120	0.060	0.030
30%	0.020	0.050	0.110	0.150	0.320	0.320	0.150	0.110	0.050	0.020
10%	0.010	0.030	0.080	0.100	0.100	0.100	0.100	0.080	0.030	0.010
	0.04 - very low	0.08 - low	0.16 - moderate	0.32 - high	0.64 - very high	0.64 - very high	0.32 - high	0.16 - moderate	0.08 - low	0.04 - very low

The determination of the important risks respones is a very critical process in planning risk management, because it includes how to manage these risks during the construction project life cycle. The last process is the controlling of the risks, which is used to manage and identify any risk that may take place during the construction of the project. This improves the risk efficiency. The four strategies for negative and positive risks are, as follows, [233], [159], [80], [271], [287], [161], [267]:

(1) *Avoid*; this strategy proposes to eliminate the risk from the project. Unfortunately, this elimination may be by changing the project definition, extending the schedule, or increasing the project cost and the main problem is that rarely can be done. For example, during the execution of the project, the prices of the necessary material resources for a specific activity may increase and hence increase the total cost of this activity. In this case, the planned budget fails to meet the real conditions.

(2) *Transfer*; is the strategy used to transfer the risk to another person or company. This strategy does not remove the risk from the project. Collaboration can help in transfering the risk from one project member to another.

(3) *Mitigate*; is the reducing the probability of the risk occurrence or reducing its impact on the project. For example, use the skilled labours in a high sensitive project (e.g. Nuclear projects).

(4) *Accept*; is the acceptance of the risk because the previous three strategies are failed to solve it. For example, accept to construct a project in earthquake areas.

According to the four strategies for the positive risks are:

(1) *Exploit*; takes benefits from the positive risks, such as using a new technology in an activity to reduce its duration.
(2) *Enhance*; is the increasing of the probability or impact of the project, such as using more resources to finish an activity faster.
(3) *Share*; is used to make more parties taking the advantage of the risks. For example, making joint venture contracts where risks could be shared between contractors.
(4) *Accept*; refers to agreeing on taking advantage of the risk since it benefits the project execution. For example, if the prices of the necessary materials decreased during the project it is in the benefit of all to take advantage of the situation.

2.3.3 Project Stakeholder Management Concept

A stakeholder can be defined as any entity (company or individual person) who has an affection or can have affection on the result of a project. Examples of stakeholders are: owner, consultant, general and sub-contractors, material suppliers, labors, etc. Project Stakeholder Management is the knowledge area responsible to identify, manage and control the stakeholders in the construction projects. According to scholars [94], [233], [246], [55], [43], [193], [270], [194] the following four project management processes are the core of this knowledge area:

(1) Identify stakeholders; determining who the stakeholders of the project are. Stakeholders can have direct or indirect effect on the project.
(2) Plan stakeholder management; determining how engage the stakeholders are during the duration of the project.
(3) Manage stakeholder engagement; working with the stakeholders on determining how to deliver their needs to the project. The project manager tries to boost the stakeholders' engagement and support to the project.
(4) Control stakeholder engagement; controls the relationships with the stakeholders in the project.

- **Project Stakeholder Management Tools**

The first process in the stakeholder planning is to determine who the stakeholders are in the entire project. This step is the first to be developed in the Project Initiation phase; it is vital to determine all the project's stakeholders before starting the planning process group. The following step in this process is determining the power and interest of each stakeholder by using the stakeholder analysis, shown in Figure 2-6. In this figure, there is a example of some stakeholders, which are A,B,C,…J,K. These stakeholders have different powers and interest on the project. Stakeholder A has high power and interest on the project, so it is important to be managed carefully. In the next step – managing the stakeholders' engagement - the stakeholder engagement in the project is determined by using the analytical technique. According to scholars [233], [267], [193], [94], [194] the engagement is based on five categories; they are:

(1) *Unaware*; has no information about the project. For example, the police officer that has the project is in his region responsibility area.
(2) *Resistant*; is aware of the project and against its construction. For example, the neighbours of project that is making noise through the nights to them.
(3) *Neutral*; is aware of the project but he is not supportive or resistant to it. For example, the part time skilled labour.
(4) *Supportive*; is aware of the project and support it. For example, the junior engineer working in the project.
(5) *Leading*; is aware of the project and on it. This stakeholder is engaging in finalizing the project. For example is the project construction manager.

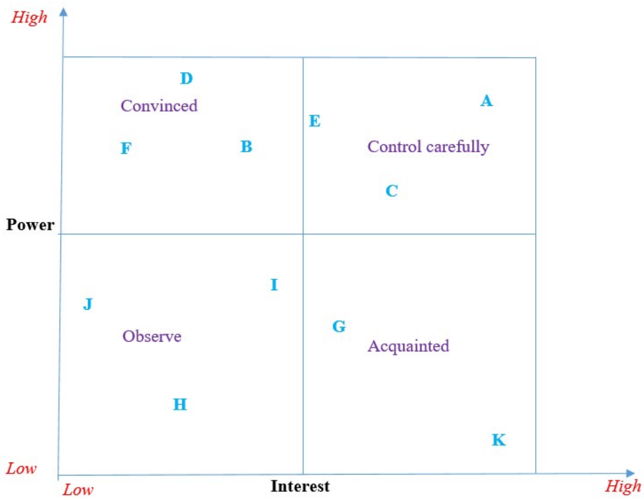


Figure 2- 6: Application of power and interest diagram for stakeholders [233]

In order to better manage the stakeholders' engagement, a project manager should work with them to determine the best way to deliver their requirements and needs for the entire project. This process is essential to increase the support of the stakeholders if they are *resistant* or *neutral* to the project. Finally, the last process in this knowledge area, stakeholder planning, is controlling the relationships with the stakeholders. The target of this step is to keep track of the performance of stakeholders' involvement in the project through consistent observation of their relationship to the project [233], [194].

Despite the issue of stakeholders' involvement being emphasized under the PM approach as demonstrated, there still is problematic gap; lack of stakeholders' engagement in the early stages of the project. This matter is addressed under Lean Construction through Integrated Project Delivery (IPD) system, as further explained in the specified chapter.

2.4 Project Management approach studies

Tables 2-2 to 2-14 summarizes the studies related to Project Management (PM) approach according to the country where each study was applied. The main motives of each study are determined. The studied project sector and the methodology used are listed. Finally, the results of the study are presented.

Table 2- 2: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
4	(Adekunle & Ajibola, 2015)	Nigeria	Determine the project delays factors and their affection on the projects.	Building projects	Survey	Increase the project's cost and extension in project duration are the most important factors.
7	(Adnan, Bachik, Supardi, & Marhani, 2012)	Malaysia	Determine the success factors that support Design and Build.	Construction projects in general	Survey	The owner should understand well the exact need of project's scope and the changes should be limited.
8	(Adnan, Hashim, Marhani, & Johari, 2013)	Malaysia	Understand how to make better application of Project Management concept.	Construction projects in general	Survey	The engineers are aware of the project management, but it needs better planning to have project success.
9	(Adnan, Yusuwan, Yusof, & Bachik, 2014)	Malaysia	Determine and rank the critical success factors.	Construction projects in general	Survey	By understanding the identified critical success factors, the project planning is improved.
10	(Agyeman, Asare, & Ankomah, 2016)	Ghana	Determine the affection of design data on the trustworthy progress of the project and the estimation of the cost.	Road projects	Site observation, interviewss and analysing case studies	The delays in the projects are mainly due to the design changes. The projects' costs are increased because the design changes and the bad project management.
11	(Ahmed, Georgy, & Osman, 2014)	Egypt	Determine the percentage of success and knowledge for both Critical Path Method and delays analysis.	Construction projects in general	Survey and interviews	Select the most relative delays analysis. Apply training to the delays analysis to increase the awareness.
14	(Al Nasseri & Aulin, 2016)	Oman	Determining the factors for management performances and the attitude of the organisation on scheduling the projects.	Construction projects in general	Survey	Any factor relates to both management performances and the attitude of the organisation are considered critical factor.
17	(Alashwal, Abdul-Rahman, & Radzi, 2016)	Malaysia	Determine how the utilization knowledge affect the projects.	Road projects	interviews, site observation and analysing case study	The identified factors can affect the performance of the projects, the projects' decision-making and delays in projects.
18	(Albogamy, Scott, & Dawood, 2013)	Saudi Arabia	Determining the reasons for the exceeding the expected duration.	Building projects	Survey	Identification of the delays reasons and ranked them.
19	(Albogamy, Scott, Dawood, & Bekr, 2013)	Saudi Arabia and Jordan	Determining the results of the factors leads to project's delay.	Building projects	Survey	The delays factors have different raking in the two countries.

Table 2- 3: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
21	(Alptekin & Alptekin, 2017)	Turkey	Find other factors affect the contractor selection not relate to lowest price	Construction projects in general	Survey	The ending project work and the staff's technical are the highest factors in ranks.
22	(Alsendi, 2015)	Bahrain	Determine the delays criteria in the architecture projects and ranking them	Construction projects in general	Survey, interviews and analysing case studies	Identified delays criteria and the most important are financial issues and design changes.
23	(Aminbakhsh, Gunduz, & Sonmez, 2013)	Turkey	Determine the safety risks criteria and ranking them.	Construction projects in general	Analysing case studies	The criteria, which relate to accidents on site, are the most important.
30	(Arditi, Nayak, & Damci, 2017)	USA and India	Determine the relation between the company's culture and the project's delay.	Construction projects in general	Survey	The American companies with high experiences are lower in projects delay. In contrast, the Indian companies with high experiences are higher in projects delay. In USA the delays due to the clients while in India they are due to the main contractors.
32	(Artto, Ahola, & Vartiainen, 2015)	Finland	Determine the criteria of the project value during the construction phase and its link with the usage phase.	Building projects	Analysing case studies and site observation	Identifying some integration points and recommendations.
38	(Aziz & Abdel-Hakam, 2016)	Egypt	Determine the ranking of the delays reasons and how to prevent their occurrence.	Road projects	Survey, interviews, site observation and analysing case study	Identified that the highest risk is considered to be the financial client's issues. The determination of the root cause of delays considered to be the better process to reduce the risks.
43	(Baroudi, 2014)	Australia	Determine the improvement process of teaching Project Management to postgraduates students.	Construction projects in general	State of the art	The study recommends edits on the process of the education.
44	(Batool & Abbas, 2017)	Pakistan	Determine the causes led to delays in finished projects during the previous 5 years.	Electrical projects	interviewss and analysing case study	Determination of list for the causes of delays and their frequencies.
52	(Braimah, 2013)	UK	Determining the reasons for the project delays and the avoiding process.	Building projects	Analysing case study and site observation	Listing factors lead to delay in the projects. Identification of factors that are mainly ignored as resources levelling.
55	(Burger, 2013)	South Africa	Determine if the project management needs additional awareness.	Construction projects in general	Survey, interviews, site observation and analysing case studies	Identification of some needed awareness as technical and sufficient construction management.

Table 2- 4: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
58	(Chiu & Lai, 2017)	Hong Kong	Determining the reasons for the project delays.	Electrical Projects	Survey	Factors as poor skills of labours were identified to be the highest-ranking factors.
60	(Cristóba, 2014)	Spain	Determining which project activities by their delays will increase the project duration and identify the cost of this delays.	Building projects	Game simulation	The increasing in project duration will cost money to the project.
61	(Cserháti & Szabó, 2014)	Austria, Czech Republic, Germany, Hungary, Poland, Slovakia, Slovenia and Switzerland	Analyse the relation between the successful of the project from stakeholder perspectives and the decreasing on both final duration, final cost and increasing on quality.	Construction projects in general	Survey	The factors relate to the communication between stakeholders are very important.
69	(Dias, Tereso, Braga, & Fernandes, 2014)	Portugal	Determine the project managers skills need in the construction projects.	Construction projects in general	Survey	Results show that 20% of the skills are required in different construction projects.
71	(Ding, Zuo, Wu, & Wang, 2015)	China	Get more knowledge on the structure of using Building Information Modelling regards to the architects.	Construction projects in general	Survey	The lack of technical knowledge are main challenge faces the architects during using Building Information Modelling.
74	(Doloi, 2013)	Australia	Determine the importance reasons lead to increase the project cost.	Construction projects in general	Survey	Identification these reasons and make their ranking. The poor in planning is considered one of the most important factors.
75	(Doloi, Sawhney, Iyer, & Rentala, 2012)	India	Determining the reasons for the project delays in India.	Construction projects in general	Survey and interviews	Identification these reasons and make their ranking. The poor in site management is resulted as one of the most important reasons of delays.
79	(Durdyev, Omarov, & Ismail, 2017)	Cambodia	Determining the reasons for the project delays in Cambodia.	Building projects	Survey	Identification these reasons and make their ranking. The lack of materials is finalized to be one of the most important reasons of delays.
80	(Dziadosz & Rejment, 2017)	Poland	Determine the pros and cons for three risk management methods.	Construction projects in general	State of the art	Identify of the required pros and cons. The analysing risks process should be malleable and multidisciplinary.
83	(Elhaniash & Stevovic, 2016)	Libya	Determining the reasons for the project delays in Libya.	Construction projects in general	Survey	Identification these reasons and make their ranking. The reasons relevant to humans are the most important.

Table 2- 5: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
84	(Emam, Farrell, & Abdelaal, 2015)	Qatar	Determining the reasons for the infrastructure project delays in Qatar.	Infrastructure projects	Survey	Identification these reasons and make their ranking. The design changes is determined to be one of the most important reasons of delays.
89	(Gambo, Said, & Ismail, 2016)	Nigeria	Determine the relations between the technical achievement and the important cost factors.	Building projects	Survey	Identify the relation; one of the highest impact cost factors on the technical achievement is the conditions on the projects.
90	(Ghadamsi, 2016)	Libya	Determine the more used procurement methods on the construction industry in Libya.	Construction projects in general	Survey	Design Bid Build and Design Build are considered the common procurement methods on the construction industry in Libya.
92	(Ghoddousi, Ansari, & Makui, 2017)	Iran	Determine both the project schedule and project cost improvements by using buffer to solve the project's problems.	Dam project	Analysing a case study and simulation modelling	Both the cost and duration for the project are decreased.
91	(Ghoddousi, Ansari, & Makui, 2016)	China	Determine the effect of using buffer methods on affection the schedule, regards to the risks factors. These apply by making a comparative analysis between traditional and new buffer methods	Infrastructure projects	Analysing a case study and simulation modelling	Identify that the new buffer method has more stability duration than the traditional method.
94	(Glenn, 2015)	Netherlands	Determining the conditions, which can be taken before the contract, used to improve the infrastructure projects.	Infrastructure projects	Survey and interviews	The integrated contracts are the highest recommended contracts.
98	(Gudienė, Banaitis, Podvezko, & Banaitienė, 2014)	Lithuania	Determining the reasons lead the project to be successful in Lithuania	Construction projects in general	Survey	Identification these reasons and make their ranking. Some of the most important reasons are clear identification of the scope and economic conditions.
97	(Gudienė, Banaitis, & Banaitienė, 2013)	Lithuania	By using analytic tool, determine the ranking of the reasons lead the project to be successful in Lithuania.	Construction projects in general	Survey	Identify the ranking of these factors.
99	(Guerrero, Villacampa, & Montoyo, 2014)	Spain	Estimate the project duration by using previous project information, regards to regression analysis.	Building projects	Simulation model	The factor of multiplying the area of the building floor by the number of the floors has greater impact on the project duration than the project's cost.
113	(Hossen, Kang, & Kim, 2015)	South Korea	Determine the reasons of the projects delays regards to the risks estimating in Nuclear power plant projects.	Industrialised building projects	Survey	Identify the risks factors that are the reasons of project delays and ranking them. The factor that relates to financial issues is the most important factor.

Table 2- 6: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
114	(Hsu, Aurisicchio, & Angeloudis, 2017)	UK	Determining the reasons for the project delays in infrastructure projects.	Infrastructure projects	Survey and analysing a case study	Identification these reasons and make their ranking. The shortage in construction technology knowledge and design changes are the most important reasons of delays.
115	(Hui, Abdul-Rahman, & Chen, 2017)	Malaysia	Identify the reasons of changes in design in building projects.	Building projects	State of the art	The rework activities are listed as the main reason for changes in design.
120	(Ihuah, Kakulu, & Eaton, 2014)	Nigeria	Determine the reasons lead the project to be successful in building projects.	Building projects	State of the art	Identification these reasons and make their ranking. The using of qualified team members is the highest ranking reason.
122	(Iram, Khan, & Sherani, 2016)	Pakistan	Analyse the relation between the successful of the project (from stakeholders perspectives) and the decreasing on both final duration, final cost and increasing on quality in Pakistan.	Construction projects in general	Survey	There is strong relationships between the successful of the project and the decreasing on both final duration, final cost and increasing on quality.
123	(Islam & Khadem, 2013)	Oman	Determine the reasons lead to be increase the productivity in Oman.	Construction projects in general	Survey	Identification these reasons and make their ranking. The shortage in materials are considered to be one of the most factors affect the project productivity.
126	(Islam M. , Trigunarsyah, Hassanain, & Assaf, 2015)	Afghanistan, Bangladesh, China, India, Indonesia, Malaysia, Pakistan, Sri-Lanka, Thailand, Vietnam, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, UAE, Egypt, Ghana, Libya, Nigeria, South Africa, Tanzania, Uganda, and Zambia	Determining the reasons for the project delays in some countries.	Construction projects in general	State of the art	Identification these reasons and ranking them based on their appearance on previous studies. The design changes and bad conditions of site management are the main reasons.
124	(Islam & Trigunarsyah, 2017)	Australia	Determine the methods used to analyse the risks in construction projects.	Construction projects in general	State of the art	Identification of the methods used to make the management of the risks.
125	(Islam, Nepal, Skitmore, & Attarzadeh, 2017)	Bangladesh	Determining the reasons for the project delays in Bangladesh for each project partner.	Building projects	Survey	Identification these reasons and make their ranking. Not qualified manager is the main reason for the owner, contractor and consultant.
128	(Jalal & Koosha, 2015)	Iran	Determine the factors have impacts on the management office.	Construction projects in general	Survey	Identification these factors and make their ranking. One of the highest factors is the professionalism of the management in the construction company.
130	(Jin, Deng, Li, & Skitmore, 2013)	China	Determine the factors used to identify and evaluate the achievement of the construction companies in China.	Construction projects in general	Survey, interviewss and analysing case study	Identification these factors and determine the importance weights of each factor.

Table 2- 7: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
134	(Joseph, 2017)	South Africa	Determine the criteria that has impact on Information technology projects.	Information technology projects	State of the art	Identification five criteria that has the impacts on these projects, one of them are the successful of the projects.
135	(Joslin & Müller, 2015)	France	Identify the link between the procedure of project management and the successful of the project.	Construction projects in general	Survey	The results identify that the procedure of project management affect the successful of the project by less than 25%.
141	(Kalu, Lew, & Sim, 2013)	Nigeria	Determine the relations between the project to be successful and the managers of the project.	Information technology projects	Survey	Identified that there is positive correlations between the two items.
144	(Khan, Turner, & Maqsood, 2013)	Pakistan	Determine the reasons lead the project to be successful in Pakistan.	Construction projects in general	Survey	Identification these reasons, one of these reasons are the support of the top management.
150	(Kumar, 2016)	India	Determining the reasons for the project delays in India.	Construction projects in general	Survey	Identification these reasons and make their ranking. The highest-ranking reason lack of the managing of risks.
151	(Kuo & Lu, 2013)	Taiwan	Determine the reasons of risks in metropolitan projects.	Metropolitan construction projects	Survey, interviews and analysing a case study	Identification these reasons and make their ranking. One of the most important reasons are mistakes in the shop-drawings, which lead to design changes
154	(Larsen, Shen, Lindhard, & Brunoe, 2016)	Denmark	Determining the reasons for each of the project delays, increasing in project cost and decreasing the quality.	Construction projects in general	Survey	Identification these reasons and make their ranking. The highest reasons for time, cost and quality are financial issues, wrong documents from the consultant and rework activities respectively.
159	(Lehtiranta, 2014)	Finland	Determine the relation between the knowledge in varied organisation of applying the management of projects risks and the previous studies.	Construction projects in general	State of the art	Some gaps are identified and not applied in the varied organisation such as, the projects opportunities are not added as the threats during managing the project risks.
160	(Lessing, Thurnell, & Durdyev, 2017)	New Zealand	Determining the reasons for each of the project risks in New Zealand.	Construction projects in general	Survey and interviews	Identify these reasons. One of the main reasons are delay in the shop-drawings.
161	(Li, Al-Hussein, Lei, & Ajweh, 2013)	Canada	Determine the reasons for project risks in modular construction projects and determine their effect on time and cost.	Building projects	Analysing case study, simulation model and interviews	Identify these reasons and their effect. The main reasons that affect time and cost are delay in the shop-drawings and design change respectively.

Table 2- 8: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
163	(Liu, Xie, Xia, & Bridge, 2017)	China	Determine the reasons for project risks in Design Build projects and determine their effect on project duration.	Construction projects in general	Survey and interviews	Identify these reasons, one of the main reasons are changes in the project design.
164	(Liu, Zhao, & Yan, 2016)	China	Determine the reasons for project risks in Chinese construction projects.	Construction projects in general	Survey and interviews	Identify these reasons, one of the main reasons are changes in the project design and lack of reliability between project partners.
167	(Locatelli, Mikic, Brookes, & Kovačević, 2017)	UK	Determine the reasons lead the project to be successful in mega construction projects.	Mega construction projects (Infrastructure projects, Energy projects and Hydro-technical projects).	Survey and analysing case studies	Identify these reasons and finalize by the projects need to increase the collaboration with stakeholders.
168	(Ma & Voo, 2014)	Australia and Malaysia	Determine the pros and cons of applying construction Joint Venture contracts in Australia and Malaysia.	Construction projects in general	Survey, interviews and analysing a case study	Identify the pros and cons. One for pros and cons is as the risks shared, while there is conflict in interest in Joint Venture contracts
169	(Ma, Luong, & Zuo, 2014)	Australia	Determine the relation between the project managers' skills and the successful of the project.	Construction projects in general	Survey and interviews	The impact of successful of the projects in case the project manager has high skills or no are almost same.
171	(Mante, Ndekugri, Ankrah, & Hammond, 2012)	Malaysia	Determine the ways to avoid the construction project conflicts in infrastructure projects.	Infrastructure projects	Survey and analysing a case study	The main way is to add in the contracts the details need to be applied in case of the conflicts during the project.
174	(Marzouk & El-Rasas, 2014)	Egypt	Determining the reasons for each of the project delays in Egyptian construction projects.	Construction projects in general	Survey, analysing case study and simulation modelling	Identify these reasons and the indices in priority, frequencies and intensity. The reasons relate to owner are the highest.
176	(Marzouk, El Kherbawy, & Khalifa, 2013)	Egypt	Determining the factors for the sub-contractor selection in Egyptian construction projects.	Construction projects in general	Survey and simulation modelling	Identify these reasons and their ranking. One of the highest factors are the bad management of the sub-contractor.
177	(Maués, Santana, Santos, Neves, & Duarte, 2017)	Brazil	Determining the reasons for each of the project delays in Brazilian real estate projects.	Building projects	Survey	Identify these reasons; two of the most important factors is the project size and the number of houses.
178	(Mavasa, 2017)	South Africa	Determine actions need to be taken to solve the consultant's poor skills in duration estimating. Determine which project partner responsible on the unreal project duration.	Construction projects in general	Survey, interviews, site observation and simulation modelling	Identify that this issue affect both the project quality and duration. the owner has the highest responsibility in estimating the project duration.

Table 2- 9: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
179	(McCord, McCord, Davis, Haran, & Rodgers, 2015)	Northern Island	Determining the reasons for each of the project delays in Northern Island	Building projects	Survey	Identify these reasons and their impact. One of these reasons is the poor in communication.
180	(Mehlawat & Gupta, 2016)	UK	By using a new decision making tool determine the critical path in construction projects and making a comparison with other tools.	Construction projects in general	Analysing case study	Determine the required critical path.
182	(Memon, 2014)	Malaysia	Determining the reasons for each of the project delays in Malaysia, regards the contractors opinions.	Construction projects in general	Survey	Identify these reasons and their ranking. One of these reasons is the changes in project design.
183	(Memon, Abdul Rahman, & Memon, 2014)	Malaysia	Determine how to control the material construction wastes in projects.	Construction projects in general	Survey	Identify of the requirements needed. One of them are the risks factors updated frequently.
184	(Memon, Abdul Rahman, Akram, & Ali, 2014)	UK	Determine the effect of supply chain on project achievement.	Construction projects in general	Survey and interviews	Identify these impacts and one of them is as the relationships with supply chain not good this can lead to increase in duration, cost and decrease in quality.
185	(Meng, 2012)	Malaysia	Determining the reasons for each of the project delays in Malaysia.	Construction projects in general	Survey	Identify these reasons and their ranking. One of these factors is the changes in design.
187	(Minchin Jr., Li, Issa, & Vargas, 2013)	USA	Determine which system of delivery, Design Build and Design Bid Build, has better impact on the project duration and cost.	Road and bridge construction projects	Analysing case study	Design Bid Build is better in case of project cost. While Design Build is better in case of project duration.
188	(Mir & Pinnington, 2014)	UAE	Analyse the relation between the successful of the project (from stakeholders perspectives) and the decreasing on both final duration, final cost and increasing on quality in UAE.	Construction projects in general	Survey	There is strong relationships between the successful of the project and the decreasing on both final duration, final cost and increasing on quality.
189	(Mirawati, Othman, & Risyawati, 2015)	Malaysia	Determine the relation between the project achievement factors (decreasing on both final duration, final cost and increasing on quality) and other measurements as reliability and communication.	Construction projects in general	State of the art	There is strong relations between the two measurements.
192	(Mohammed, Mohammed, & Hassan, 2017)	Sudan	Determining the reasons for each of the design changes in building projects.	Building projects	Survey, interviews and analysing case study	Identify these reasons and their ranking. One of these factors is changing in the value of the project.

Table 2- 10: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
193	(Mohan & Paila, 2013)	India	Identify the stakeholders' responsibilities in infrastructure projects by using a stakeholders' relations tool.	Infrastructure projects	State of the art	During the planning of the project, it is essential to focus on the stakeholders' relations
194	(Mok, Shen, & Yang, 2015)	Hong Kong	Understand the process on managing stakeholders in mega construction projects.	Mega construction projects	State of the art	Manage the stakeholders in early project stages is essential to ease the communication and their evolving in the project.
195	(Momanyi, 2017)	Kenya	Determine the managing the project time, which was scheduled, has impact on successful of finishing the road projects.	Road projects	Survey, site observation and analysing case study	There is a strong relation between the time management tools and successful of finishing the road projects.
197	(Muhwezi, Acai, & Otim, 2014)	Uganda	Determining the reasons for each of the project delays in building projects.	Building projects	Survey, interviews and analysing case study	Identify these reasons and their ranking. One of these factors is bad site management
198	(Mukhtar, Amirudin, Sofield, & Mohamad, 2017)	Nigeria	Determining the reasons for successfully finishing the Nigerian housing projects.	Building projects	Survey and interviews	Identify these reasons and one of them is the availability of the machines maintenance in the projects.
200	(Nadzirah, 2015)	Malaysia	Determine measures to be used to control the criteria relate to the cost and time during the project stages.	Construction projects in general	Survey	Determine these criteria used to control time and cost. In case of time, the schedule should be accurate. While for cost, the estimating of cost should be planned in detail.
220	(Perrenoud, Lines, & Sullivan, 2014)	USA	Determine the management of risks in construction projects.	Construction projects in general	Analysing case studies and site observation	The stakeholders are the main reasons of the projects risks.
225	(Prihartanto & Bakri, 2017)	Indonesia	Determine the risks factors for the construction project.	Road projects	Survey	Identify these factors and their ranking. One of the most important factors is the price's seller is more the estimating cost.
228	(Ram & Corkindale, 2014)	Australia	Determine the significant of the successfully finishing the project of the planning of the resources.	Construction projects in general	State of the art	The studies review show that there is few number of study in this issue.
229	(Ram, Corkindale, & Wu, 2013)	Australia	Determining the impact of the criteria for successfully finishing the project on the planning of the resources.	Construction projects in general	Survey, site observation and analysing case studies	Identify those criteria for successfully finishing the project is important to facilitate the achievement of the organisation in planning of the resources.

Table 2- 11: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
231	(Rodrigues, Costa, & Gestoso, 2014)	Portugal	Determine if the country's culture affect the successfully of the project.	Construction projects in general	Survey	Results show country's culture has weak impact on the successfully of the project.
233	(Rose, 2013)	United Nations	Determine the processes need to be respected to manage the projects, regards the Project Management (PM) approach.	Construction projects in general	State of the art	Explain in detail ten knowledge areas categorised under five project management process groups. These knowledge areas used to manage the projects, specially construction projects.
237	(Saadé, Dong, & Wan, 2015)	Canada	Determine the reasons for successfully of the projects, regards to managers of the projects	Construction projects in general	Survey	Identify these factors and the most important factor is the ways of project managers' communication with other project partners.
239	(Samarah & Bekr, 2016)	Jordan	Determining the reasons for each of the project delays in public construction projects.	Public projects	Survey	Identify these factors and ranking them. The most important factor is the poor managing of the project.
246	(Sebestyen, 2017)	Hungary	Determine how the successfully of the project is defined	Construction projects in general	State of the art	The project is named successfully regards time, cost and quality. Additionally, the stakeholders need to be satisfied by the final value of the project.
247	(Seman, Hanafi, & Abdullah, 2013)	Malaysia	Determine the criteria, which lead to dispute in industrialised building projects	Industrialised building projects	Survey and interviews	Identify these factors and ranking them. The most important factor is design changes lead to delays in other projects' activities.
252	(Sharma & Goyal, 2014)	India	Determining the reasons for each of the project risks in construction projects.	Construction projects in general	State of the art	Identify these factors and ranking them. One of the most important factors are bad management and changing in project's design.
254	(Siddique & Hussein, 2016)	Norway	Determine the factors of the successfully of the project in Norwegian software industry from the suppliers' area.	Software projects	interviewss	Identify these factors and one of them is removing the activities' risks.
255	(Sinesilassie, Tabish, & Jha, 2017)	Ethiopia	Determining the criteria lead to the decreasing in project achievement in Ethiopian public construction projects.	Public projects	Survey, site observation and analysing case studies	Identify these factors and ranking them. One of the most important factor is shortage in knowledge for the project managers'.
258	(Soliman, 2017)	Kuwait	Determine how to control the schedule delays in Kuwait construction projects.	Construction projects in general	Survey and interviewss	Identify the suggestions for the schedule delaying factors and ranking them. One of these suggestions is improvement of the schedule planning process.

Table 2- 12: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
260	(Son, Kim, & Cho, 2017)	South Korea	Determine how to update the schedule by using a software and identify the data about the critical schedules.	Building projects	Analyse a case study and simulation model	Make the comparison between the real and estimated schedules.
261	(Soto, Rosarius, Rieger, Chen, & Adey, 2017)	Switzerland	Use an algorithm to schedule the project with 4D simulation model to improve the project items (time and cost).	Building projects	Analyse a case study and simulation model	Reduce in both time and cost of the project.
263	(Subramanyan, Sawant, & Bhatt, 2012)	India	Determine the criteria affect the successfully of the project.	Construction projects in general	Survey	Identify these factors and one them is the rework activities.
104	(Suleiman & Luvara, 2016)	Tanzania	Determine the reasons for the design changes in building projects.	Building projects	Survey	Identify these factors and one the most important reason is bad in project management.
266	(Sweis, 2013)	Jordan	Determining the reasons for each of the project delays in public construction projects.	Public projects	Survey	Identify these factors and one the most important reason is design changes.
267	(Szymanski, 2017)	Poland	Make a review on how the risks are managed in construction projects.	Construction projects in general	State of the art	It is shown that the risks need to be determined before find ways to avoid them.
269	(Tamošaitienė, Zavadskas, & Turskis, 2013)	Lithuania	Determine the estimation of risks in building projects.	Building projects	Analysing case studies	Identify these factors and one of these risks is risks relate to design.
270	(Tanko, Abdullah, & Ramly, 2017)	Nigeria	Determining the project risks in Nigerian construction projects.	Construction projects in general	Survey	Identify these risks and their ranking. One of the most important is the owner does not receive the project value.
271	(Taroun, 2014)	UK	Give a knowledge relates to the risks management and its estimation process.	Construction projects in general	State of the art	The concept of Probability/Impact need more improvement to be used effectively in the more complex projects.
273	(Taylan, Bafail, Abdulaal, & Kabli, 2014)	Saudi Arabia	Determining the reasons for each of the project risks in building construction projects.	Building projects	Survey	Identify these reasons and their ranking. One of the most important reason is the delay due to the extreme number of authorisation processes

Table 2- 13: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
276	(Thorat, Khandare, & Kanase, 2017)	India	Determine the reasons for each of the project delays in residential building projects.	Building projects	Survey	Identify these reasons and their ranking. One of the most important reason is unskilled workers.
279	(Tsiga, Emes, & Smith, 2017)	UK	Determine the factors affect the successfully of the project.	Petroleum projects	Survey and analysing case study	Identify these reasons and their ranking. One of the most important reasons is the experience of the project manager
283	(Vilventhan & Kalidindi, 2016)	India	Determining the reasons for each of the project delays in Indian	Road and bridge projects	interviews, site observation and analysing case study	Identify these reasons. One of the most important reasons is delays due to dispute between stakeholders.
285	(Wang , Lin, Wang, Liu, & Lee, 2014)	Taiwan	Make evaluation of the delays relate to the design.	High-tech construction projects	Survey, interviews and analysing case study	Identify that the criteria, which is the risks relate to cost, is main reasons changing in the design.
287	(Xiang, Zhou, Zhou, & Ye, 2012)	China	Determine the process to be used to reduce the construction projects' risks	Construction projects in general	State of the art	Lack of the construction project information leads to increase the projects' risks
288	(Xiong, et al., 2014)	Malaysia	Determine how some factors (such as reliability, scope clearness and management of risks) affects the gratification of the contractor.	Construction projects in general	Survey	It is shown that it is essential to divide the gratification of the contractor into two scales. First relates to economic gratification and second relates to the production gratification. Some factors have strongly impact on gratification of the contractor, while others not.
290	(Yap, Abdul-Rahman, & Chen, 2017)	Malaysia	Determine the effects of changing in project designs on the project delays in Malaysian projects.	Construction projects in general	Survey and interviewss	Identify these reasons. One of the most important reasons is decrease in productivity leads to increase in project duration
291	(Yap, Abdul-Rahman, & Wang, 2016)	Malaysia	Determine the reasons of changing in project designs on the project delays in building projects.	Building projects	State of the art	Identify these reasons. One of them is the project scope was not clear.
292	(Yap, Low, & Wang, 2017)	Malaysia	Determine the relation between rework activities and the project duration. Identify the reasons of the rework activities. Find how to reduce these types of activities.	Building projects	Survey	It is find that high increasing in duration projects due to rework activities. Identify the reasons of these activities and one of them is bad management in construction site. Finally, it is determined the ways to reduce the rework activities such as improve the communication skills with the stakeholders.
295	(Zakari Danlami, Emes, & Smith, 2016)	UK, Netherlands, USA, Germany, China and Nigeria	Determine the factors affect the successfully of the project.	Manufacture industry	Survey	Identify these reasons and their ranking. One of the most important reasons is to apply the management of the projects' risks.

Table 2- 14: Information of Project Management (PM) approach studies

#	Study	Country	Aim	Project sector	Methodology	Results
299	(Zhao, Hwang, & Phng, 2014)	Singapore	Understand the situation of the management of the projects' risks in Singapore	Construction projects in general	Survey	Identify some of the risks' reasons and their ranking. One of the most important is the risks are different between one project to another.
300	(Zhou, Zhou, & Liu, 2017)	China	Make a comparison based on the factors affect the successfully of the project. This comparison is between two buildings are modified, historical and non-historical building projects.	Building projects	interviews and analysing case study	In case the two projects, it is shown that government has the most important part of influences on the successfully of the project. However, it is more regards to the historical building projects.
301	(Zou & Sunindijo, 2013)	Australia	Determine which skills need to be aware by the management of the project teams to make safety risks management.	Construction projects in general	Survey	It is recommended to be aware of four categories of skills. These categories are skills relate to conceptual, human, technical and political.

2.4.1 Studies analysis

Tables 2-15 to 2-17 and Figures 2-7 to 2-9 show the analysis of the studies reviewed; those that apply the Project Management (PM) approach on different project sectors. Table 2-15 and Figure 2-7 show the analysis of these studies based on the country where each study was applied. The majority of the studies analysed were applied in different countries (dispersed rather than concentrated in one specific country) leaving the biggest percentage (16%) under the category "Other". The highest concentration in one country was found to be in Malaysia; where 11% of the studies applying the Project Management (PM) approach could be spotted.

Table 2-16 and Figure 2-8 show the analysis of the studies reviewed based on the different project sectors. The majority of studies (51.6%) address the application of the traditional approach in general without mentioning a specific project sector. More than fifth (22.7%) of the studies analysed focus on the building projects sector. The application of PM in both road and infrastructure projects was found in 11% of the studies reviewed.

Table 2-17 and Figure 2-9 show the analysis of the studies reviewed based on the methodology of each study. The biggest majority (44.7%) of the studies reviewed use survey questionnaire. This is followed by using projects' data analysis (18.1%). It is important to mention that the summations in some tables exceed the number of the studies because some studies used more than one methodology or were applied in more than one country. For example, one study [295] was applied in the UK, Netherlands, USA, Germany, China and Nigeria.

Table 2- 15: Country analysis used Project Management (PM) approach

Country	Country quantity	Country analysis	Note
Nigeria	8	4.9%	Some countries are hidden
Malaysia	18	11.0%	
Ghana	2	1.2%	
Egypt	5	3.1%	
Oman	3	1.8%	
Saudi Arabia	4	2.5%	
Jordan	4	2.5%	
Turkey	2	1.2%	
India	9	5.5%	
USA	4	2.5%	
Finland	2	1.2%	
Australia	8	4.9%	
Pakistan	4	2.5%	
UK	8	4.9%	
South Africa	4	2.5%	
Hong Kong	2	1.2%	
Spain	2	1.2%	
Germany	2	1.2%	
Hungary	2	1.2%	
Poland	3	1.8%	
Switzerland	2	1.2%	
Portugal	2	1.2%	
China	9	5.5%	
Libya	3	1.8%	
Qatar	2	1.2%	
Netherlands	2	1.2%	
Lithuania	3	1.8%	
South Korea	2	1.2%	
Tanzania	2	1.2%	
UAE	2	1.2%	
Kuwait	2	1.2%	
Indonesia	2	1.2%	
Bangladesh	2	1.2%	
Uganda	2	1.2%	
Taiwan	2	1.2%	
Canada	2	1.2%	
Other	26	16.0%	For values equal or less than 1%
Total	**163**	**100.0%**	

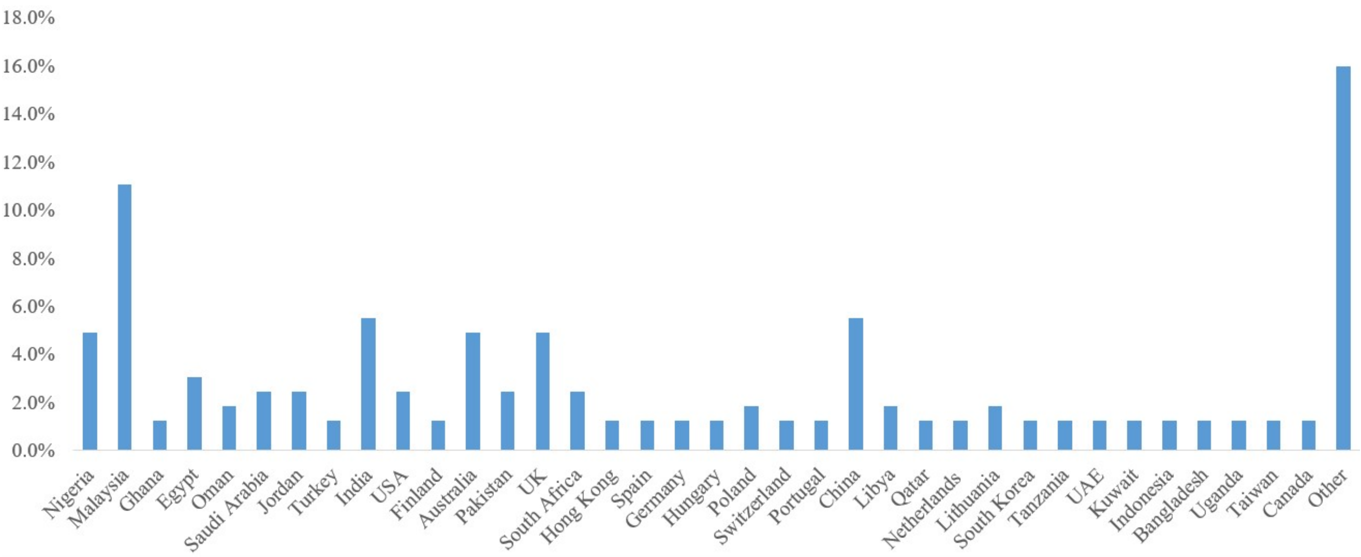


Figure 2- 7: Country analysis used Project Management (PM) approach

Table 2- 16: Project sector analysis used Project Management (PM) approach

Project sector	Project sector quantity	Project sector analysis	Note
Building projects	29	22.7%	**Some project sectors are hidden**
Construction projects in general	66	51.6%	
Road projects	7	5.5%	
Infrastructure projects in general	7	5.5%	
Public projects	3	2.3%	
Other	16	12.5%	**For values equal or less than 2%**
Total	**128**	**100.0%**	

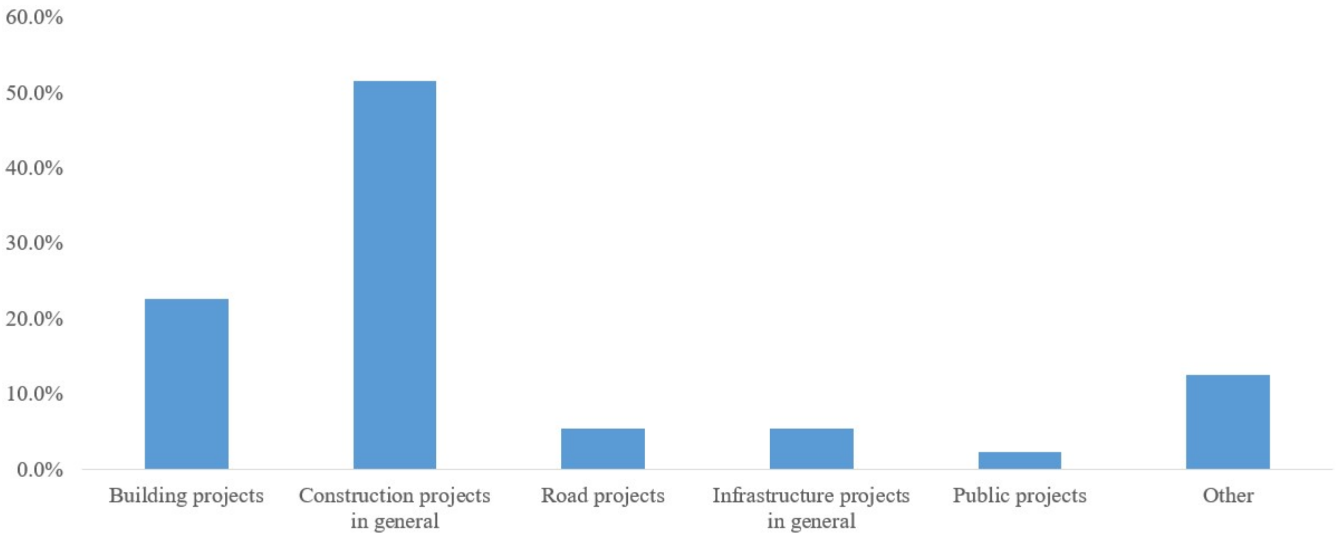


Figure 2- 8: Project sector analysis used Project Management (PM) approach

Table 2- 17: Methodology analysis used Project Management (PM) approach

Methodology	Methodology quantity	Methodology analysis
Site observation	12	6.4%
Analysing case study	34	18.1%
Survey	84	44.7%
Interviews	29	15.4%
State of the art	19	10.1%
Game simulation	1	0.5%
Simulation modelling	9	4.8%
Total	**188**	**100.0%**

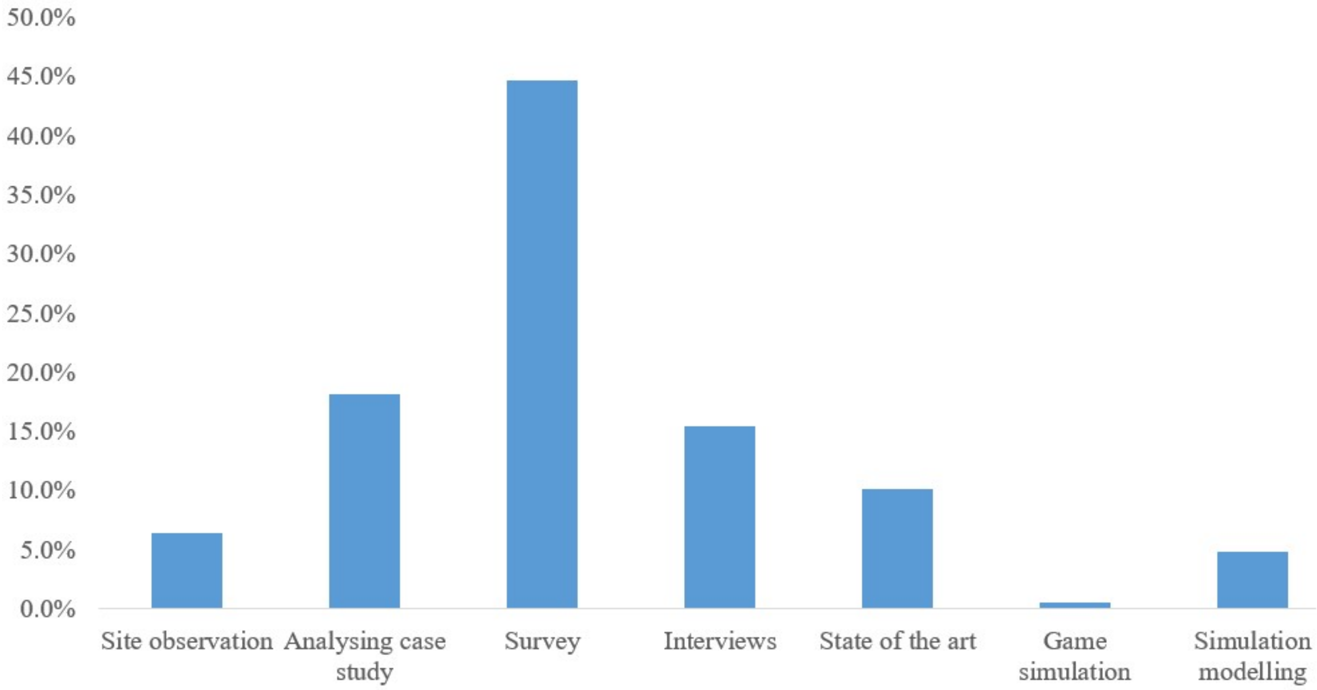


Figure 2- 9: Methodology analysis used Project Management (PM) approach

2.5 Application of Project Management (PM) approach on road and infrastructure projects

Tables 2-18 and 2-19 is summarized the studies relate to Project Management (PM) approach on road and infrastructure projects. This summary is based on the country of each study where it is applied. The main reasons of the study are determined. The studied project sector, which project type in the infrastructure sectors, and the methodology used are listed. Finally, the results of the study are presented.

Table 2- 18: Information of Project Management (PM) approach on road and infrastructure projects

#	Study	Country	Aim	Project sector	Methodology	Results
10	(Agyeman, Asare, & Ankomah, 2016)	Ghana	Determine the affection of design data on the trustworthy progress of the project and the estimation of the cost.	Road projects	Site observation, interviews and analysing case studies	The delays in the projects are mainly due to the design changes. The projects' costs are increased because the design changes and the bad project management.
17	(Alashwal, Abdul-Rahman, & Radzi, 2016)	Malaysia	Determine how the utilization knowledge affect the projects.	Road projects	interviews, site observation and analysing case study	The identified factors can affect the performance of the projects, the projects' decision-making and delays in projects.
38	(Aziz & Abdel-Hakam, 2016)	Egypt	Determine the ranking of the delays reasons and how to prevent their occurrence.	Road projects	Survey, interviews, site observation and analysing case study	Identified that the highest risk is considered to be the financial client's issues. The determination of the root cause of delays considered to be the better process to reduce the risks.
84	(Emam, Farrell, & Abdelaal, 2015)	Qatar	Determining the reasons for the infrastructure project delays in Qatar.	Infrastructure projects	Survey	Identification these reasons and make their ranking. The design changes is determined to be one of the most important reasons of delays.
91	(Ghoddousi, Ansari, & Makui, 2016)	China	Determine the effect of using buffer methods on affection the schedule, regards to the risks factors. These apply by making a comparative analysis between traditional and new buffer methods	Infrastructure projects	Analysing a case study and simulation modelling	Identify that the new buffer method has more stability duration than the traditional method.
94	(Glenn, 2015)	Netherlands	Determining the conditions, which can be taken before the contract, used to improve the infrastructure projects.	Infrastructure projects	Survey and interviews	The integrated contracts are the highest recommended contracts.
114	(Hsu, Aurisicchio, & Angeloudis, 2017)	UK	Determining the reasons for the project delays in infrastructure projects.	Infrastructure projects	Survey and analysing a case study	Identification these reasons and make their ranking. The shortage in construction technology knowledge and design changes are the most important reasons of delays.
167	(Locatelli, Mikic, Brookes, & Kovačević, 2017)	UK	Determine the reasons lead the project to be successful in mega construction projects.	Mega construction projects (Transportation projects, Energy projects and Hydro-technical projects).	Survey and analysing case studies	Identify these reasons and finalize by the projects need to increase the collaboration with stakeholders.

Table 2- 19: Information of Project Management (PM) approach on road and infrastructure projects

#	Study	Country	Aim	Project sector	Methodology	Results
171	(Mante, Ndekugri, Ankrah, & Hammond, 2012)	Malaysia	Determine the ways to avoid the construction project conflicts in infrastructure projects.	Infrastructure projects	Survey and analysing case study	The main way is to add in the contracts the details need to be applied in case of the conflicts during the project.
187	(Minchin Jr., Li, Issa, & Vargas, 2013)	USA	Determine which system of delivery, Design Build and Design Bid Build, has better impact on the project duration and cost.	Road and bridge construction projects	Analysing case study	Design Bid Build is better in case of project cost. While Design Build is better in case of project duration.
193	(Mohan & Paila, 2013)	India	Identify the stakeholders' responsibilities in infrastructure projects by using a stakeholders' relations tool.	Infrastructure projects	State of the art	During the planning of the project, it is essential to focus on the stakeholders' relations
195	(Momanyi, 2017)	Kenya	Determine the managing the project time, which was scheduled, has impact on successful of finishing the road projects.	Road projects	Survey, site observation and analysing case study	There is a strong relation between the time management tools and successful of finishing the road projects.
225	(Prihartanto & Bakri, 2017)	Indonesia	Determine the risks factors for the construction project.	Road projects	Survey	Identify these factors and their ranking. One of the most important factors is the price's seller is more the estimating cost.
283	(Vilventhan & Kalidindi, 2016)	India	Determining the reasons for each of the project delays in Indian	Road and bridge projects	Interviews, site observation and analysing case study	Identify these reasons. One of the most important reasons is delays due to dispute between stakeholders.

2.5.1 Studies analysis

Tables 2-20 to 2-22 and Figures 2-10 to 2-12 show the analysis of the literature studies applied by Project Management (PM) approach on road and infrastructure projects. Table 2-20 and Figure 2-10 are shown the analysis of these studies based on the country applied these studies. The majority of this list relate to Malaysia, UK and India they are by 14.3%. Table 2-21 and Figure 2-11 are shown the analysis of the different project sectors. The majority is the application of the traditional approach in road projects by 50%. The application of road projects is followed by the application of the traditional approach in the infrastructure sector in general by 42.9%. Table 2-22 and Figure 2-12 are shown the application of the methodology in the studies. The majority of them is the application of questionnaire survey by 33.3%. This is followed by the application of both site observation and conducting interviews by 20.8% per each.

Table 2- 20: Country analysis used Project Management approach on road and infrastructure projects

Country	Country quantity	Country analysis
Ghana	1	7.1%
Malaysia	2	14.3%
Egypt	1	7.1%
Qatar	1	7.1%
China	1	7.1%
Netherlands	1	7.1%
UK	2	14.3%
USA	1	7.1%
India	2	14.3%
Kenya	1	7.1%
Indonesia	1	7.1%
Total	**14**	**100.0%**

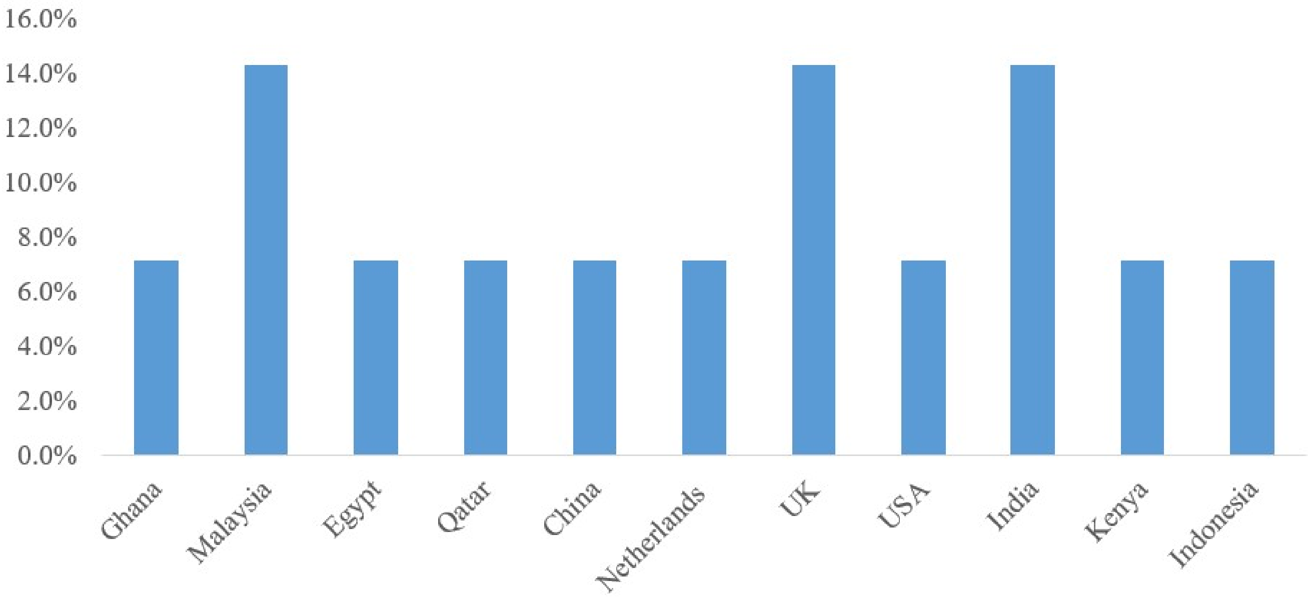


Figure 2- 10: Country analysis used Project Management approach on road and infrastructure projects

Table 2- 21: Project sector used Project Management approach on road and infrastructure projects

Project sector	Project sector quantity	Project sector analysis
Road projects	7	50.0%
Infrastructure projects	6	42.9%
Transportation projects	1	7.1%
Total	**14**	**100.0%**

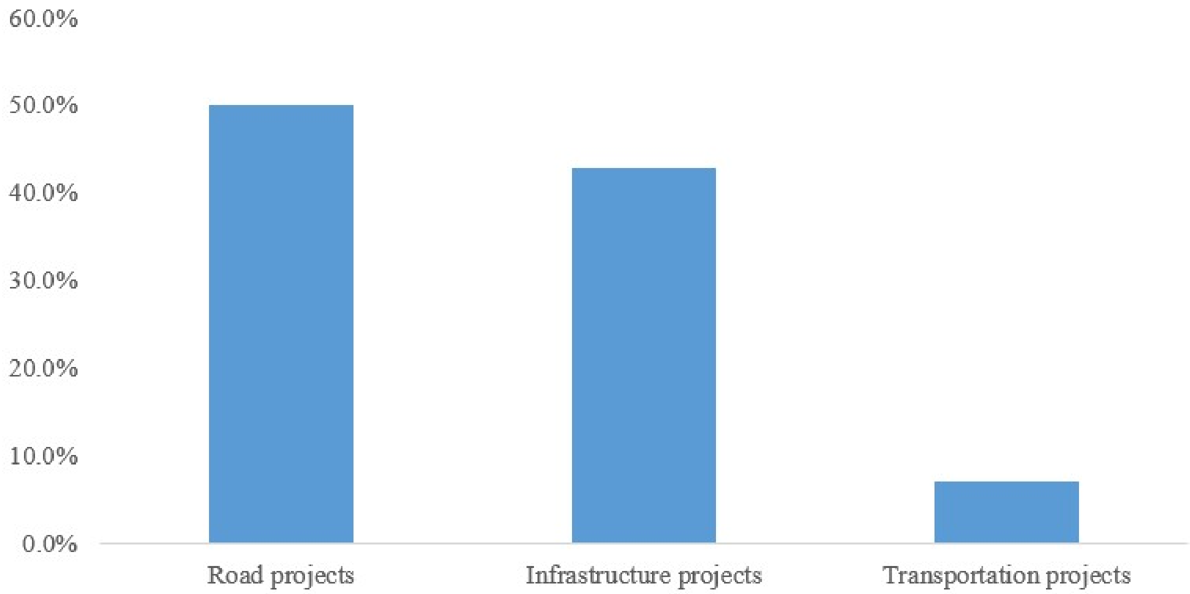


Figure 2- 11: Project sector used Project Management approach on road and infrastructure projects

Table 2- 22: Methodology used Project Management approach on road and infrastructure projects

Methodology	Methodology quantity	Methodology analysis
Site observation	5	20.8%
Interviews	5	20.8%
Analysing case study	4	16.7%
Survey	8	33.3%
Simulation modelling	1	4.2%
State of the art	1	4.2%
Total	**24**	**100.0%**

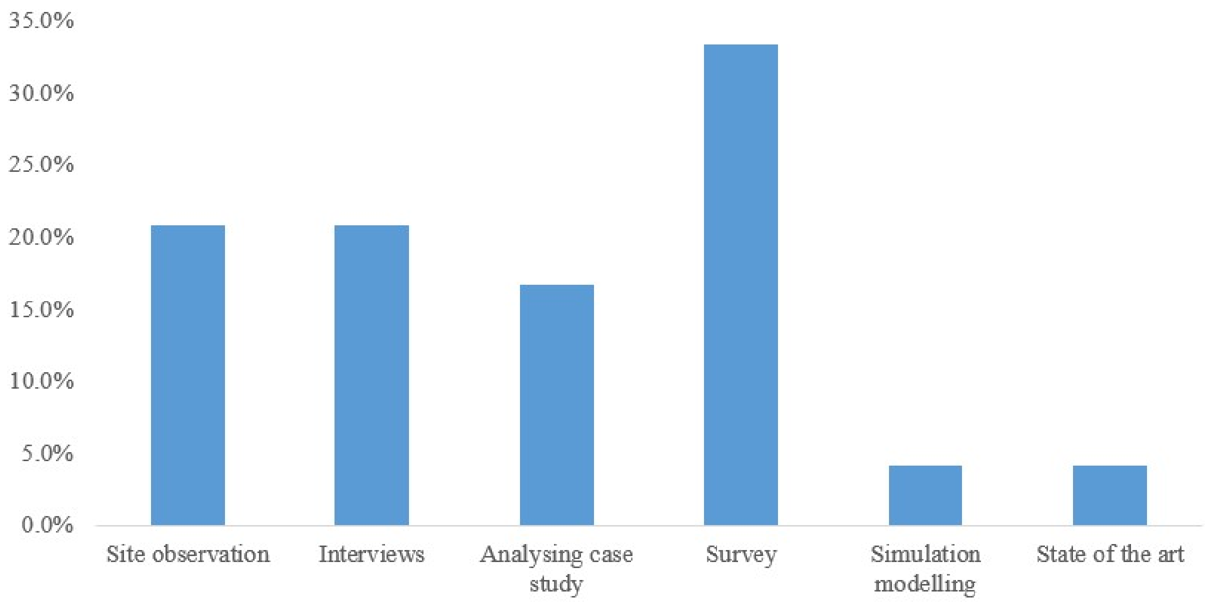


Figure 2- 12: Methodology used Project Management approach on road and infrastructure projects

2.6 Conclusion

Project Management (PM) approach focuses on analysing the risks that can take place in the construction projects. An example of these risks is the delay in the project duration. These risks are not the root of the problem, while the main issue is the huge number of different time wastes, eventually leading to the risks. The word waste is used in this study mainly to refer to delays in activities as a result of the time wasted upon the occurrence of problems which can be avoided with efficient management. Hence, eliminating these wastes will consequently eliminate the risks. The Project Management approach does provide the tools to analyse potential risks like project delay, however does not address the root causes of such risks; the time wastes. Although, scholars [233], [271] emphasize that a project will be successful by managing the projects' risks, still the quantitative risk analysis is rarely developed in many construction projects. The reason behind this is that in order to conduct such analysis, experience and data from previous projects is necessary, which is unfortunately not available in many instances. Project Management (PM) approach focuses only on the highest risk probability and impact, while the lower risks are neglected and ignored. These risks are ranked based on the project stakeholders' knowledge, which can be inaccurate in some instances. Additionally, the risks ranked lower in importance and potential occurrence can have higher impacts on the projects when they occur. In that sense, three main arguments all related to risk have been noted in this chapter; how the PM approaches risk analysis, time management and stakeholders’ collaboration.

The first and most importance argument for the purpose of this study, is related to the PM not addressing the root causes of risks in real life projects. Scholars [263], [151], [23], [164], [287] agree that, thanks to the fact that it is nearly impossible to find two similar construction projects, the construction industry has a higher number of risks than other industries. In accordance, the PMBOK GUIDE explains that every project – in any industry - has different nature and characteristics; for example, a music concert is defined as a project, and then if the music concert failed for some reason, it is superficially blamed on the high number of risks. However, it is important to question: is this really the case? That is, do projects fail because of the risks posed? What about delving deeper into the roots of the problem, or in other words, what causes such risks? Unfortunately, the PM does not address the roots of the problem; the wastes that potentially causes the risks. In our case, this refers to the time wastes potentially causing delays in the projects. However, it is important to mention that some studies applying the PM approach investigate the root cause of delays [4], [11], [17], [18], [19], [22], [30], [38], [44]. Still, the industry suffers the application of this concept in real life projects. Throughout the chapter, it has been highlighted that risk analysis, historically, has not been properly implemented in the construction industry. This calls for innovative tools to go beyond the traditional risk analysis that anticipates its occurrence and impact without addressing its causes. Lean Construction comes as a provider of pioneering solutions in that sense; through developing tools that directly address the root causes of risks.

The second argument is concerned with the time management tool the Project Management (PM) approach; Critical Path Method (CPM). This tool helps in managing risks through using time buffers for the different activities on the project as explained before. It is essential to highlight that in the planning phase risks are a possibility that might or might not occur. This means that introducing buffers to the different activities result in time wastes in case that the anticipated risks did not occur.

The third argument is concerned with lack of stakeholders collaboration under the PM approach. As a result of this lack of collaboration, risk transfer is resorted to; transferring the responsibility of risk occurrence from one stakeholder to another. One of PM's most popular tools in this area is Design Bid Build through which the owner makes two different contracts for the contractor and designer. In a modified version of this tool – known as Design Build – the owner can make one contract for both the designer and contractor attempting to transfer risks responsibility to the contracted entity. This means that by making one contract for the contractor to design and construct the project, any failure in the project will be solely blamed on the contractor. But does this solve the problem? Does it achieve the aspired results at the end of the project? Transferring risks does not reflect neither successful project management nor does it result in successful projects. It is far more efficient to focus on the end result of having a successful project than to direct the energy towards risks transfer. Collaboration between project's stakeholders has essential goals in that sense, which do not include transfer of risks.

Considering the presented details about the PM approach, the next chapter focuses on Lean Construction while presenting tools that address the aforementioned problems in a more efficient manner.

CHAPTER 3 LEAN CONSTRUCTION (LC)

3.1 Introduction

This chapter starts by explaining the history of the Lean concept and the reasons behind the invention of this relatively recent approach. The main principles of this approach are then demonstrated. After defining and generally overviewing LC, a comparison between the new (LC) and traditional approaches (PM) is presented. The chapter then delves into how LC defines and approaches the projects activities followed by presenting the different Lean Construction tools. Detailed explanation of the two most relevant tools to the main purpose of this study is demonstrated after; Last Planner System and Integrated Project Delivery System. The benefits and barriers of Lean Construction are explained in the following section followed by a summary of the Lean Construction application on different project sectors and its analysis. Lastly, an overview and analysis of the Lean Construction studies specifically focused on road and infrastructure projects are presented.

3.2 Lean concept history

Toyota Production System (TPS) invented Lean concept in Japan during 1950s after the Second World War to apply to the production industry at that time [230], [221], [211]. TPS was facing some challenges such as, the need to make variety of cars models while they had a limited production space so, they needed to decrease the production time and the time between cars with the least amount of production items. TPS invented Lean concept with two main golden rules: minimization in total cost and regarding workers as humans not machines. The creation of Lean concept became a perfect technique to be used in Japan because of scarcity of human resources and the strong competition in the cars market, [216], [139], [236], [245], [25], [210], [35], [206], [15], [16], [298], [221], [51], [268], [20], [40], [230], [39], [117], [262], [86], [211], [172], [152].

Construction projects are considered a temporary stage in the production systems. However, construction industry suffers from high waste percentage when compared to manufacture industry as shown in Figure 3-1. It can be seen there that the waste – Non-Value Added activities - in construction industry are more than half the project's activities (53%). While in manufacture industry the added value activities are almost 90% of the total activities. It is essential to note that the definition of waste as addressed in this study is explained in details in the next section (Lean Construction activities) and that one of the main aims of Lean

Construction is to eliminate such waste. Lean concept can be categorized under the following fields; these are Lean Production (LP), Lean services and Lean Construction (LC), which includes building and transportation industries as shown in Figure 3-2. The Lean concept is defined as the elimination and/or reduction of time waste, delivering the material on the needed time giving the customer the best product value. [103], [278], [139], [142], [129], [277], [236], [111], [121], [173] and [147].

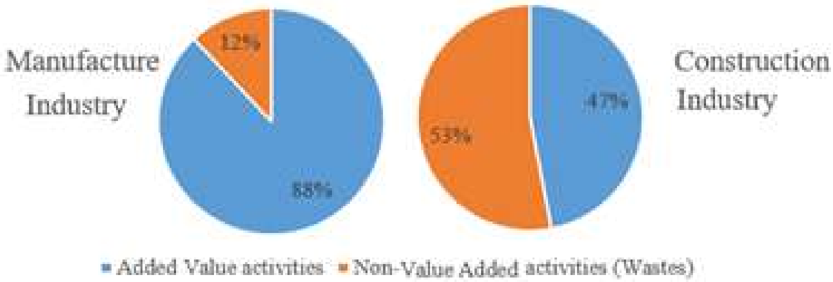


Figure 3- 1: Comparison between Manufacture and Construction industries regards production and waste percentage [40]

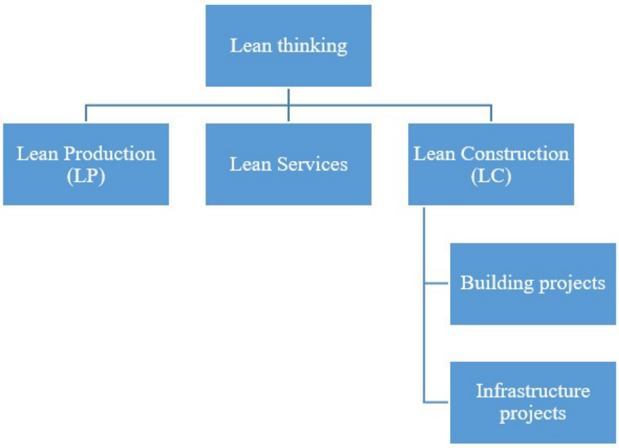


Figure 3- 2: Lean concept structure [147]

3.3 Lean Construction activities

Time waste in construction industry is every Non-Value Adding (NVA) activity. Construction projects suffer from many kind of wastes; some of these waste are unnecessary transportation, inefficiency in using human resources and the inventories of the materials. According to [1], Non-Value Adding (NVA) activities (which are wastes) could occupy 66% of the labours performance. Eliminating these wastes impacts the project's cost and duration positively. According to scholars [272], [45], [245], [1], [65], [262], [104] and [223] considering the construction activities as "Flow processes" rather than "Conversion process", could improve the wastes elimination process.

According to [40], [64], [100], [272] waste can be determined under four following categories:

(1) Defects and Controls.
(2) Utilization of resources; these two categories (1) Defects and Controls and (2) Utilization of resources; represent 10% of the total production cost [100].
(3) Health and safety; this category represents 12% of total production cost.
(4) System and Structures; this category represents 5% of total production cost. While it was determined that in general, wastes represent between 30% and 55% of the total construction project's costs [100].

In another categorization [105], wastes were identified to be under three categories:

(1) *Muda*; which means Non-Value Adding activities.
(2) *Muri*; which means overwhelm. This category of wastes refers to overloading the workers or machines, which can lead to machine's breakdown or bad quality in an activity.
(3) *Mura*; which means variability and refers to the occurrence of variations in the activities.

Toyota Production System (TPS) listed seven general wastes and added the eighth waste later, as shown in Table 3-1. These wastes are: (1) Overproduction. (2) Waiting. (3) Transportation. (4) Rework. (5) Inventory. (6) Unnecessary motion. (7) Processing and (8) Unused talented workers. The explanation of these wastes is summarized in the table below after reviewing how different scholars demonstrate the idea, [39], [72], [272], [248], [57], [15], [250], [59], [139], [66], [25], [16], [245], [211], [121], [20], [51], [70], [40], [221], [201], [170], [190], [242], [56], [152], [240], [249], [265], [119].

Construction projects activities were identified to be three main types, [33], [147], [87] and [112]:

(1) Essential Non-Value Adding activities (ENVA); these activities do not add value to the project and cannot be eliminated. An example is machines maintenance; despite the fact that this activity does not add direct value to the project, it is still essential to maintain the work flow and avoid potential delays. Accordingly, this type of activities need to be done efficiently not to affect productivity. Back to the example of the machines maintenance, this means carry out maintenance when the machine is not needed on site.

(2) Non-Value Adding activities (NVA); these activities also do not add value to the project, but they should be eliminated as they are considered to be wastes. For example, this applies in a situation such as having skilled labour waiting for the shop-drawing being modified after introducing design changes. This results in time and cost waste and can be eliminated by thorough planning and efficient management.

(3) Value Adding activities (VA); these activities are the only activities that add value to the project. This mainly refers to all the activities on the project necessary to reach the aspired final product. In road projects for instance this applies to sub-base layer excavation, filling with aggregate, putting asphalt layer, etc.

Table 3- 1: Lean concept wastes [245]

Lean concept wastes	Definition
Overproduction	Make unecessary items or extra quantity.
Waiting	Labours stop working on an activity for different reasons.
Unecessary Transportation	Make excess transportantion can be reduced.
Overprocessing	Make extra added value while the owner does not pay for it.
Inventory	Increase the inventory by extra materials that will be used later in the project.
Unecessary Movement	Labours make unecessary movements do not add value to the project.
Reworks	Make a repair and re-build of an activity due to defects.
Unused talented workers	Do not use the qualified labour for an activity.

3.4 Lean Construction principles

According to scholars [275], [131], [245], [238], [104] the main rules of the Lean concept are: (1) Continuous improvement and (2) Respect for the workers. Lean concept applies the continuous improvement by involving all the project members during the early stage of the project. This continuous improvement is based on five principles (explained below) and the challenge is to apply these principles correctly to achieve benefits in the construction project activities'. It is regarded as a challenge because every construction project is unique and different from other project.

The five principles are identified with the suggested actions for each principle as shown in Figure 3-3. These principles have been repeatedly demonstrated and explained by scholars investigating Lean Construction as follows [238], [190], [25], [248], [6], [20], [206], [142], [210], [181], [139], [49], [221], [173], [211], [172], [236], [294], [51], [230], [46], [112], [165], [191], [152], [70], [105], [166], [147], [5], [34], [72], [175], [223], [213], [240], [249], [265]:

(1) Value; refers to determining the need of the project. This principle should be identified correctly in the early stage of the project. It considers an important principle because it is the starting point.
(2) Value Stream; refers to determining the current process of the project. This principle is the benchmark to identify the wastes and determine the ways to eliminate them.
(3) Flow; is the principle through which the wastes are eliminated. The aim of this principle is to make sure that the information flows efficiently (in the design stage). During the application of this principle, it is essential for those in charge to be involved to ease the elimination of the wastes.
(4) Pull; this principle aims to deliver the material to the construction project on time [34], [51], [70], [112], [105]. The importance of this principle lies in its tool (Just In Time JIT which explained later), which minimizes the inventories.
(5) Perfection/Continuous improvement; is the continuous improvement of the previous four principles during the construction stage of the project.

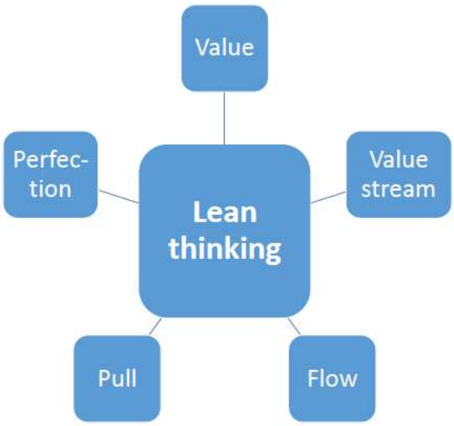


Figure 3- 3: Lean concept principles [230]

According to scholars [39], [268], [274], [282], [6], [211], [230], [181], [298], [117], [221], [13], [121], [166], [5] Lean concept is based on the following twelve laws:

(1) Reducing the rework activities.
(2) Eliminating of Non-Value Adding (NVA) activities.
(3) Reducing the waiting times.
(4) Reducing the wastes resulting from materials and energy.
(5) Clearly identifying the customer's value and the process through which this value will be delivered.
(6) Working on the Value Adding (VA) activities smoothly without interruptions.
(7) Applying the Pull concept.
(8) Applying the continuous improvement concept.
(9) Reducing variability; unplanned changes that occur during the execution of the project such as design changes.
(10) Increasing flexibility; smoothly moving from one activity to the following one in a steady flow without delays.
(11) Working in teams.
(12) Improvement in transparency.

The variability is a main problem in the construction projects; mainly because variability decreases the productivity and the motivation of the labours consequently. The variability in construction industry differs from that in the manufacture industry. Lean Construction focuses on preventing the occurrence of variability during the project by identifying the wastes and finding ways to eliminate them, which improves the workflow reliability. And hence, this fosters stakeholders' collaborations by boosting their trust in the attainability of the project's results. Two factors that affect each other are the workflow and labour efficiency in accomplishing activities. Sticking to a well-defined work plan is the key to more efficient labour work, that is, reducing the variability in the activities labour is required to accomplish leads to better results. This in turn reflects on the workflow in the same manner. Decreasing the variability in these two factors reflects a more reliable plan targeting to finish the construction project on time. [281], [262], [253].

Lean concept can be considered as a group of tools used to reduce and eliminate waste and to increase the production efficiency. By applying Lean tools, the productivity increases, while decreasing defects and inventories. Its principles help to reduce the defects by choosing the best general contractor with the most adequate resources and good experience in managing projects. The foundation of Lean concept is that every task should add value to the project. The logic behind Lean concept is to give the client the best product they need; in this case the final results of the project as expected.

Lean concept is not just a group of tools and techniques, it is a different "way of thinking", [104]. All project members should understand this new approach to reach improvement in the construction project. The fifth principle of Lean concept (which is perfection/continuous improvement) depends on the concept Plan, Do, Check and Act (PDCA), is based on the following steps [72], [296], [104], [298] and [140]:

(1) Plan; identification of the current situation or problem and the planning is done to solve this situation.
(2) Do; the planed situation took place.
(3) Check; determine if this planned situation achieved the expected results.
(4) Act; determine the results and make recommendations for the next PDCA.

Table 3-2 shows some benefits that can be reached after the correct application of the three perspectives. The Project Management (PM) approach mainly focuses on one perspective, the Transformation, while Lean concept uses the three perspectives. The most important benefit of Transformation is the right breakdown of the activities. While the most important benefit for Flow is the decrease of the variability. The last perspective gives the customer what he needs by reaching his requirements, [223].

Table 3- 2: Transformation, Flow and Value (TFV) benefits [223]

Transformation	**Flow**	**Value**
Decrease in the Value Adding activities' costs.	Reduce the actvity's variability and duration.	Apply the owner's factors
Apply breakdown of the activities correctly.	Increase the flexibility and transparency.	Ensure the owner's comprehensive factors.
		Calculate the value.

Lean Construction (LC) uses planning to determine the factors and processes necessary to finalize the project, in addition to applying consistent continuous evaluation throughout the implementation process to finalize the project tasks according to the expected estimations [145]. Lean concept merges the three following perspectives; Transformation, Flow and Value, (TFV). Table 3-3 shows the concepts, main principles and the contributions of each perspective. According to scholars [131], [59], [242], [156], [103], [66], [162], [105], [40], [147], [222], [215] and [257] the perspectives can be explained as follows;

(1) Transformation: refers to converting the project concept to real building through different activities, which meets the customer's needs. Its main goal is to do the work with more efficiency.

(2) Flow: refers to collecting all the needed items to finish an activity while eliminating the Non-Value Adding (NVA) activities. For example, to make the design process, gathering all data and information is needed to finish this step. Figure 3-4 shows the seven flows needed to finalize a construction activity. To finish an activity, this requires using the approved design based on the customer needs with the qualified and professional workers, who use the required equipment and materials in the construction project site. This is also required the qualified workers and the working area for this activity. The other activities, predecessors and successors, are important to determine their relations with this activity. Lastly, the external factors are also needed to be observed because they can affect, positively or negatively, the required activity.

(3) Value: determining and identifying the Value Adding activities that will take place to finalize the activity with the best possible value.

Table 3- 3: Transformation, Flow and Value (TFV) concept, principle and contribution [40]

	Transformation	Flow	Value
Main concept	The conversion of inputs to outputs.	Determine what is needed and what is not needed to finish the required activity.	The owner's value is done based on his required project criteria.
The principle	Improve the production process.	Remove the Non-Value Added activities.	The value is finished with the best viable way.
Contribution	Be aware of what have to be done.	Determine the unwanted activities to be decreased.	Determine how to improve the owner's value to the possible the peak percentage.

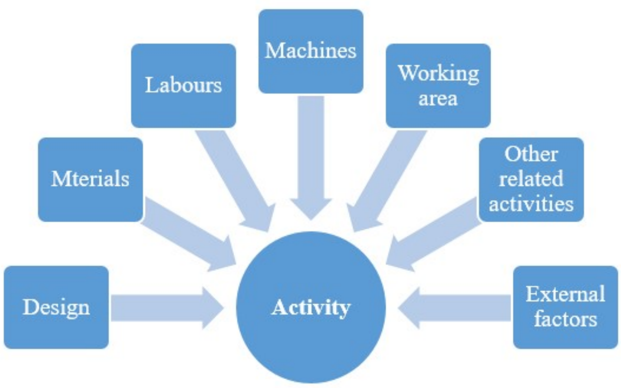


Figure 3- 4: The seven flows needed for a construction activity [131]

Glenn Ballard in the year 2000 was the first to introduce the concept of Lean Project Delivery System (LPDS) for the project management [244]. Lean Project Delivery System (LPDS) is the combination of Lean principles and Lean tools. This system is used to increase the labour productivity, elimination of waste and improvement of the work efficiency.

Lean Project Delivery System (LPDS) is based on two questions: first what needs to be done and second who will be responsible for every task in the project. The second question – related to assigning responsibilities for every task - is not applied in the traditional project management approach. According to scholars [244], [230], [59], [156], [39], [15], [16], [117], [136], [152], [223], [265] the main characteristics of Lean Project Delivery System (LPDS) are:

(1) The managing and structuring for the project based on a value generating process.
(2) The stakeholders are participated in the early project stage.
(3) Pull technique is used with stakeholders.

The five phases can be explained as follows [244], [230], [59], [156], [39], [15], [16], [117], [136], [152], [223], [265]:

(1) Project definition, to determine the need and the characteristics of the project.
(2) Lean design; include the detailed information about the design of the project based on its concept.
(3) Lean supply; the information about fabrication components of materials will be delivered based on the previous designs.
(4) Lean assembly; in this phase the detailed information about construction activities will be determined.
(5) Lean use; includes the information about maintenance, operation and decommissioning. During every phase, the work structuring and production control is applied. Work structuring allows engineers to breakdown the activities into smaller sub-activities, while production control allows them to control the plans in case any uncertainties occur.

Some scholars [223], [48], [244], [54], [12], [15] present Lean Project Delivery System (LPDS) on 13 modules and 5 phases (which are Project definition, Lean design, Lean supply, Lean assembly and Lean use) as shown in Figure 3-5. These modules start by stating the purpose or the concept of the project. This follows by the design's steps, which are the criteria of the design and its idea until conducting the final project design. These modules fall under two phases: project definition and lean design. Lean supply interconnects with lean design in the product design, and then there is the detailed engineering. Lean supply interconnects with lean assembly through the fabrication module. The next module is the installation. Lean use interconnects with lean assembly with commissioning. The maintenance and decommissioning are the last modules on lean use. Finally, LPDS ends with Production control and work structure.

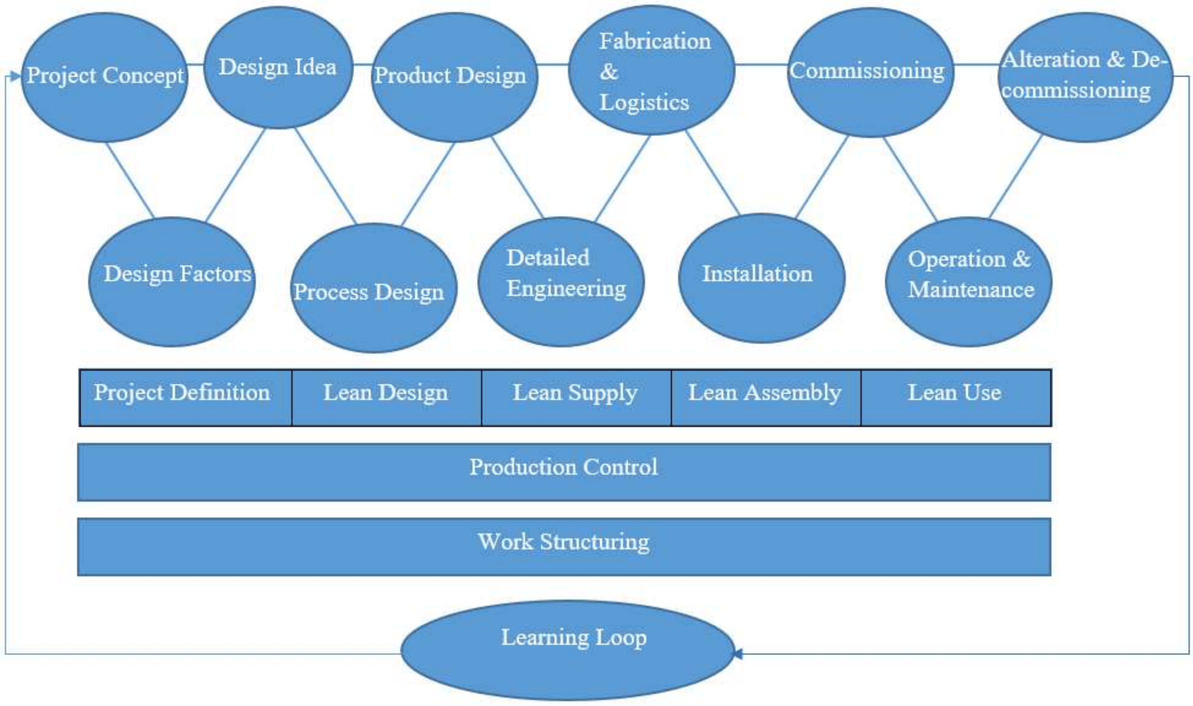


Figure 3- 5: Lean Project Delivery System (LPDS) [223]

3.5 Comparison between Lean Construction and Project Management approach

The differences between Lean Construction (LC) and Project Management (PM) approach can be explained through the following points according to scholars [265], [191] and [152]:

(1) LC use the concept of pull (e.g., delivering the material on time), while PM use the concept of push (e.g., delivering the material based on the expected duration).

(2) LC is used to reduce the projects' variations during the early stages, while in PM variations are not mentioned.

(3) LC is used to expect the wastes before their occurrence, while in PM the actions are taken after the occurrence of problems.

(4) The main aim of LC is to improve the value of the whole process, while PM works on each activity individually.

Table 3-4 shows a general comparison between Project Management (PM) approach and Lean Construction (LC). The main difference between the two concepts is that Lean Construction

(LC) uses the three perspectives of Transformation, Flow and Value (TFV). Another important difference is that the stakeholders are not involved in the early project stage in the traditional approach unlike Lean Construction. In order to apply Lean Project Delivery System (LPDS) in construction projects, there are some requirements that need to be met first. According to [223], [131] and [298] these requirements are:

(1) The project engineers should manage and execute, as a team, the Value Adding activities according to the quality and owner needs.
(2) Involve the stakeholders in the early stage of the project.
(3) Understand the activities to be executed.
(4) Focusing on making the workflow reliable instead of focusing on increasing the productivity.
(5) Instead of focusing on the flow of materials and information, apply the pull concept.
(6) Maintain the feedback between stages to have organizational learning.

Table 3- 4: Comparison between Project Management (PM) approach and Lean Construction (LC) [223]

Lean Construction	Project Management approach
Apply Transformation, Flow and Value concept.	Apply Transformation concept.
Target to improve the production system.	Target on the contracts' procedures.
All the life cycle of the product are involved in the design stage.	Not all the life cycle of the product are involved in the design stage.
Efforts are taken place to decrease supply chain's duration.	No concern on this issue.
The design of both product and process are taken place at the same time.	The product design is finished first then the porcess design starts.

3.6 Lean Construction tools

Lean Production used some tools to achieve improvement in work; some of these tools are suitable to be applied to the construction industry, while others are not. Lean Construction tools improve in the project duration, productivity and total cost. The successful application of Lean concept in construction industry cannot take place without applying and adapting these tools together [1], [3], [24], [29], [39], [47], [131].

Some of the main Lean Construction tools are:

(1) 5S and 6S; is a housekeeping tool, which refers to five Japanese words Seiri (means Sort), Seiso (means Straighten), Seiton (means Shine), Seiketsu (means Standardize)

and Shitsuke (means Sustain) and according to scholars [162] 5S is newly added with the sixth "S", which refers to Safety. This concept is applied widely in construction projects. To have a correct application of 5S/6S, is required support from the top management. The application of 5S/6S increase the quality, productivity and the works finish within the expected date. This tool reduces the wastes in time [15], [25], [24], [27], [29], [39], [40], [47], [51], [57], [59], [66], [73], [86], [88], [104], [147], [152], [162], [173], [191], [206], [221], [223], [230], [240], [245], [250], [256], [265], [289], [293], [297].

(2) Six Sigma; is used to improve the quality by removing the defects and reducing the variability. The merging between Lean principle and this tool leads to waste elimination [15], [29], [59], [68], [73], [78], [88], [149], [173], [196], [206], [230], [240], [245], [250].

(3) Kaizen; is a Japanese word referring to the tool used to improve quality by removing waste from the second principle, which is value stream. This tool is used to improve the project activities' efficiency with more safety and in less time. It includes three phases: (a) Phases 1; Lean training, illustrating a work map, identifying the areas which need improvements and determining the best solution to be applied. (b) Phase 2; applying the improvements in the required areas and documenting the performance of these improvements after application. (c) Phase 3; presenting the results. This tool maintains the application of the Lean principle Continuous Improvement [27], [51], [59], [73], [78], [147], [149], [172], [202], [206], [221], [223], [230], [240], [245], [250], [256], [298].

(4) Last Planner System (LPS); is used to improve the workflow for the activities and reduce the wastes. This tools consists of five main steps, which are Master Plan, Phase Planning, Look-Ahead Planning, Make Ready Process and Weekly Work Planning [3], [25], [24], [27], [29], [39], [40], [47], [51], [59], [65], [66], [73], [86], [88], [127], [131], [147], [152], [162], [172], [173], [191], [196], [199], [206], [211], [221], [223], [230], [240], [242], [259], [265], [268], [280], [296], [297], [298].

(5) Poka-Yoke; is a Japanese word, which means Error Proofing, referring to the tool used to detect the errors and prevent their occurrence [25], [27], [40], [51], [66], [73], [173], [206], [221], [240], [250], [256]. Different applications for this tool include checking material quality such as that of the asphalt making sure that the main component exists with the necessary percentage. Not less, nor more.

(6) First Run Studies; tool which is used to redesign the critical activities with the attempt to discover different manners in which the activity could be accomplished. This tool is applied two weeks before the execution week [24], [27], [51], [65], [66], [73], [86], [88], [152], [173], [191], [206], [221], [240],

(7) Total Productive Maintenance (TPM); used to carry out "preventive" maintenance to the machines in order to improve their efficiency and put them to use according to their maximum potential. This occurs by enabling operators to sustain their machines [15], [57], [73], [78], [104], [173], [206], [240], [256], [298].

(8) Integrated Project Delivery (IPD) system; a new delivery system mainly concerned with involving the project's stakeholders in the early project stage, which improves communication between the project's members [24], [66], [86], [131], [152], [191], [206], [211], [221], [223], [230], [265], .

(9) Visual Management (VM); to increase efficiency by using visual tools; use of visual control boards in the construction projects. On these boards, the projects' information can be easily shared. These boards may include information about safety requirements, schedule updates and quality information for the construction project activities [3], [27], [33], [40], [51], [65], [66], [73], [152], [162], [173], [191], [206], [223], [245], [265], [297], [298].

(10) 5 Whys; to improve the quality in the project by frequently asking five why questions until the engineers have answers to remove any problem that might occur by understanding the "root causes" and eliminate them. [27], [40], [59], [73], [206], [221], [230], [240], .

(11) Just In Time (JIT) is a tool mainly used to apply the pull principle; it is responsible for ensuring having the data, tasks or orders exactly when needed. In other words, the right information becomes available in the right place, the moment it is needed. This tool is used to reduce the inventories and handling and is one of the most important Lean concept tools [1], [3], [15], [24], [25], [26], [34], [39], [51], [57], [59], [66], [73], [86], [88], [104], [127], [131], [147], [152], [162], [172], [173], [191], [196], [206], [211], [221], [230], [240], [245], [265], [268], [289], [297], [298].

(12) Value Stream Mapping (VSM); is a tool used to improve the flow of the process and the identification of the project wastes. It mainly entails the determination of the production chain by creating the Current State Map that includes Value Adding (VA) and Non-Value Adding (NVA) activities, then determining and removing the wastes and finally applying the Future State Map after introducing the improvements. By

using this tool, the Value Adding (VA) activities and Non-Value Adding (NVA) activities are easily determined then the Non-Value Adding (NVA) activities, which are considered wastes, are eliminated [1], [24], [25], [27], [39], [40], [47], [51], [57], [59], [66], [73], [78], [147], [152], [191], [196], [199], [204], [206], [212], [221], [223], [227], [230], [240], [245], [250], [259], [265], [293], [296], [297], [298].

In the next two sections, there is a detailed explanation of two Lean Construction (LC) tools, Last Planner System (LPS) and Integrated Project Delivery (IPD) system. The application of Lean Construction (LC) requires the right merging between different Lean tools that lead to success of the project. Since this study focuses on decreasing the duration of construction projects, it is considered essential to go further in depth into these two Lean tools. LPS is the Lean tool mainly concerned with time management or schedule planning, and IPD is the tool concerned with fostering collaboration between the stakeholders. As previously discussed, the two variables are interdependent. In accordance, the application of LPS mainly depends on efficient collaboration between stakeholders. Hence, by applying Last Planner System (LPS) with Integrated Project Delivery (IPD) system, this eventually decreases the duration of the project.

3.6.1 Last Planner System (LPS)

Ballard and Howell proposed Last Planner System (LPS) in 1992 [217], which is based on the following five general ideas acknowledged by many scholars; [234], [5], [108], [217], [65], [145], [222], [251], [76], [140], [240], [157]:

(1) Make sure that as the execution week of the working activity gets closer, enough information about its details is available.
(2) Make sure that those who are doing the activity's planning will execute it.
(3) Determine the constraints (or risks) that should be removed from the activity.
(4) Ensure that the plan developed by the engineers is reliable and accurate.
(5) Learn from the failure that occurred in the past to avoid repeating mistakes.

According to scholars [217], [85], [66], [219], [53], [284], [109], [131], [81], [116], [105], [5], [251], [119], [265], [107], [143], [63], [76], [96], [102], [205], [2], [153], [145], [41] and [249] Last Planner System (LPS) can be illustrated through the following six processes::

(1) Master plan or Milestone planning, which entails the milestones of the project. It is an Initial long-term planning used to identify the milestones of the project and the general information.

(2) Collaborative programming or Phase planning, which addresses the collaboration of all the project's stakeholders in the early project stage.

(3) Look-Ahead planning, which includes the breakdown of activities into more detailed information and identifying and removing the wastes. It is a medium-term planning and identifies the tasks of the project with more details. This process is used to determine the availability of the different resources. It usually takes place three to six weeks before the execution week. Two concepts are part of this process; the Screening and Pulling concepts. The Screening concept is used to identify the constraints in the tasks before starting to work on them. While the Pulling concept is used to eliminate these constraints. Project Management approach (PM) introduces master plan to determine what should be done, while Lean Construction's tool, Last Planner System (LPS), introduces project details until lower levels of decomposition on the required project activities (Weekly Work Plan, WWP explained below in step 5). This step is shown in Figure 3-6. Look-Ahead planning steps include:

a) Determining the activities, which are expected to be finished in the next few weeks.
b) Making sure that these activities will be finished in the expected duration with the required resources.
c) Determining if there is any activity with potential delays.
d) Identifying any activity which might finish before its planned duration. In general, Last Planner System (LPS) improves the project performance, reduces the wastes and decreases the construction project's cost in contrast to the traditional management approach.

(4) Make ready process, which aims to identify and remove the wastes from the activities to prepare them for execution.

(5) Production planning and evaluation or Weekly Work Planning (WWP), is the stage in which the Percentage of Plan Complete (PPC) of the activities which took place in the previous week is calculated. As shown in Equation 1 below, PPC is calculated by dividing the total number of activities completed by the total number of planned activities [217]. WWP is also named "Commitment planning", in the level in which the engineers have to answer to the question of what will be done in the following

week. This level is considered short-term planning (weekly planning). WWP aims to protect projects from variabilities and as the PPC increases; this means the reliability increases. Weekly Work Planning (WWP) is also used to determine the reason of the failure of non-complete activities. The PPC parameter is used to measure the rate of non- compliance; as the percentage of PPC decreases, the project's reliability decreases. Some scholars [107], [217] found that there is a positive correlation between Percentage Plan Complete (PPC) and factors such as workers productivity, involving of Last Planner (LP) in the decision-making meetings, elimination of the reasons of the constraints occurrence.

Equation 1: $PPC = \frac{Total\ Number\ of\ Activities\ Completed}{Total\ Number\ of\ Activities\ Promised} \times 100\%$

(6) First run studies, is used to understand the construction process before starting the execution process. It focuses on understanding the critical activities and finding ways to improve them, as shown in Figure 14. This figure presents the explained steps of the Last Planner System (LPS).

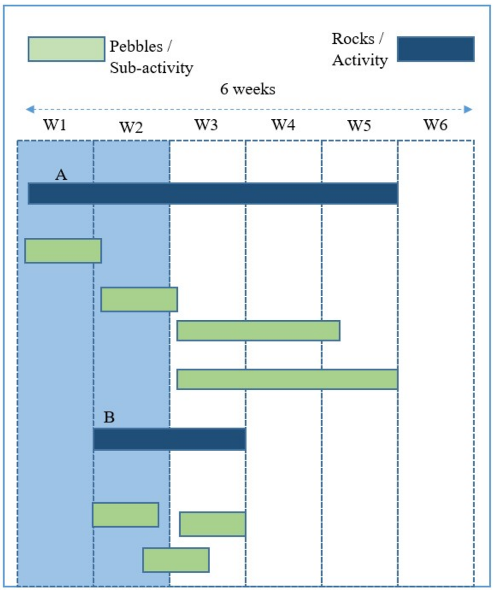


Figure 3- 6: Look-Ahead planning in LPS [105]

Last Planner System (LPS) helps in managing the project by using the concepts SHOULD-CAN-WILL-DO. Figures 3-7 & 3-8 demonstrates the concept of Last Planner System (LPS) in details. As demonstrated in the figures, the very beginning of any project is its main idea, which is then broken down to activities that are planned for based on a specified time schedule throughout the stages shown. LPS uses information about the main idea of the project as input data, based on which the activities planning process is developed, resulting in the activities schedule as the output. This output displays which activities SHOULD be done to achieve the aspired results in the project. Having determined that, the project team then need to answer the question: CAN the required activities be done? Responding affirmatively to that question does not mean that the activity is wastes free, however it means that it is achievable. In other words, the activities that *should* be done are turned to activities that *can* be done –are attainable- based the scheduled time for each activity's execution. The next stage is what activities WILL be done. In order to reach this conclusion, potential wastes for each activity are estimated to put expectations based on which the roots cause of such potential wastes are treated. Accordingly, the possibility of wastes occurrence becomes eliminated paving the way for a more efficient execution of the activities. Using the resources necessary, the activities are then executed. Having done that, the finished project activities become in the 'DID' phase. The PPC values are calculated for such activities in this stage to give an estimate of the efficiency of each activity. High PPC values signifies better results in terms of efficiency. In case of low PPC values the reasons are analysed creating a learning experience for future implementation [284], [25], [136], [39], [48], [62], [251], [95].

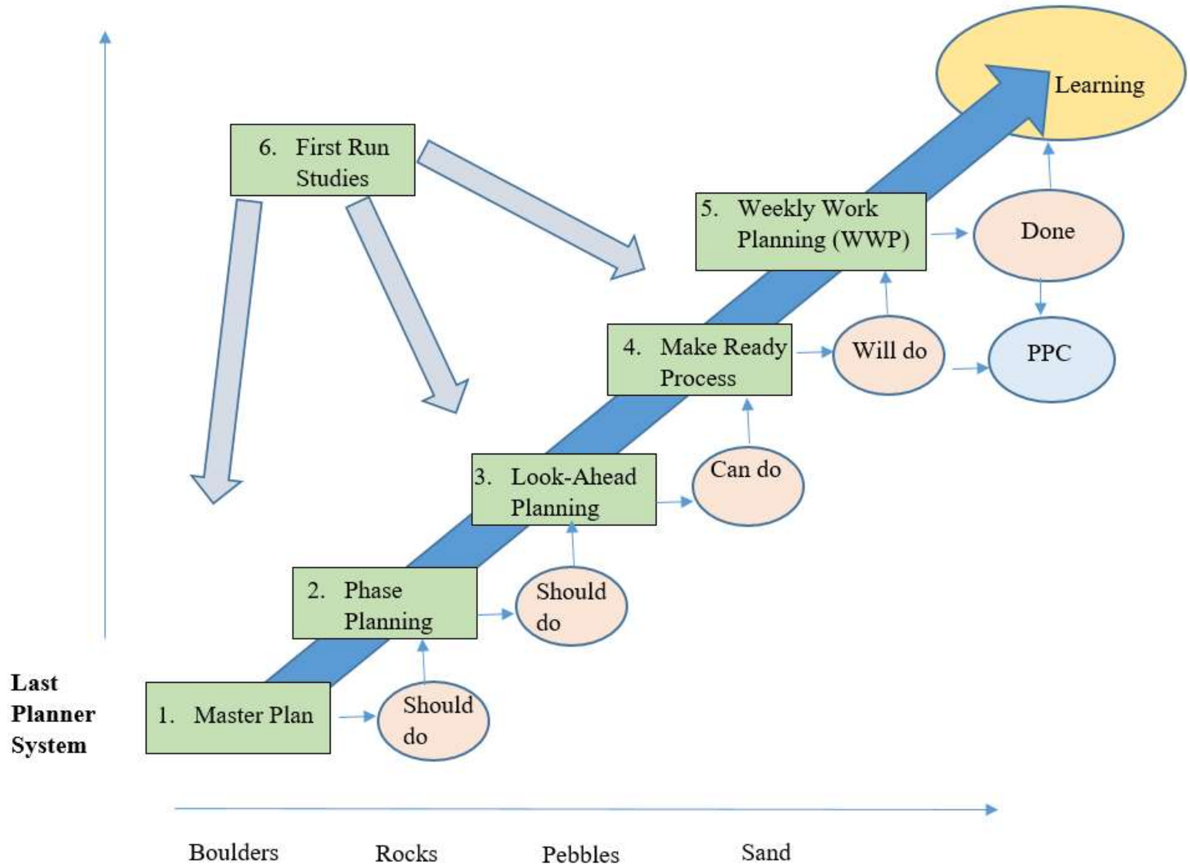


Figure 3- 7: Last Planner System (LPS) [217]

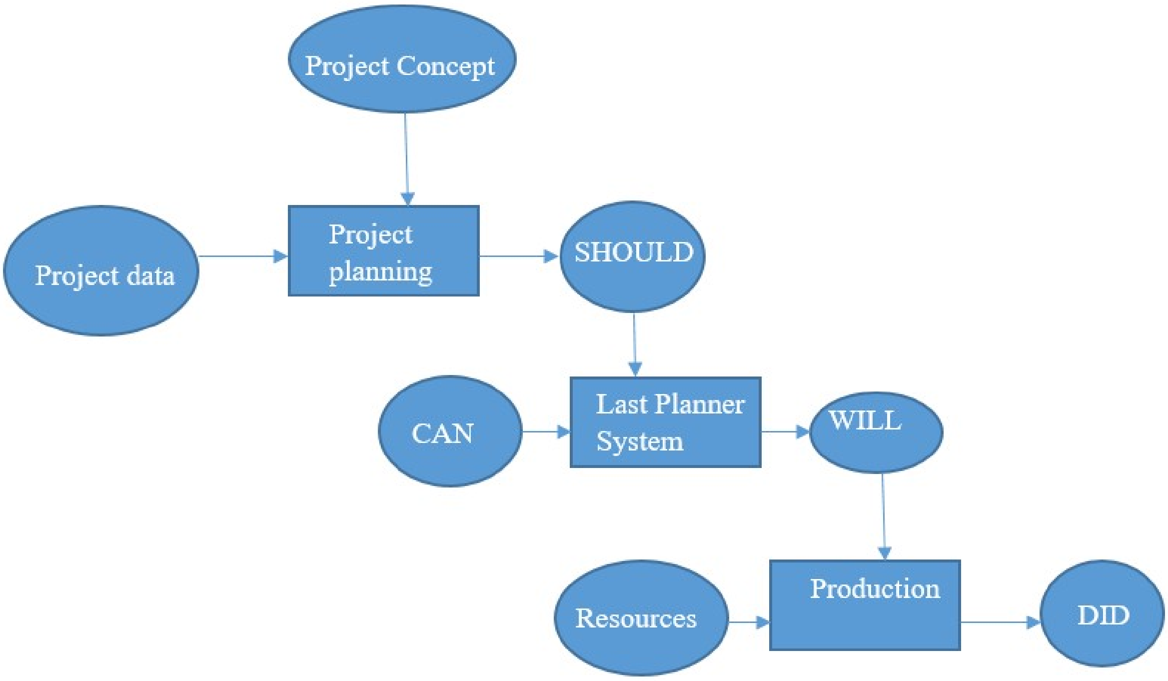


Figure 3- 8: Last Planner System (LPS) concept [251]

Last Planner System (LPS) is considered as a trademark of the Lean Construction Institute (LCI) [217]. According to scholars [209], [129], [50], [110], [51] Last Planner System (LPS) is explained as a tool that solves some issues related to the project's uncertainty/constraints and also the project's complexity, while improving the project's reliability and expectations. This is applied by mainly involving the project's stakeholders in the early project phases. Last Planner (LP) is the person/team, who is responsible to determine how to produce the output (which is the finishing of the project).

3.6.2 Integrated Project Delivery system (IPD)

Integrated Project Delivery system (IPD) is defined as a deliver system mainly concerned with involving the project's stakeholders in the early project stage, which improves communication between the project's members. The American Institute of Architects (AIA) defines [152], Integrated Project Delivery system (IPD) 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 minimize efficiency through all phase of design, fabrication and construction", [86], [232], [82], [6], [156], [224], [208], [118], [133], [101], [137], [186], [235].

According to scholars [138], [224], [155], [232], [156], [101], [118], [221], [86], [37], [235] Integrated Project Delivery System (IPD) was identified to have some general laws:

(1) Early involvement of the stakeholders and improvement of the collaboration.
(2) Sharing the risks and the profit.
(3) Early determination of the goal early.
(4) Open communication.
(5) Multiparty contract.
(6) High respect and reliable.
(7) Agreements from different stakeholders.
(8) Early goal definition.
(9) Using advanced and updated communications and technologies.

Figure 3-9 shows a comparison between traditional project delivery and IPD. This comparison focuses on the involvement period of different project stakeholders. Applying Integrated Project Delivery system (IPD), the involvement of stakeholders takes place in the early stage of the project, in contrast to the traditional project delivery.

Figure 3-10 shows the comparison between Design-Bid-Build (DBB), Design-Build (DB) and Integrated Project Delivery (IPD) system. This comparison focuses on the percentage of the design finished during the involvement of stakeholders. In the Design-Bid-Build (DBB), the project's owner (client) makes the contract with the general contractor after finalizing the design by 100% the client makes another contract with the. While in Design-Build (DB), the client makes the contract with the general contract after 20% of the design is finished. By using Integrated Project Delivery system (IPD), all the stakeholders are involved in all the project stages, including before starting the design phase. Using Integrated Project Delivery system (IPD) reduces the projects' cost and ensures having higher quality in shorter duration, [186], [81].

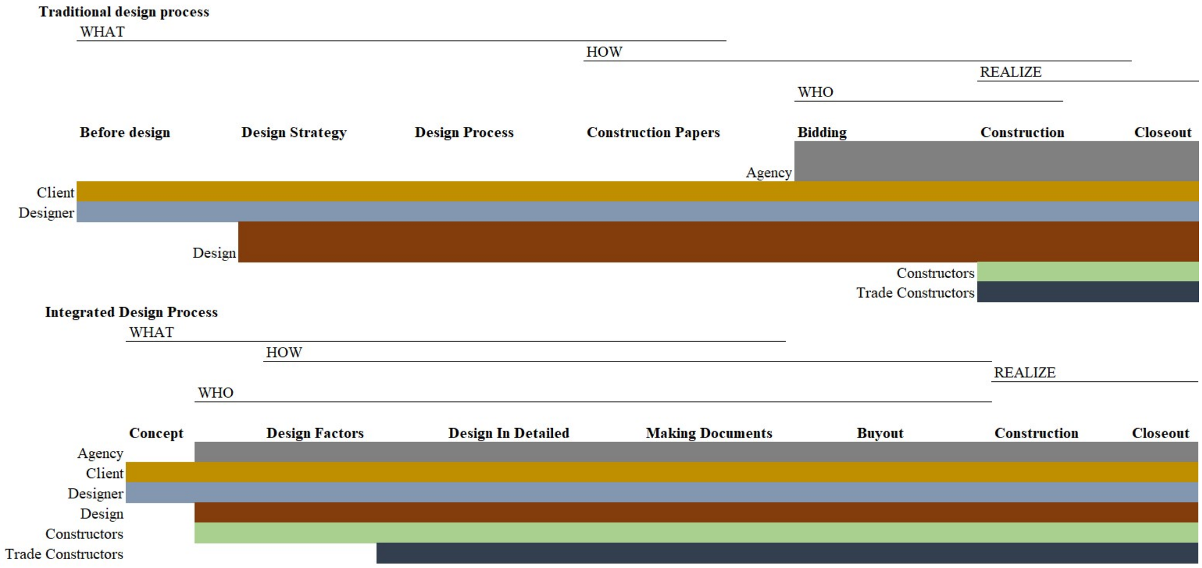


Figure 3- 9: Collaborations in traditional project delivery and IPD [186]

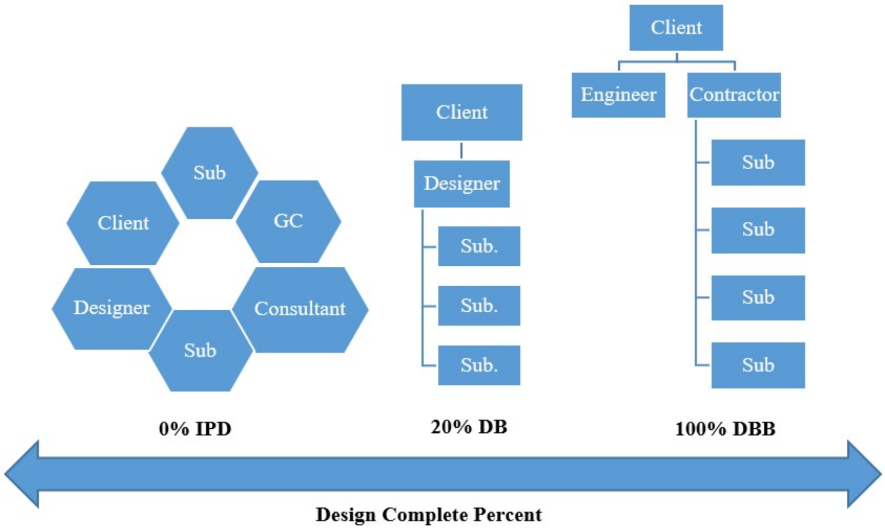


Figure 3- 10: Comparison between Design-Bid-Build (DBB), Design-Build (DB) and Integrated Project Delivery (IPD) system [81]

According to scholars [102], [230], [133], [143], [53], [157], [37] Integrated Project Delivery (IPD) integrates all the project members in the construction project from the design stage until the end of the construction stage. By the integration the communication between project stakeholders improves, the risks are shared and the trust between project stakeholders takes place. Moreover, it is found that the presence of collaboration problems leads to lower productivity. Integrated Project Delivery (IPD) is a perfect Lean tool due to the involving the project's stakeholders in the early stages so the risks and profit are shared.

Integrated Project Delivery system (IPD) was found to decrease the changes in project designs in comparison to the Design-Bid-Build (DBB), Design-Build (DB) [81]. By using IPD, some general risks can be identified and reduced. By using Integrated Project Delivery system (IPD), the total cost in construction projects is reduced. Through the application of Integrated Project Delivery system (IPD) the schedule will be met and the owner will be satisfied by the project's final result [105], [158], [81].

3.7 Lean Construction benefits and barriers

Lean concept improves the performance of Value Adding activities and elimination the wastes. Many previous studies present the benefits, which took place after the application of Lean Construction tools. Based on previous studies [265], [31], [112], [119], [117], [108], [87] the application of Lean Construction (LC) led to enhancements in different areas:

(1) Reducing the total cost of the project and final duration by eliminating waste.
(2) Enhancing the quality of the activities by reducing the rework activities.
(3) Positively impacting the environment by reducing CO_2 emission from the machines.

Many studies explained more benefits behind the invention new Lean concept. The following list illustrates the main targets of Lean Construction (LC), which represent its strength areas, [146], [238], [250], [72], [242], [298], [34], [20], [147], [201], [118], [86], [265], [119], [227], [223], [243], [15], [112], [297], [73], [40], [296], [72], [3], [77], [207], [272], [70], [170], [51], [53], [173], [196], [172], [211], [48], [142], [221], [46], [262], [191], [166], [6], [132], [131], [127], [274], [240], [5], [104], [28], [100], [33], [181], [35], [66], [93], [230], [36], [286], [16], [294], [282], [206], [26], [1], [165], [121], [41], [56], [65], [148], [245], [213], [42], [268], [289], [222], [105], [88], [249], [45], [102], [24], [214], [2]:

(1) Improves the planning of the design process.
(2) Eliminates the "muda" (means wastes in Japanese or in other words Non-Value Adding activities) in the activities, which leads to reduction in the total cost of the project and improvement in the efficiency of resources.
(3) Using Lean principles to eliminate the eight wastes categories after identifying them.
(4) Delivering the customer's value (Output) with lower cost, less materials, time, space, human resources and equipment (Inputs). The concept focus on delivering the customer's need without inventory.
(5) Focuses on minimizing wastes and maximizing the customer's needs.
(6) Lean concept on switching "muda" to value adding activities on the project. Consequently, production of the work increases.

(7) Lean concept put two main concepts for Lean. These concepts are minimization in total cost by minimizing the Non-Value Adding activities (activities that do not add any value to the project), while the second concept is improving the workers' treatment and not considering them machines.
(8) Reducing the time taken to finish the machine works and improving the quality of the work.
(9) Minimizing the construction project wastes and reducing the causes of defects.
(10) Having improvements in the main three project's factors time, quality and cost. In general, Lean concept focuses to improve the productivity, increase the customer's value and continuous improvement.
(11) Focusing to deliver the customer's need without inventory. This aim later was changed; Lean concept was focused to minimize wastes and maximizing the customer's needs.
(12) Lean concept is using the Pull concept instead of Push concept, which is used by Project Management (PM) approach.
(13) Improving in the working on the Essential Non-Value Adding activities, (ENVA).
(14) Making the construction supply chain caring about their effect on the project.
(15) Improvement of the inefficiency of the labours and materials.
(16) Improvement in customer satisfaction
(17) Inventories reduction.
(18) Employee satisfaction.
(19) Increase the construction projects' performance
(20) Increase project's transparency.
(21) Improvement of the concept project delivery method.
(22) Improvement in the reliability.

There are benefits to applying and implementing Last Planner System (LPS), [27], [251]. [286], [116], [106], [297], [219], [107] and [108]:

(1) Variability reduction.
(2) Application of pull concept.
(3) Management of the prerequisite activities.
(4) Increase collaboration between project stakeholders.
(5) When the execution week comes closer, the activities are determined with more details.

(6) Collaboration between the engineers who will do the planning to increase the trust level of the engineers promises.
(7) Determining and removing wastes takes place before execution week.
(8) Determining the process of removing wastes and documenting the previous failures to maintain continuous improvement.
(9) Improvement in Look-Ahead planning process improves the Weekly Work Plan (WWP) reliability.
(10) Perfection of Weekly Work Plan (WWP) will improve the final projects duration.
(11) Increases the construction projects' reliability and predictability.

Although, Lean Construction has a countless number of benefits, as demonstrated, it is still not easy to apply this concept in construction projects. Lean Construction has also many barriers, which prevent its spreading globally. Some of these barriers are [243], [148], [241], [218] and [131], [108], [226], [103], [49], [268], [51], [245], [117], [27], [142], [298], [210], [34], [35], [203], [67], [152], [230], [86], [173], [294], [16], [96] and [238]:

(1) Poor contracts between project members.
(2) The human culture, which resists changes.
(3) The political situation in each country.
(4) Lack of background about the Lean concept.
(5) The contractor is not received his monthly payment from the invoices on time.
(6) The interest rate is high.
(7) Lack of materials availability.
(8) Lack of trust between project members.
(9) Change in the design during the construction stage.
(10) Partial or late implementation of the Lean tools (such as Last Planner System).
(11) Confusion in the planning responsibilities.
(12) Inaccurate expectation of the wastes.
(13) Refusing to collaborate.
(14) Lack of knowledge about Lean Construction
(15) Lack of support from top management
(16) Delaying in materials delivery.
(17) Acceptance of the wastes that will be done.
(18) Conflict in government policies.
(19) Lack of interest from the client.

(20) Lack of detailed explanation of the project.

(21) Corruption.

(22) Poor communication between project members.

(23) Leadership problems.

(24) Problems between the project team members.

(25) Lack of long-term vision.

(26) Fragmentation and sub-contracting; sub-contractors sign their contracts with the main-contractor and not with the owner, which means that the owner does not maintain any influence over the sub-contractor. This can have an effect on the quality of the project, for instance because it becomes less binding for the sub-contractor to apply LC.

(27) Financial problems; to have a successful application of Lean concept, this barrier should be overcome through having adequate salaries, conducting trainings for workers, and also have machine maintenance done on time.

According to scholars [223], [175] some other barriers were identified during the design stage. These barriers have a direct impact on the Value Stream principle:

(1) The information stuck from flowing due to the lack of the critical process.

(2) Information stuck from flow because it cannot be identified or contradict the shared process.

(3) High amount of information is created which leads to difficulty in identifying the accurate information.

(4) Wrong information is created, which leads to inaccurate results.

Another barrier for Lean Construction (LC) is “Patience”; the reason is regarded as a barrier is the fact that LC needs more time in the early construction projects' (such as design and planning), however, this will eliminate the project's changes. These changes can increase the final project's duration and cost, [223] and [214]. Further, based on another study [127] some risks are not eliminated by using Lean Construction (LC):

(1) Variations in materials costs.

(2) The contractor does not receive his payment on the required time.

(3) The design are not accurate, which leads to some errors.

(4) The delivered materials are poor in quality.

3.8 Lean Construction studies

Tables 3-5 to 3-35 summarize Lean Construction (LC) studies related to different project sectors. This summary is based on the country where each study is applied. The main reasons of the study are determined. The studied project sector and the Lean Construction tools used on each study are shown. The methodology used on each study are also listed. Finally, the results of the study are presented.

Table 3- 5: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
1	(Abbasian-Hosseini, Nikakhtar, & Ghoddousi, 2014)	Iran	Determine the impact of lean principles on bricklaying activity.	Building projects	Value Stream Mapping (VSM)	Simulation modelling, site observation, analysing case study and survey.	High improvement in the studied activity, the productivity increases by 40%. This is due to removing of Non-Values Adding activities.
2	(Adamu & Howell, 2012)	Nigeria	Determine the advantage of using Last Planner System in a building project. Make a comparison between Last Planner System and the traditional used tool.	Building projects	Last Planner system (LPS)	Site observation and interviewss, analysing case study	Last Planner System makes high improvement. The project's duration is less by about 50 days than the traditional tool, the expected total duration is 120 days. The total worker days are less by more than the half, when compare to the traditionl tool. The total worker days is 1200 days in traditional tool and 560 days by using Last Planner System.
3	(Adamu & Adulhamid, 2016)	Nigeria	Identify the pros of application Lean Construction in Nigerian construction projects.	Building projects	Lean tools in general	Site observation and analysing case study	By using Lean Construction tools, the productivity's project increased by near 20%. The project duration finished in less than 6 weeks than it was expected.
5	(Adio-Moses & Asaolu, 2016)	Nigeria	Determine the impact of using technology and softwares in Nigerian building projects.	Building projects	Integrated Project Delivery (IPD) system	State of the art	It is determined that the application of new softwares with Integrated Project Delivery (IPD) system and other Lean tools can have high benefits to the envirnment and pollution conditions.
6	(Adio-Moses & Oladiran, 2016)	Nigeria	Determine the impact of applying the concept of sustainability in the high technology buildings in Nigeria.	Building projects	Integrated Project Delivery (IPD) system	Site observation and analysing case study	It is determined that the application of new softwares with Integrated Project Delivery (IPD) system and other Lean tools can be used to achieve the goals of sustainability.

Table 3- 6: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
12	(Ahuja, Sawhney, & Arif, 2016)	India	Determine if the Building Information Modelling can improve the impact of lean principles and the green factors in Indian building projects.	Building projects	Lean Green	interviews and analysing case studies	High improvement is determined after applying this combination in the final results such as, reducing in the material wastes, and increasing the final value of the project.
13	(Al Hattab & Hamzeh, 2015)	Lebanon	Make a comparison between the traditional concept and the combination of Building Information Modeling/Lean concept, regards the management of design faults.	Construction projects in general	Lean tools in general	Simulation modelling	The integration of the Building Information Modeling and Lean concept eases the process to determine the design faults and minimize to replicate them.
16	(Al-Aomar R. , 2012b)	UAE	Determine the reasons of the wastes in Abu Dhabi construction projects.	Construction projects in general	Lean Six Sigma	Survey	Identify 27 of the wastes in the construction projects and one of them is the shortage in machines.
15	(Al-Aomar R. , 2012a)	UAE	Determine the impact of applying Lean Construction in the projects.	Construction projects in general	Lean Six Sigma	Analysing case study	Identify 27 of the wastes in the construction projects. One of the most important wastes are the work fault.
20	(ALMUHARIB, 2014)	Saudi Arabia	Determine the quality level in the airport services using measures as trustworthy.	Airport services	Lean Six Sigma	Site observation, analysing case study, interviews and survey	By applying the concept of Define, Measure, Impreve, and Control, the airport services has high improvements. The quality services increases from acceptable to good also high reduction in wasting duration due to waiting in queues.
24	(Andersen, Belay, & Seim, 2012)	Norway	Determine the impact of applying Lean Construction in the hospital building projects.	Building projects	Last Planner system (LPS)	Site observation, analysing case study, interviews and survey	Results show high improvement in some measures as decreasing in waiting time, increasing quality and decreasing in cost.

Table 3- 7: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
25	(Andreu, 2016)	Spain	Determine the impact of applying Lean Construction in the library building projects.	Building projects	Last Planner system (LPS)	Site observation and analysing case studies	By using Lean Construction tool (Last Planner System) in three case studies, the productivity's project increased and the project duration decreased
26	(Anifowose, Ola-awo, & Mohammed, 2013)	Nigeria	By using Lean Construction tool, the study analyzes the management of the costs regards to surveyor's quantities.	Construction projects in general	Just In Time (JIT)	Survey	The results determine that any activity depends on the surveyor's quantities is very essential.
27	(Ankomah, Ayarkwa, & Agyekum, 2017)	Ghana	By making review on the previous studies, determine the situation of Lean Construction on Ghanaian organisation with small and medium scales.	Construction projects in general	Last Planner system (LPS), 5S, Value Stream Mapping (VSM) and 5 Why's	State of the art	It is shown that Lean Construction tools, such as Last Planner System and 5S, have high improvements on projects' factors without paying too much by the organisation.
28	(Ansah, Sorooshian, Mustafa, & Duvvuru, 2016b)	USA	Give information about the benefits that can be happened from the application of the Lean Construction tools.	Construction projects in general	Last Planner system (LPS), 5S, Value Stream Mapping (VSM), 5 Why's, Just In Time (JIT), Visual Management and Plan Do Check Act (PDCA)	interviews and analysing case studies	Make explanation for 40 lean tools and from the interviews determine the appropriate lean tools in construction industry.
29	(Ansah, Sorooshian, Mustafa, & Duvvuru, 2016a)	USA	Determine the reasons of the construction projects' delays and identify how to deal with them.	Construction projects in general	Lean tools in general	State of the art	It is determined that construction industry has high number of wastes in the projects and this affect the project's time, cost and quality. It is recommended the combination of the lean tools to achieve the required improvements.

Table 3- 8: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
31	(Arroyo & Gonzalez, 2016)	Chile	Determine the wastes the relate to the social and environment in the construction projects.	Building projects	Lean tools in general	Analysing case studies	It is stated the wastes that relate to the two aspects. For example of these wastes on social and environment are hazards wastes and pollution wastes respectively.
33	(Asim, Deep, & Ahmad, 2017)	India	Determine the responsibilities of the construction projects' delays in building construction project.	Building projects	Lean tools in general	Site observation and analysing case studies	It is concluded that the increasing in the knowledge relate to construction delays for the project's staff is essential to reduce their incidence.
34	(Asri, Nawi, Saad, Osman, & Anuar, 2016)	Malaysia	Determination the reasons make Lean Construction has a high improvement in Malaysian building manufacture industry.	Building manufacture	Just In Time (JIT)	State of the art	The cocnept of Just In Time need more application on building manufacture industry. However, it is expected that there is more improvement can take place by using lean tools in building manufacture industry. It is stated the challenges of application Lean Construction.
35	(Ayalew, Dakhli, & Lafhaj, 2016)	Ethiopia	Determine the advantages and challenges of application Lean concept in Ethiopian construction industry.	Construction projects in general	Last Planner System (LPS), Just In Time (JIT) and Value Stream Mapping (VSM)	Survey	The pros and challenges are identified and one of the most important for each are increase the productivity for pros and shortage in lean concept information for challenges.
36	(Ayarkwa, Agyekum, Adinyira, & Osei-Asibey, 2012)	Ghana	Determine the awareness of the Lean Construction in Ghanian construction industry.	Construction projects in general	Just In Time (JIT)	Survey	The results allow the construction industry in Ghana to host events for Lean Construction to increase the awareness of the concept.

Table 3- 9: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
37	(Azhar, Kang, & Ahmad, 2015)	USA	Fill the identified research gap, which is the relation between Integrated Project Delivery system and the using of technologies in the information and communication in the public construction projects.	Construction projects in general	Integrated Project Delivery (IPD) system	Survey	It is determined that Integrated Project Delivery system has high improvement in the construction industry and the using of echnologies in the information and communication enhance this lean tool. It is identified that there is shortage of awareness of Integrated Project Delivery system in the public sector.
39	(Aziz & Hafez, 2013)	Egypt	Understand the concept of Lean Construction.	Construction projects in general	Last Planner system (LPS)	State of the art	Implementation of Lean Construction tools, specially Last Planner System, have increasing the performance of projects by decreasing the project's duration with elimination of project's wastes.
40	(Bajjou, Chafi, Ennadi, & El Hammoumi, 2017)	Morocco	Determine the relation between the Lean Construction tools and the green construction projects.	Construction projects in general	Value Stream Mapping (VSM), 5S, Just In Time (JIT) and Last Planner System (LPS)	State of the art	Lean Construction tools are determined to be used for wastes elimination, and increasing the project's value. Lean tools are concluded that they enhance the concpet of green construction projects.
41	(Baladrón & Alarcón, 2017)	Chile	Determine the influence of application Lean Construction tools in the mining projects.	Mining projects	Last Planner system (LPS), 5S and Value Stream Mapping (VSM)	Analysing case study, interviews and survey.	Implementation of Lean Construction tools increase the project's reliability and decrease the project's variability.
42	(Balashova & Gromova, 2017)	Russia	Determine the influence of Lean Construction in the Arctic region.	Building projects	Last Planner system (LPS)	State of the art	Lean Construction has high improvements in construction projects in terms of time, cost and quality. Lean Construction is assuring qpproach to construct construction projects in Arctic region in Russia.

Table 3- 10: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
45	(Becker, Shane, & Jalselskis, 2012)	USA	Apply a comparison between Lean Construction and Design Build in construction industry during design and construction stages.	Construction projects in general	Integrated Project Delivery (IPD) system	State of the art	By applying this comparison regards to some factors, one of these factors are the changes in design. In Design build, the designers may edit these changes without the approval of the client if these changes do not affect the materials quantity. While in Integrated Project Delivery system, the engineers calculate the reparation of these damages.
46	(Bekdik, Hall, & Aslesen, 2016)	USA	Dtermine the requirements that is needed to have successful manufacture during the prefabricated building method	Building projects	Value Stream Mapping (VSM)	Site observation, analysing case study and interviews	Lean Construction has high improvements due to the concept of continous improvements and it is recommended to be used in other projects sectors.
47	(Berroir, Harbouche, & Boton, 2015)	France	By using Lean Construction, determine the comparison between the project achievement targets used by managers and the stakeholders' targets	Building projects	Last Planner system (LPS), 5S and Just In Time (JIT)	Site observation and analysing case study	Make a comparison between the applying of 5S on the first target and applying both Last Planner System and Just In Time for the second target. The results are shown that application of 5S has no high improvement to the project alone, while there is much higher improvements for the application of the two tools together.
48	(Bhatla & Leite, 2012)	USA	Determine the advantages of using Building Information Modelling with Last Planner System.	Building projects	Last Planner System (LPS)	Site observation and analysing case study	This integration between the two concepts decrease the number of the changes in the construction project.
49	(Bodkhe, Waghamare, & Patil, 2017)	India	Determine the main reasons of the material wastes and identify the impact of Lean Construction to decrease these wastes. There is determination of challenges face the application of Lean Construction.	Construction projects in general	Lean tools in general	Survey	Identify the causes of the wastes of materials such as the cleaning of pump after finishing. Using the technology with Lean concept helps decreasing these material wastes. One of the challenges for Lean is bad comunication between project's participants.
50	(Bolzan, Formoso, & Tzortzopoulos, 2017)	Brasil	Identify a method used in design stage to control and plan in the prefabricated building projects.	Building projects	Last Planner System (LPS)	Analysing case study, interviews and survey	Increase the level of calibration, the deliveries of design is increased and improvement in determining the reasons of delaying in activties.

Table 3- 11: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
51	(Brady, 2014)	UK	Use Visual Management tool to improve the planning and controlling process in construction projects.	Energy projects	Visual Management (VM)	Site observation, analysing case study, interviews and survey	The visual tool aids the worker in the construction projects, by increasing the clarity and improving the communications in site
53	(Brioso & Humero, 2016)	Spain	Apply the tools of Lean Construction into the building agents with addapting to Spanish construction laws.	Building projects	Last Planner System (LPS), Target Value Design (TVD) and Integrated Project Delivery (IPD) system	Analysing case study	The Spanish laws are not in contrast with the application of Lean tools.
54	(Brioso, Humero, Murguia, Corrales, & Aranda, 2017)	Spain	Adapt the Lean Construction tool on housing projects to make the value for the cities.	Building projects	Lean Project Delivery System (LPDS)	Analysing case study	Identify decreasing of project dispute requests, this means elimination of the time wastes and high improvement for the project.
56	(Chedas Fàbregas, 2012)	Spain	Make the students understand the new concept of Lean Construction.	Building projects	Last Planner System (LPS)	State of the art	The students are more aware of the Lean Construction's application.
57	(Chiarini, 2014)	Five European countries not identified	Identify if the application of Lean Production can influence the environment on five different countries.	Production Industry	Value Stream Mapping (VSM), 5S and Total Productive Maintenance (TPM)	Site observation and analysing case study.	By using Lean Production tools, high improvements on environment are illustrated. One of these improvements are, the outflow of oil decreased from 3.8 liter each month to 0.4 liter for the same project.
59	(Chowdhury, 2016)	USA	Determine the influence of energy utilization by using Lean Construction and Six Sigma in the construction projects.	Building projects	Lean Six Sigma and Value Stream Mapping (VSM)	Site observation and analysing case study.	Decrease in the waiting time after application of Lean Six Sigma and Value Stream Mapping. This leads to decreasing in the cycle time which finalizes by decreasing in the energy utilization.

Table 3- 12: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
62	(Ćwik & Rosłon, 2017)	Poland	Illustrate a comparison between Last Planner System and Critical Path Method.	Construction projects in general	Last Planner System (LPS)	Survey	The main difference between the two tools that in the traditional tool no identification of the activities that has possibility to be done.
63	(Daniel & Pasquire, 2017)	UK	Give supportive information for the project's partners of the Last Planner System implementation.	Construction projects in general	Last Planner System (LPS)	Analysing case study.	Identify the explanation of Last Planner System, also explain its challenges and advantages. Determine the impact of applying Last Planner System, such as the identification and elimination of the risks from the activities.
64	(Daniel, Pasquire, & Ameh, 2014)	Nigeria	Identify the time wastes in the Nigerian construction projetcs.	Construction projects in general	Last Planner System (LPS)	State of the art	Determine the wastes and their ranking. One of the most important wastes is poor planning in construction projects.
65	(Daniel, Pasquire, & Dickens, 2015)	USA, Barsil, Norway, Venezuel, UK, Chile, Nigeria, Finland, Lebanon, Peru, Mexico, Ecuador, India, Saudi Arabia and New Zealand	Make an explanation for Last Planner System.	Construction projects in general	Last Planner System (LPS)	State of the art	The study suggest that the field work of construction industry need to be more focusing on the research studies to improve the construction projects.
66	(Dave, 2013)	USA	Focus on applying Lean Construction and Building Information Modelling to have improvements in construction projects.	Road projects	Last Planner System (LPS)	Analysing case study, interviews, survey and applying simulation modelling.	It is concluded that the using any program with Lean Construction has a high improvement in the construction projects.
67	(Dave, Hämäläinen, & Koskela, 2015)	Finland	Determin the Last Planner System's challenges.	Infrastructure and building projects	Last Planner System (LPS)	Site observation and analysing case study.	Identify of the Last Planner System's challenges such as failure in making collaboration.

Table 3- 13: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
68	(Desai & Dhawale, 2017)	India	Explain the implementation of Six Sigma in construction projects.	Construction projects in general	Six Sigma	State of the art	Six Sigma needs to be applied more widely in construction projects.
70	(Dinesh, Sethuraman, & Sivaprakasam, 2017)	India	Explain the implementation of Lean Construction in construction projects.	Construction projects in general	Lean tools in general	State of the art	Explain the concept of Lean Construction, benefits and the used lean tools.
72	(Dinis-Carvalho & Fernandes, 2016)	Portugal	Explain to the universities students the application of Leann Construction.	Construction projects in general	Lean tools in general	Analysing case study.	The students are more aware by the Lean Construction's principles and the benefits.
73	(Dixit, Mandal, Sawhney, & Singh, 2017)	India	Determine the relation between the Lean Construction and the project's greenery.	Construction projects in general	Lean tools in general	Survey	Identify the factors on this relation and rank them. One of these factors is the managing of resources.
76	(Dos Santos & Tokede, 2016)	Australia	Determine the benefits of applying Last Planner System in construction projects.	Building projects	Last Planner System (LPS)	Site observation, survey and analysing case studies.	By applying a comparison between the traditional approach and Last Planner System, the project's achievements are improved by using the lean tool.
77	(Drevland, Lohne, & Klakegg, 2017)	Norway	Determine the requirements to deliver the needed owner's value, regards the ethical factors.	Construction projects in general	Lean tools in general	State of the art	Explain the ethical factors based on the owner, such as the project's value may be better for the owner but worse to the neighbours.
78	(Drohomeretski, Costa, Lima, & Garbuio, 2013)	Brasil	Determine the differences between Lean concept, Six Sigma and Lean Six Sigma.	Manufacture industry	Lean Six Sigma	Survey and analysis case study	The results show that by using Lean Six Sigma has the best achievements on the measures rather than the other tools.

Table 3- 14: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
82	(El Asmar, Hanna, & Loh, 2015)	USA	Compare Integrated Project Delivery (IPD) system with Design Bid Build (DBB) and Design Build (DB), regards to project's key achievements (cost, time and quality).	Construction projects in general	Integrated Project Delivery (IPD) system	Survey and interviews	Based on the project's key achievements (cost, time and quality), Integrated Project Delivery (IPD) system is finalized to be the best tool than other two traditional tools.
81	(El Asmar, Hanna, & Loh, 2013)	USA	Make a comparison between Integrated Project Delivery (IPD) system, Design Bid Build (DBB) and Design Build (DB), regards to some criteria as Percent Plan Complete and material wastes.	Construction projects in general	Integrated Project Delivery (IPD) system	Survey and interviews	Integrated Project Delivery (IPD) system is finalized to be the best tool than other two traditional tools in different criteria such as Percent Plan Complete and material wastes.
85	(Emdanat & Azambuja, 2016)	USA	Determine the ability of the planning in the short period exepects the long period planning.	Construction projects in general	Last Planner System (LPS)	Analysing case studies	The project's teams apply the concept of Last Planner System without the phase schedule.
86	(Fakhimi, 2017)	USA	Determine the possibility of applying Integrated Project Delivery (IPD) system with of Lean Construction and Building Information Modelling (BIM). Identify the advantages and challenges of Integrated Project Delivery (IPD) system.	Infrastructure and building projects	Integrated Project Delivery (IPD) system	State of the art	No clear identification of the using of three tools, there are few studies on this concept. The advantages and challenges are determined, as one of the most advantages is increasing the productivity.
87	(Fullalove, 2013)	UK	Determine the achievements of highway projects in UK after applying Lean Construction.	Road projects	Lean tools in general	Analysing case studies	The identification of the projects' achievements are identified such as more wastes are determined and eliminated, increasing in the productivity and decreasing in the projects' costs.

Table 3- 15: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
88	(Gade, 2016)	India	Determine how the Lean Construction can improve the project's achievements by using limited resources.	Construction projects in general	Last Planner System (LPS) and Just In Time (JIT)	State of the art	Decreasing in the project's costs and duration and increasing in the productivity.
93	(Giuda, Villa, Giana, Tagliabue, & Ciribini, 2017)	Italy	By using Lean Construction and Building Information Modelling, identify the benefits on using the two concepts and the impacts on the project's bid.	Building projects	Lean tools in general	Site observation and analysing case study.	Improvements in quality and project's reliability, due to the project is brokendown to factors and sub-factors and the suggested lean principle is illustrated for each.
95	(Gomes, Koskela, Biotto, Talebi, & Pikas, 2017)	UK	Explain the concepts of Lean Construction and Building Information Modelling.	Construction projects in general	Last Planner System (LPS)	State of the art	Give an explanation of the two concepts and understand their advantages to construction projects.
96	(Gowtham & Sivakumar, 2017)	India	Understand the concept of Last Planner System.	Construction projects in general	Last Planner System (LPS)	State of the art	Identify the barriers and advantages of Last Planner System. The barriers is such as absence of training.
100	(Gustafsson, Vessby, & Rask, 2012)	Sweden	Determine the construction wastes that affect the building projects.	Building projects	Lean tools in general	Site observation analysing case study and interviews.	Identify of the wastes and grouped them. One of these wastes is the materials delay.
101	(Gutierrez-Bucheli, Caldarón, Londoño-Acevedo, & Ponz-Tienda, 2016)	Colombia	Improve the level of knowledge for the students in areas Integrated Project Delivery system and Building Information Modelling.	Construction projects in general	Integrated Project Delivery (IPD) system	Survey	The students are more aware of the Integrated Project Delivery system and Building Information Modelling. The students recognize how these tools improve the projects' achievements.

Table 3- 16: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
102	(Gutierrez-Bucheli, Romero-Cortes, Calderón, Londoño-Acevedo, & Ponz-Tienda, 2017)	Colombia	Determine how the Last Planner System improves the reduction of the projects' variability.	Construction projects in general	Last Planner System (LPS) and Integrated Project Delivery (IPD) system	Simulation modelling	By using the software,the students apply the concept of Last Planner System and determine how it reduces the projects' variability.
103	(Haarr & Drevland, 2016)	Norway	Identify the benefits of using Lean Construction during the tender process in building project.	Building projects	Last Planner System (LPS)	Analysing case study and interviews	It has unsuccessful results due to some reasons, the project's partners do not apply Lean concept during construction stage and there is bad cooperation.
104	(Hamdar, Kassem, Srour, & Chehab, 2015)	Lebanon	Determine the impact of applying Lean Construction in a road project.	Road projects	Lean tools in general	Site observation and analysing case study.	Improvements in road project by using Lean Construction such as decreasing in the project wastes, decreasing in the project's cost and improvemts in the quality.
105	(Hamzeh, 2009)	USA	Determine the ways to modify the steps of Last Planner System.	Building projects	Last Planner System (LPS)	Simulation modelling, site observation, analysing case studies and survey.	Measures, like expected the activities that ready to be done, have high improvement on the Percent Plan Complete. It is also essential to expect the project's risks on different levels of details.
106	(Hamzeh & Aridi, 2013)	USA	Determine the relations between factors as the expected activities and Percent Plan Complete.	Building projects	Last Planner System (LPS)	Analysing case study	The value of the expected activities is not high, however, the Percent Plan Complete is high. This is due to the project's teams are expected activities only two weeks ahead.
107	(Hamzeh, Ballard, & Tommelein, 2012)	USA	Evaluate the achievements of look-ahead planning.	Building projects	Last Planner System (LPS)	Site observation, interviews, analysing case studies and survey.	By applying the steps of Last Planner System correctly the project's reliability improve and the values of Percent Plan Complete increase.
108	(Hamzeh, Kallassy, Lahoud, & Azar, 2016)	Lebanon	Determine the pros of using Last Planner System in Lebanon big building projects.	Building projects	Last Planner system (LPS)	Site observation and analysing case study	It is shown some improvements in different factors such as the increasing in project's reliability, identifying the reasons of project delays, increasing in quality and productivity.

Table 3- 17: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
109	(Hamzeh, Morshed, Jalwan, & Saab, 2012)	Lebanon	Appraise the look-ahead process, which is a step in the Last Planner system.	Building projects	Last Planner system (LPS)	Site observation, analysing case study and interviews	Identify this appraising, on of the reuslts show that there is almost an agrrement on estimate an activity even its predecessor is still in progress.
110	(Hamzeh, Zankoul, & El Sakka, 2016)	Lebanon	Determine the relation between Percent Plan Complete, project duration and the activities' reliability.	Construction projects in general	Last Planner system (LPS)	Simulation modelling	The results show that by decreasing the duration of the project, both the Percent Plan Complete and the project's reliability increase.
111	(Heyl, 2015)	Germany	Explain the traditional approach situation and understand how to solve the seen problems (wastes). This is applied by implementing a simulation game.	Road projects	Lean tools in general	Game simulation	High improvements in the productivity is shown by eliminating the wastes.
112	(Hosseini, Nikakhtar, & Ghoddousi, 2012)	USA	Determine the advantage of Lean Construction on construction projects by using simulation modelling.	Building projects	Lean tools in general	Simulation modelling	The results show that the concept of lean decreanse the duration of the project and improve its effectiveness.
116	(Hussain, Krishna, & Kumar, 2014)	India	Evaluate the performance of Last Planner System.	Building projects	Last Planner system (LPS)	Site observation and analysing case study	After applying the lean tool, there are reduction on the project's duration and cost.
117	(Hussain, Nama, & Fatima, 2016)	India	Determine the challenges of application Lean Construction in Indian construction projects.	Construction projects in general	Lean Project Delivery System (LPDS)	Survey	Determine these challenges and rank. One of the most important challenges is the declining of changes. It is stated that the explanation of the lean principles.

Table 3- 18: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
118	(Ibrahim, 2016)	USA	Explain the difference between Integrated Project Delivery system, Design Build and Design Bid Build	Building projects	Integrated Project Delivery (IPD) system	Survey	The results of this comparison is based on some factors as communication, project's quality and duration. These results state that Integrated Project Delivery system is recommended to be used in construction projects.
119	(Idiake, 2014)	Nigeria	Determine the influence of the activities variability on the project's team achievements.	Building projects	Lean tools in general	Site observation, analysing case study, survey and interviews	The activities variability is finalized that it have strong correlation with project's team achievements.
121	(Ingle & Waghmare, 2015)	India	Evaluate the advantage of applying Lean Construction.	Construction projects in general	Lean tools in general	State of the art	Lean Construction has high improvements on the construction projects. These improvements are such as eliminating the wastes, decreasing the duration and cost.
127	(Issa, 2013)	Egypt	Apply Last Planner System to reduce the project's constraints and analyse two variables, Percent Plan Complete and the delays in the activities.	Tunnel projects	Last Planner system (LPS)	Site observation and analysing case study	By using the lean tool, the Percent Plan Complete increased while the variable of the delays in the activities is decreased. This is due to the elimination of the wastes from the studied project.
137	(JUNG, BALLARD, KIM, & HAN, 2012)	USA	Explain a lean tool, Target Value Design, and determine why it is better to be used with Integrated Project Delivery system than Design Build	Construction projects in general	Integrated Project Delivery (IPD) system and Target Value Design (TVD)	Game simulation	Integrated Project Delivery system integrates all stakeholders of the project and not exclude any as the traditional approach. This is one of the reasons that makes the application of Integrated Project Delivery system with Target Value Design is the best option.

Table 3- 19: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
129	(Jeong, Chang, Son, & Yi, 2016)	USA	By using software of Building Information Modelling, determine the expectations of project's factors by using Just In Time and the advantages of this combination.	Building projects	Just In Time (JIT)	Simulation modelling, site observation, analysing case study and interviews.	It is determined that this combination ameliorate the duration reliability, decrease the materials wastes and decrease the project's cost.
131	(Johansson & Silversten, 2016)	Sweden	Explain the benefits of the collaboration between project's teams during the project's stages.	Building projects	Last Planner System (LPS), Lean Project Delivery System (LPDS) and Integrated Project Delivery (IPD) system	Site observation, analysing case study and interviews	The study determine that there is reluctance to attend the meetings due to different reasons. This leads to shortage in the information to be distributed between project's teams.
132	(Johnsen & Drevland, 2016)	Norway	Determine the influences of using lean concept on construction project's sustainability.	Construction projects in general	Lean Green	Interviews	Lean concept has high advantages on the project's sustainability. These benefits are such as increase the resources efficiency, improvements in productivity and increasing in the work's quality.
133	(Jones, 2014)	USA	Identify the barriers that affect the project's sustainavility.	Construction projects in general	Integrated Project Delivery (IPD) system	Survey	Determine these barriers and ranking them based on three prespectives, main contractor, consultant and the architature designers. One of the most important barrier is correct estimating of project's duration.
136	(Juarez & Erichsen, 2016)	Norway	By using Last Planner System, determine how to reduce the influences of criteria has affection on the supply chain.	Maritime industry	Last Planner System (LPS)	Analysing case study and interviews	Last Planner System overwhelm these barriers. The integration process, which is applied by the lean tool, increases the percentage of identifying and eliminating the project's constraints. The lean tool has high improvements on the project reliability.

Table 3- 20: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
138	(Kahvandi, Saghatforoush, Alinezhad, & Noghli, 2017)	Iran	Explain the concepts of Integrated Project Delivery system.	Construction projects in general	Integrated Project Delivery (IPD) system	State of the art	Integrated Project Delivery system improves the project's performances by early identifying and removing the project's constraints.
139	(Kaipainen, 2017)	Finland	By using the lean concept, determine the ways to improve the effeciency of the resources in the Finnish construction industry.	Building projects	Lean tools in general	Analysing case study, survey and interviews	Lean concept improves the project's performance by improving the value added activities and eliminating the non-value added activities or in another word the project's wastes.
140	(Kalsaas, 2012)	Norway	Explain the concepts of Last Planner System.	Construction projects in general	Last Planner System (LPS)	State of the art	Last Planner System improves the project achievement due to it increase the collaboration between project's members, this leads to improve the communications. There are some barriers are identified and one of the most common is the culture knowledge and declining of the changes.
142	(Kawish, 2017)	USA	Determine the barriers of Lean Construction and identify how to overwhelm them in transportation projects.	Transportation projects	Lean tools in general	Survey	The barriers are identified and racnked. The most important barrier is the shortage in the training for the project's members. By increasing the training for the workers, this barrier's impact is reduced.
143	(Kerosuo, Mäki, Codinhoto, Koskela, & Miettinen, 2012)	UK	Determine if the Last Planner System increase the designers' collaboration.	Building projects	Last Planner System (LPS)	Interviews	The lean tool recieves optimistic feedback from the project management's. However the project members decline to apply the lean tool due to the refusing of changes.

Table 3- 21: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
145	(Khanh & Kim, 2016)	Vietnam	By using Last Planner System, determine the performance during the planning process in the Vietnam construction projects.	Building projects	Last Planner System (LPS)	Analysing case study and survey	Last Planner System is not applied completely by using all the required steps. It is also recognized that there are a shortage of knowledge on applying Last Planner System.
146	(Khodeir & Othman, 2016)	Egypt	Determine the impact of the interface between Lean Construction and the project's sustainability.	Building projects	Lean tools in general	Analysing case studies and survey	This interfaces increase the project's value, improve the aspect of environment and reduction in the material and duration wastes.
147	(Kivistö & Ohlsson, 2013)	Sweden	Determine the ways to correctly apply Lean Construction in infrastructure projects.	Transportation projects	Last Planner System (LPS)	Analysing case study, interviews and survey	It is determined that all lean principles can be adapted to infrastructure projects. The application of Last Planner System can be determined that has high improvements on the infrastructure projects.
148	(Knotten, Svalestuen, Lædre, & Hansen, 2016)	Norway	Determine the impact of mutual evaluation on the design stage.	Construction projects in general	Last Planner System (LPS)	Analysing case study, interviews and survey	The explanation of mutual evaluation is the continous improvement, which is one of the lean principles. It is recognized that the applying of lean concept improves the improvements on the design stage with help from the mutual evaluation.
149	(Kuklare & Hedaoo, 2017)	India	Explain the concept of one of the lean tools, which is 5S.	Construction projects in general	5S	State of the art	Explain concept of 5S also identifyi ts benefits. The main benefits is well organise the item and make the working area tidy and clean.
152	(Kyere, 2016)	Ghana	Explain the challenges of Lean Construction and identify how to apply the concept correctly in Ghanian construction projects.	Building projects	Lean tools in general	Survey	Determine the Lean Construction challenges such as shortage in knowledge. It is also identified its requirements to be applied correctly such as the assisstance of the project management.

Table 3- 22: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
153	(Lagos, Herrera, & Alarcón, 2017)	Chile	Determine the Last Planner System benefits with using knowledge technologies.	Construction projects in general	Last Planner System (LPS)	Analysing case studies	By using 18 construction projects, the results show that the majority of these projects have high achievement on the project performances.
155	(Laurent, 2017)	USA	Determine the firm's criteria that impacting the project's teams, regards Integrated Project Delivery system.	Building projects	Integrated Project Delivery (IPD) system	Site observation, analysing case study and interviews.	Regards the application of the interviews, it is determined some firm's criteria such as the frequently meetings improve the communication between project's teams. It is also determined that it is recommended to make the team with smaller number of members responsible on a smaller task.
156	(Lee, 2012)	USA	Determine the factors of challenges affect the investing on improving the effectiveness of the energy building projects. Understand to minimize these factors by using lean tools.	Building projects	Target Value Design (TVD) and Integrated Project Delivery (IPD) system	Simulation modelling, site observation and analysing case studies	Determine these factors such as the risks relate to the cost of the projects. It is recognized that Integrated Project Delivery system has improvements on the risks reduction relevant to increasing in the projects' costs.
157	(Lee, Anderson, Kim, & Ballard, 2014)	USA	Identify the level of knowledge for the project's members about a lean tool, which is Integrated Project Delivery system.	Construction projects in general	Integrated Project Delivery (IPD) system	Survey	It is recognized that the project's participants have low knowledge on the high techniques of technology while are more aware of Integrated Project Delivery system
158	(Lee, Tommelein, & Ballard, 2013)	USA	Identify the benefits of using Integrated Project Delivery system.	Building projects	Target Value Design (TVD) and Integrated Project Delivery (IPD) system	Site observation and analysing case studies	Integrated Project Delivery system is the best delivery method can be used on the management of the constraints.
162	(Li, Wu, Zhouc, & Liu, 2017)	China	Determine the range of applying Lean Construction on the Chinese construction companies	Construction projects in general	Last Planner System (LPS), Just In Time (JIT) and 5S	Analysing case studies, survey and interviews	There are a widely application of Lean Construction in different Chinese construction companies.

Table 3- 23: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
165	(Liu & Chua, 2016)	China	Determine how to apply the concept of lean correctly in the supply chain sectors.	Construction projects in general	Lean tools in general	State of the art	The application of lean concept into supply chain sectors has achievement on the flow of the knowledge. The owner's deadlines are better to be met by using the lean concept.
166	(Locatelli, Mancini, Gastaldo, & Mazza, 2013)	UK	Explain the cocnept of Lean Construction and state the benefits that lean can give to construction industry.	Construction projects in general	Lean tools in general	Analysing case studies, survey and interviews	The application of the Lean Construction principles increase the process of wastes elimination, which leads to high improvements in project's performances.
170	(Mandujano, Alarcón, Kunz, & Mourgues, 2016)	Chile	Determine the benefits of applying Lean Construction with using high technologies in both design and construction stages.	Construction projects in general	Lean tools in general	State of the art	The review of the studies show that the concept of elimination wastes is improved with using Lean Construction and high technologies.
172	(Marhani, Jaapar, & Bari, 2012)	Malaysia	Explain the awareness of Lean Construction in the Malaysian construction industry and determine the benefits that lean can give.	Construction projects in general	Just In Time (JIT) and Last Planner System (LPS)	State of the art	The majority of project's partners understand the concept of lean, but still not have the details information about the concept. By using Lean Construction in Malaysian construction industry, the project's performances improved.
173	(Marhani M. , Jaapar, Bari, & Zawawi, 2013)	Malaysia	Explain the awareness of Lean Construction in the Malaysian construction industry and determine its challenges.	Construction projects in general	Lean tools in general	State of the art	It is determined that the project's partners need more training on Lean Construction to understand it into more detailed. The challenges that face Lean Construction is identified such as the refusing of changes.
175	(Marzouk, Bakry, & El-Said, 2012)	Egypt	Determine the influences of using the principles of lean concept during design process.	Building projects	Lean tools in general	Simulation modelling, interviews and analysing case studies.	By making comparison between Lean Construction and the traditional approach, there is increasing in the using of the activity by 40% than the traditional approach.

Table 3- 24: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
181	(Meiling, Backlund, & Johnsson, 2012)	Sweden	Evaluate the application of Lean Construction in the offsite manufacture.	Offsite manufacture	Lean tools in general	Survey and analysing case studies	The results determine that the last principle in Lean Construction need more focus to be applied correctly.
186	(Mihic, Sertic, & Zavrski, 2014)	Croatia	Apply a comparison between Integrated Project Delivery system and Design Build.	Construction projects in general	Integrated Project Delivery (IPD) system	State of the art	It is determined that the lean tool is better to be used in the project delivery than the traditional tool. This reason is due to the Integrated Project Delivery system makes all project's partiners integrating in the project from early stages.
190	(Mohamad, 2015)	Germany	Explain the application of standardization with applying Lean concept.	Building projects	Lean tools in general	Interviews, site observation and analysing case studies	The wastes are eliminated by different targets such as with integrating the project's partners in the early stages.
191	(Mohammed & Khodeir, 2017)	Egypt and USA	Determine the impact of Lean principles on the repairing construction projects.	Building projects	Last Planner System (LPS), Just In Time (JIT), 5S and Visual Management (VM)	Survey and analysing case studies	Identify the benefits that take place by applying Lean principles in case studies and from previous studies.
196	(Montes, 2017)	Denmark	Determine the influences of construction management on the projects greenery.	Building projects	Lean tools in general	Interviews and analysing case studies	It is determined that the application of lean principles improve the communication between the projects' stakeholders which decrease the percentage of errors and mistakes.

Table 3- 25: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
199	(Murguía, Brioso, & Pimentel, 2016)	Peru	Identify the improvement that could be occurred on a finishing phase in a large community-housing complex.	Building projects	Last Planner System (LPS) and Value Stream Mapping (VSM)	Site observation and analysing case studies	By using the lean tools, it is determined that minimizing in the projects' duration. This is taken place due to the identification and elimination of the wastes.
201	(Nahmens & Ikuma, 2012)	USA	Determine the influences of Lean Construction on the projects greenery.	Building projects	Lean tools in general	Interviews and analysing case studies	It is found that the construction material wastes decreased by more than 60% by using the principles of lean on the projects.
202	(Nahmens, Ikuma, & Khot, 2012)	USA	Dtermine the impact of using lean tool on the goodwill of the workers on the construction projects.	Building manufacture	Lean Kaizen	Survey and analysing case study	By applying the lean concept the workers are more goodwill and more satisfaction.
203	(Namadi, Pasquire, & Manu, 2017)	UK	Determine the relation between stakeholders' collaboration and the cost management in construction projects.	Construction projects in general	Target Value Design (TVD)	State of the art	The using of Target Value Design (TVD) in the construction projects improve the project performances' factors and specially the cost factor. This lean tool also improve the collaboration situation between project's partners.
204	(Nath, Attarzadeh, Tiong, Chidambaram, & Yu, 2015)	Singapore	Determine the risks that can be taken place on the precast activity during making the shop-drawings.	Precast projects	Value Stream Mapping (VSM)	Survey, interviews and analysing case study	By applying the lean tool, Value Stream Mapping, the changes on the activity is identified. This is improved the productivity and reduced the number of non-value added activities.
205	(Nieto-Morote & Ruz-Vila, 2012)	Spain	Identify the results obtain from applying Last Planner System on a case study.	Building projects	Last Planner System (LPS)	Analysing case study	The application of Last Planner System improves the productivity and the final quality. This is taken place by identifying and eliminating the project's risks.
210	(OMOTAYO, 2017)	Nigeria	Identify the factors that is used to monitor the cost after making the contracts on different construction firms' sizes.	Construction projects in general	Lean Kaizen	Survey and interviews	Identify these factors and ranking them, one of the most imprtant factrs is the engineers experiences.

Table 3- 26: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
206	(Ogunbiyi, 2014)	UK	Determine the relation between Lean concept and the greenery of the construction project and identify the challenges to apply this combination	Construction projects in general	Lean tools in general	Survey, interviews and analysing case studies	This relation has high improvement on the project also the most imortant challenge is the declining of changes.
207	(Okere, 2017)	USA	Determine the barriers for managing the knowledge in the construction industry.	Construction projects in general	Lean tools in general	Survey, interviews and analysing case study	Determine these challenges and one of them is the shortage in the project's knowledge.
208	(Oliva & Granja, 2013)	Brasil	Identify the situation of the collaboration in the design stage in the Brasilian construction projects.	Building projects	Target Value Design (TVD) and Integrated Project Delivery (IPD) system	Survey, interviews and analysing case study	The process of the collaboration in the Brasilian construction projects need more improvement.
209	(Olivieri, Seppänen, & Granja, 2016)	Brasil	By using Last Planner System and Crtical Path Method, try to improve the processes of the planning and controlling in the construction projects.	Construction projects in general	Last Planner System (LPS)	Analysing case study	By this combination of the two tools, the project's schedule is better in planning and controlling. This combination takes the benefit from the two tools and applies.
211	(Onyango, 2016)	Sweden	Identify the integration between Lean concept and Building Information Modelling.	Road projects	Last Planner System (LPS) and Just In Time (JIT)	Survey and analysing case study	By using the two concepts together, there is high improvement in the stakeholders collaboration during the project's stages.
212	(Orihuela, Orihuela, & Pacheco, 2015)	Peru	Identify a procedure data on the explanation of the project concept and the design stages.	Building projects	Target Value Design (TVD) and Value Stream Mapping (VSM)	Interviews	These procedures is determined. The main one which is used to improve the value added activities on the project, the project's data have to be well defined.

Table 3- 27: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
213	(Othman, Ghaly, & Abidin, 2014)	Egypt	Determine the influences of Lean Construction on the projects greenery in Egyptian construction sector.	Building projects	Lean tools in general	Survey, site observation and analysing case studies	Application of Lean Construction has high improvements on the greenery and environmental aspects. This new approach decreases the number of material wastes, consumptions of the energy from different machines and increases the owner's value of the project.
214	(Ozorhon, Abbott, & Aouad, 2014)	UK	Dtermine the challenges for the applying a new concept in the building construction projects.	Building projects	Lean tools in general	Survey, interviews, site observation and analysing case studies	Determine these challenges and one of them is the declining of changes.
217	(Pasquire, Daniel, & Dickens, 2015)	UK	Identify the collaboration procedures in the road construction project.	Road projects	Last Planner System (LPS)	Survey, interviews, site observation and analysing case studies	The concept of collaboration in construction industry depends mainly on the Last Planner System. The study reconginzes that the lean tool is still not applied with details in the construction industry.
216	(Pasquire & Ebbs, 2017)	UK	Identify the project delivery method that improves the reliability of the construction projects.	Construction projects in general	Last Planner System (LPS)	Survey and interviews	This study determines that the knowledge sharing is very essential in the project.
215	(Pasquire & Court, 2013)	UK	Identify the situation of knowledge for the project's stakeholders on determining the reasons of the project.	Building projects	Last Planner System (LPS) and Integrated Project Delivery (IPD) system	Interviews, site observation and analysing case study	It is identified that the competing between project's partners as the main challenge to share the information.
218	(Pellicer & Ponz-Tienda, 2014)	Spain	Understand the concept of Lean Construction in Spanish university.	Construction projects in general	Last Planner System (LPS)	Simulation game	This study is a simualtion game applied on master students to teach them the Lean Construction, specially Last Planner System. This course is recognized that the students are interested to understand more the new approach.

Table 3- 28: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
219	(Pellicer, Cerveró, Lozano, & Ponz-Tienda, 2015)	Spain	Make a recommendations after applying the first step of Last Planner System in Spanish university.	Construction projects in general	Last Planner System (LPS)	Simulation game	By using a simulation game on a real project, the students are more aware of the benefits that can be obtained by using Last Planner System.
221	(Pestana A. , 2016)	USA	Determine the benefits of applying Lean Construction on reducing the risks factrs relate to the safety.	Building projects	Last Planner System (LPS), Value Stream Mapping, Just In Time (JIT) and 5S	Survey, interviews, site observation and analysing case studies	By using different lean tools, it is observed that the application of Lean Construction reduces the factors of the risks. These risks are affect the safety of the workers on the construction projects.
222	(Pestana, Alves, & Barbosa, 2014)	USA	By using Lean Construction, determine the benefits that take place on the process of submittal.	Building projects	Lean tools in general	Interviews and analysing case studies	By using Lean Construction the two types of wastes are determined and eliminated.
223	(Pettersen, 2017)	Norway	Determine the application of Lean Construction in Norwegian road and railroad projects.	Road and railroad projects	Lean Project Delivery System (LPDS), 5S, Last Planner System (LPS), Visual Management (VM) and Target Value Design (TVD)	Survey, interviews, site observation and analysing case studies	It is determined that the studies on the bulding projects are much more than the infrasture projects. It is also recognized that the application of Lean Construction has barriers to be applied on Norway due to the laws in public projects, regards the application of Lean Project Delivery Systems.
224	(Pishdad-Bozorgi, Moghaddam, & Karasulu, 2013)	USA	Make a comparison between Integrated Project Delivery system and Design Build, regards to Target Value Design.	Construction projects in general	Target Value Design (TVD) and Integrated Project Delivery (IPD) system	Interviews	From the comparison, it is determined that the project's client will be more motivation to collaborate in design stage by using Design Build. While it is in contrast by using Integrated Project Delivery system
226	(Radhika & Sukumar, 2017)	India	Determine the concept of Lean Construction and its challenges.	Construction projects in general	Lean Six Sigma	Survey and interviews	It is identified that the Lean Construction can be used to eliminated the wastes and improve the productivity. The challenges are identified and ranked.

Table 3- 29: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
227	(Rajkumar, Saravanakumar, & Gowtham, 2017)	India	Determine the impact of Value Stream Mapping on the project productivity.	Building projects	Value Stream Mapping (VSM)	Simulation modelling, site observation and analysing case studies	The Value Stream Mapping increases the productivity due to the reducing of the number of non-value added activities.
230	(Rodewohl, 2014)	Norway	Determine the situation of Norwegian infrastructure projects by using Lean Construction.	Roads, tunnels and bridges projects	Lean tools in general	Survey, analysing case studies, site observation and interviews	By using Lean Construction, the projects' stakeholders are more cocnerned on the wastes elimination and reducing the non-value adding activities.
232	(Roebuck, Sewalk, Taylor, & Chinowsky, 2016)	USA	Understand the opinion of the mechanical sub-contractors on the concept of Integrated Project Delivery system.	Construction projects in general	Integrated Project Delivery (IPD) system	Survey and interviews	There are some barriers decrease the motivation of the mechanical sub-contractors to participate in the lean tool.
234	(Rouhana & Hamzeh, 2016)	Lebanon and Japan	Determine the method used to arise the new activities in the weekly work planning.	Building projects	Last Planner System (LPS)	Site observation, interviews and analysing case studies	Conduct the required method for the new activities. The recommendations are presented to have successfully apply the planning proces. These relate to some aspects such as the using softwares in construction projects.
235	(Roy, Malsane, & Samanta, 2017)	India	Collect the challenges that face project's partners to apply Integrated Project Delivery system	Building projects	Integrated Project Delivery (IPD) system	Focus group	Identify the required challenges and one of them is the challenges relate to the culture.
236	(Rybkowski, Shepley, & Ballard, 2012)	USA	Explain the application of Target Value Design in the healthcare sectors.	Healthcare sectors	Target Value Design (TVD)	Survey and analysing case studies	Target Value Design has high improvements on the healthcare sectors.

Table 3- 30: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
238	(Salifu-Asubay & Mensah, 2015)	Ghana	Explain the application of each lean principle and identify its challenges in Ghanian construction industry.	Construction projects in general	Just In Time (JIT)	Survey	The application of each lean principle is identified and ranked its importance from the Ghanian experts opinion. It is also determined and ranked the challenges in the construction industry in Ghana.
240	(Sarhan, Xia, Fawzia, & Karim, 2017)	Saudi Arabia	Explain the advantages, the wastes and the tools for Lean Construction in Saudi Arabian construction projects.	Construction projects in general	Last Planner System (LPS), Value Stream Mapping, Kaizen, Five Why's, Target Value Design (TVD), Total Productive Maintenance (TPM), Six Sigma, Just In Time (JIT) and 5S	Survey	It is determined that there is a growing in implementation Lean Construction. From the study, it is considered the advantage that has a highest ranking is that lean concept improves the productivity of the activities. While for the wastes, the most common is the waiting activities.
243	(Sarhan & Fox, 2013b)	UK	Determine the challenges of application Lean Construction in construction projects.	Construction projects in general	Lean tools in general	Survey and interviews	The challenges are identified and ranked. The most important challenge is shortage in knowledge on Lean Construction.
242	(Sarhan & Fox, 2013a)	UK	Investigate the knowledge on Lean Construction for the projects' partners in construction projects.	Construction projects in general	Last Planner System (LPS)	Survey	Based on the survey's respondents, it stated that the safety is the most important factor does not relate to the financial. While most respondents, state that the Last Planner System is applied on the planning stage. In the second category state that lean tool is used as key measurements.
241	(Sarhan & Fox, 2012)	UK	Determine the of application Lean Construction in construction firms.	Construction projects in general	Lean tools in general	Survey and interviews	Identify the Lean Construction challenges and rank them. One of the most important challenges is the declining to changes.

Table 3- 31: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
244	(Schöttle, 2015)	Germany	Explain a lean tool, Lean Project Delivery System.	Construction projects in general	Lean Project Delivery System (LPDS)	State of the art	Give a brief expalanation of Lean Project Delivery System.
245	(Scoggin, 2017)	USA	Determine the relationship between Lean Construction and the development of the organization.	Building projects	Kaizen and 5S	Survey, analysing case study, site observation and interviews	The results are shown that the managers have shortage of knowledge on the concept of the development of the organization.
246	(Sertyesilisik, 2016)	Turkey	Evealuate the relation between the project's greenery and the management of supply chain, regards to Lean Construction	Construction projects in general	Last Planner System (LPS), Just In Time (JIT) and Value Stream Mapping (VSM)	State of the art	The two concepts of Lean Construction and project greenery have mutual targets, which is the removing of the wastes. These two concepts are also shared by some tools such as Value Stream Mapping.
249	(Shabehpour, 2016)	Canada	Determine the influences of applying Lean Construction in complicated construction projects.	Building projects	Last Planner System (LPS) and Just In Time (JIT)	Analysing case study, site observation and interviews	It is determined that the project's reliablity is not high. This decrease the values of the project's productivity.
250	(Shah & Deshpande, 2015)	India	Explain a lean tool, Lean Six Sigma	Construction projects in general	Lean Six Sigma, 5S and Value Stream Mapping (VSM)	State of the art	Explain Lean Six Sigma in details, by determining the steps of application and the requirements to apply it successfully. It has also a brief expalanation of 5S and Value Stream Mapping.
251	(Shang & Pheng, 2014)	China	Explain a lean tool, Last Planner System in Chinese construction industry.	Building projects	Last Planner System (LPS)	Interviews	It is stated that Look-Ahead planning, the main core of Last Planner System, has shortage in implementation in Chinese construction projects. It is recommended also the trust and reliability between project's partners need more improvements.

Table 3- 32: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
253	(Shen, Zygmunt, & Wandahl, 2017)	Denmark	Determine the impact of labour's variability to the construction projects.	Building projects	Lean tools in general	Simulation modelling and analysing case study	It is stated that the decreasing in labour's variability, increase the productivity. Consequently, the project's duration decrease.
256	(Singh, Gohil, Shah, & Desai, 2013)	India	Determine the impact of Total Productive Maintenance on the reducing activity's duration.	Manufacture industry	Total Productive Maintenance (TPM), 5S and Kaizen	Analysing case study	Explain the concept of Total Productive Maintenance and its benefits on the duration. It is stated that this lean tool with aid from other tools, decrease the activity's duration and increase the productivity.
257	(Small, Al Hamouri, & Al Hamouri, 2017)	UAE	Determine the impact of Lean Construction in the Dubai construction industry.	Construction projects in general	Lean tools in general	Survey	Determine the challenges to apply Lean Construction in Dubai industry. One of the main challenges is shortage of knowledge. The recommendations are presented to overcome these challenges.
259	(Somani & Minde, 2017)	India	Identify the observed wastes and the required lean tool to reduce the wastes facors in the Indian construction industry.	Construction projects in general	Last Planner System (LPS) and Value Stream Mapping (VSM)	Survey	It is determined that waiting activities is the most common wastes. Last Planner System is determined that is the required lean tool needed to remove the construction wastes.
262	(Stevens, 2014)	Australia	Based on the contracting process with the contractor, identify the application of Lean Construction.	Construction projects in general	Lean tools in general	State of the art	It is determined that the knowledge of lean need more improvements for the construction contractors. For this reason, Lean Construction is not applied completely in the projects.

Table 3- 33: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
265	(Swefie, 2013)	Egypt	Determine the impact of applying Lean Construction in the Egyptian construction industry.	Building projects	Last Planner System (LPS), Lean Project Delivery System (LPDS), 5S, Integrated Project Delivery (IPD) system, Just In Time (JIT) and Value Stream Mapping (VSM)	Simulation modelling, site observation, analysing case study and survey	It is stated that Lean Construction has high improvements on the project's performances. The non-value added activities are reduced, which leads the project's productivity increases. These factors make reduction in the project's duration.
277	(THURANIRA, 2016)	Kenya	Determine the impact on applying lean concept on the supply chain process Kenyan factories.	Manufacture industry	Just In Time (JIT)	Site observation, analysing case study and survey	It is determined by applying this combination, the performances of the operation is improved.
268	(Tabatabaee, Mahdiyar, Yahya, Marsono, & Sadeghifam, 2017)	Malaysia	Determine the knowledge of Lean Construction in Malaysian universities students.	Construction projects in general	Lean tools in general	Survey	It is determined that the Malaysian students have understand the concept of Lean Construction.
272	(Tawfik & Othman, 2013)	Egypt	Determine the effect of applying the quality management on removing the project's wastes in Egyptian construction sector.	Construction projects in general	Lean tools in general	State of the art	The management of quality improves the process of removing the project's wastes. However, Egyptian construction industry has shortage to apply this concept.
274	(Tezel & Nielsen, 2013)	Turkey	Determine the level of conformance for Lean construction in the Turkish projects.	Construction projects in general	Lean tools in general	Survey and interviews	Based on some factors such as elimination of wastes and people culture, the level of conformance is determined by answering the related question on the survey. It is determined that the oldest and youngest firms have the highest values of the level of conformance.
275	(Tezel, Koskela, & Aziz, 2017)	UK	Determine the situation of Lean Construction in the United Kingdom's supply chain in the highway projects.	Highway projects	Lean tools in general	Survey and interviews	This situation is determined and listed based on thirty one points.

Table 3- 34: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
278	(Tran, 2017)	New Zealand	Identify the criteria that affect the elimination of wastes in New Zealand construction projects.	Building projects	Lean tools in general	Site observation, analysing case studies and interviews	There are many criteria affect this concept. This may be due to external criteria such as the country's law or internal criteria such as the used technology in the project.
280	(Uusitalo, Olivieri, Sepp–nen, Pikas, & Peltokorpi, 2017)	Finland, USA and Norway	Determine the application of Lean Construction in the design stage. This is based on three criteria, which are the process, method and the used technology.	Construction projects in general	Last Planner System (LPS) and Target Value Design (TVD)	Analysing case studies, survey and interviews	This application is determined by using the different mthodologies. It is stated that the Last Planner System (LPS) and Target Value Design (TVD) are used by some case studies.
281	(Vaidyanathan, Mohanbabu, Sriram, Rahman, & Arunkumar, 2016)	India	Determine the results of using lean tools in Indian commercial building project.	Building projects	Last Planner System (LPS) and Value Stream Mapping (VSM)	Analysing case studies, survey	It is determined that the project has improvements in reducing project duration and increasing the productivity.
282	(Viana, et al., 2017)	Brasil	Determine the influences of applying Lean Construction in construction projects.	Building projects	Lean tools in general	Analysing case studies and site observation	It is determined that the application of Lean Construction decrease the percentage of wastes by 27%. This leads to increase in the productivity which finalizes by decreasing in the project's duration.
284	(Walia & Suri, 2017)	India	Identify the barriers for Last Planner System in the Indian construction industry and determine the used process to overcome these barriers..	Building projects	Last Planner System (LPS) and Value Stream Mapping (VSM)	Analysing case studies and site observation	These barriers are determined such as the machine breakdown. It is stated that to solve this issue a better communication is required.
286	(Warcup & Reeve, 2014)	USA	Understand the impact of teaching Last Planner System on simulated case study by different teams. Compare the results with using the traditional approach.	Construction projects in general	Last Planner System (LPS)	Simulation modelling, interview, site observation, analysing case study and survey	The results for each team are shown high improvements in the durations in comparison to the traditional approach.

Table 3- 35: Information of Lean Construction (LC) studies

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
289	(Yan, 2017)	China	Determine factors need to apply in order to implement Lean Construction in the Chinese construction projects.	Construction projects in general	Lean tools in general	State of the art	These factors are determined such as the Chinese culture need to change in order to accept this new approach.
293	(Yu, Al-Hussein, Al-Jibouri, & Telyas, 2013)	USA	Determine the impact on implementing lean concept in building prefabricated.	Building manufacture	Value Stream Mapping (VSM) and 5S	Simulation modelling, site observation and analysing case study	It is determined that high improvements after applying the Value Stream Mapping. It is shown that the time of processing is decreased by about 20%. This leads to increasing in the productivity.
294	(Yunus, et al., 2017)	Malaysia	Determine the factors needed to apply lean concept successfully in building manufacture.	Building manufacture	Lean tools in general	Survey	Determine these factors and rank. One of these factors is the improvement in communication skills.
296	(Zhang & Chen, 2016)	China	Determine the relation between lean tools, its knowledge and the project's performances.	Construction projects in general	Last Planner System (LPS), Value Stream Mapping (VSM) and Six Sigma	Survey	It is stated that the factor of knowledge considers to be as a bridge between the lean tools and the project's performances. In order to have improvements in the performances the knowledge on lean tools is required first.
297	(Zhang, Azhar, & Nadeem, 2015)	USA	Determine the impact of application both Lean Construction and Building Information Modelling.	Construction projects in general	Last Planner System (LPS) and Just In Time (JIT)	Site observation, interviews and analysing case study	It is stated that high improvements recognized by applying these tools together. These are such as increasing in productivity, eliminating the wastes and increasing in quality.
298	(Zhang Y., 2017)	Canada	Determine the appraisals to convert the construction projects from the customary construction process to the construction manufactured projects.	Building manufacture	Last Planner System (LPS) and Value Stream Mapping (VSM)	Site observation and analysing case study	It is stated thet using the Value Stream Mapping with the breakdown structure of the production to identify the improvements point. For instance, this lean tool is used on the breakdown structure of the production at different level to remove the wastes.

3.8.1 Studies analysis

Tables 3-36 to 3-14 and Figures 3-11 to 3-14 show the analysis of the literature studies applying Lean Construction (LC) on different project sectors. Table 3-36 and Figure 3-11 show the analysis of these studies based on the country where these studies were applied. The majority of this list relate to USA (20.7%). This is followed by “Other”, which has the countries that are applied only once (14.5%). Table 3-37 and Figure 3-12 show the analysis of the different project sectors. The majority is the application of Lean Construction in general as there is no specific project sector mentioned (42.3%.) This is followed by the building projects(40.2%). The application of road projects is only 4.2% of the studies. Table 3-38 and Figure 3-13 show the analysis of Lean Construction tools. The majority is the application of Last Planner System (LPS) by 25.9%. Table 3-39 and Figure 3-14 show the application of the methodology in the studies. The majority of them is the application of analysing projects' data (28.7%).

Table 3- 36: Country analysis used Lean Construction (LC)

Country	**Country quantity**	**Country analysis**	**Note**
Nigeria	9	4.7%	**Some countries are hidden**
India	21	10.9%	
Lebanon	7	3.6%	
UAE	3	1.6%	
Saudi Arabia	3	1.6%	
Norway	11	5.7%	
Spain	7	3.6%	
Ghana	4	2.1%	
USA	40	20.7%	
Chile	5	2.6%	
Malaysia	5	2.6%	
Egypt	8	4.1%	
Brazil	5	2.6%	
UK	17	8.8%	
Peru	3	1.6%	
Finland	4	2.1%	
Sweden	5	2.6%	
Germany	3	1.6%	
China	5	2.6%	
Other	28	14.5%	**For values equal or less than 1%**
Total	**193**	**100.0%**	

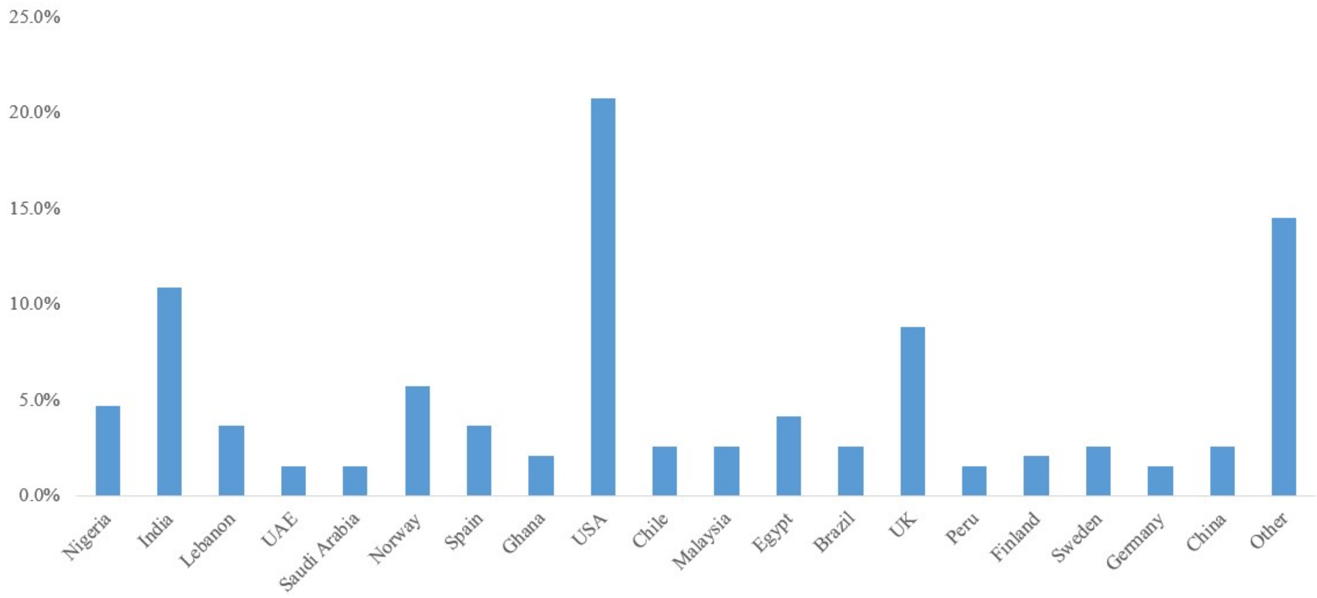


Figure 3- 11: Country analysis used Lean Construction (LC)

Table 3- 37: Project sector analysis used Lean Construction (LC)

Project sector	Project sector quantity	Project sector analysis	Note
Building projects	76	40.2%	**Some project sectors are hidden**
Construction projects in general	80	42.3%	
Building manufacture	6	3.2%	
Manufacture industry	4	2.1%	
Road projects	8	4.2%	
Other	15	7.9%	**For values equal or less than 2%**
Total	**189**	**100.0%**	

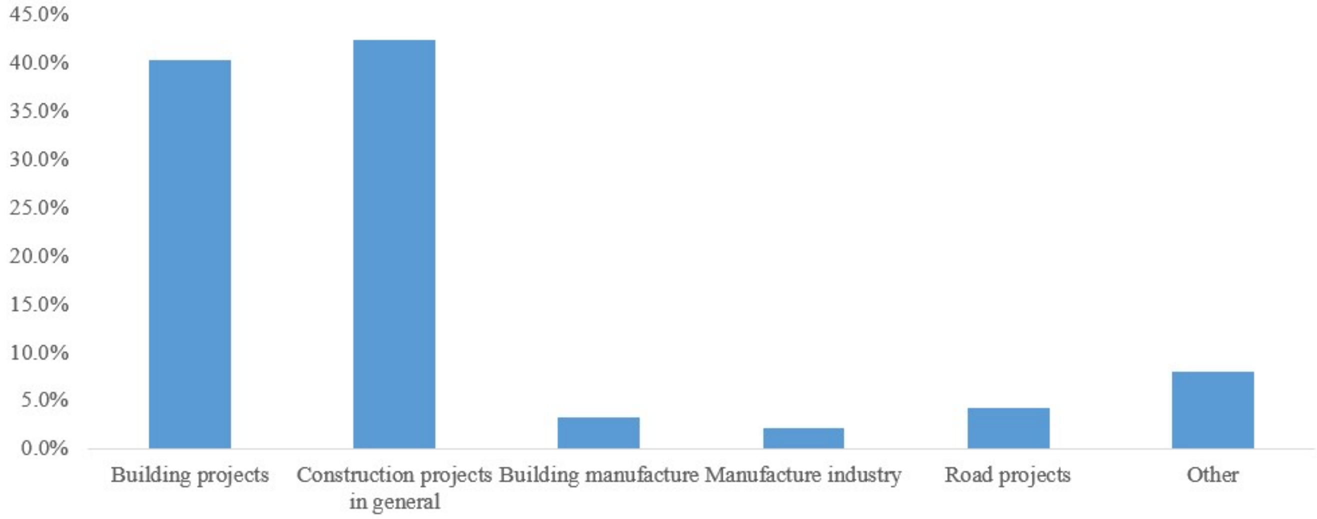


Figure 3- 12: Project sector analysis used Lean Construction (LC)

Table 3- 38: Studied lean tool analysis

Studied Lean tool	Studied Lean tool quantity	Studied Lean tool analysis	Note
Value Stream Mapping (VSM)	23	8.2%	Some project sectors are hidden
Last Planner system (LPS)	73	25.9%	
Lean tools in general	50	17.7%	
Integrated Project Delivery (IPD) system	26	9.2%	
Lean Six Sigma	7	2.5%	
Just In Time (JIT)	21	7.4%	
5S	18	6.4%	
Target Value Design (TVD)	12	4.3%	
Other	26	9.2%	For values equal or less than 2%
Total	**282**	**100.0%**	

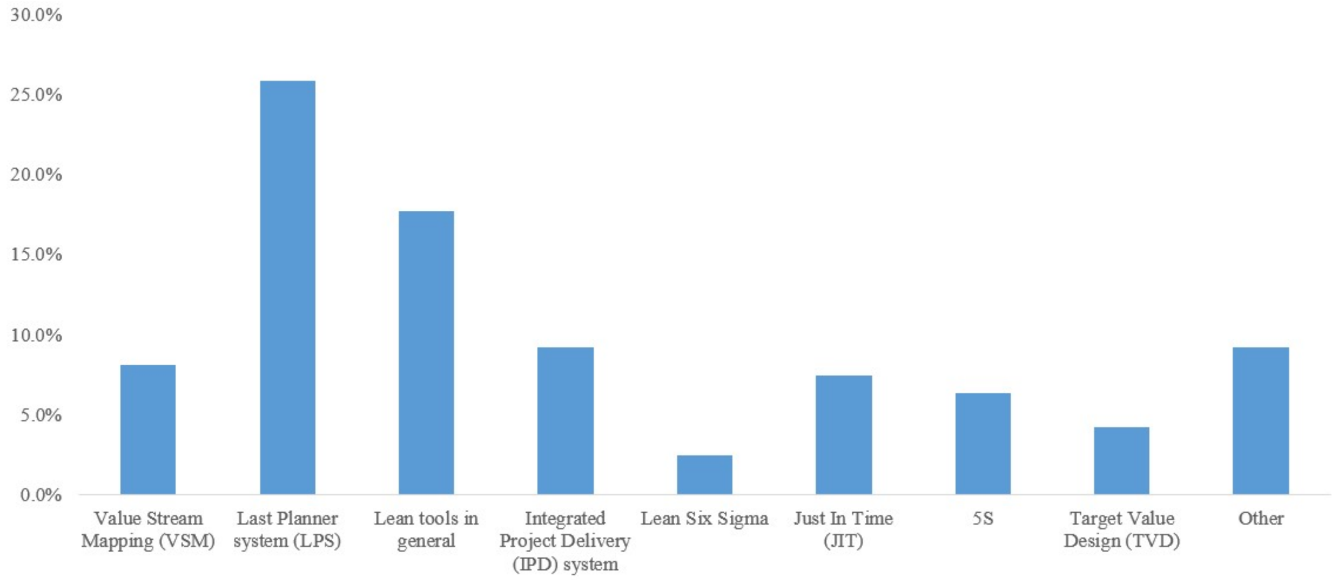


Figure 3- 13: Studied lean tool analysis

Table 3- 39: Methodology analysis used Lean Construction (LC)

Methodology	Methodology quantity	Methodology analysis
Site observation	53	15.8%
Analysing case study	96	28.7%
Survey	73	21.8%
Interviews	61	18.2%
State of the art	34	10.1%
Simulation game	3	0.9%
Simulation modelling	15	4.5%
Total	**335**	**100.0%**

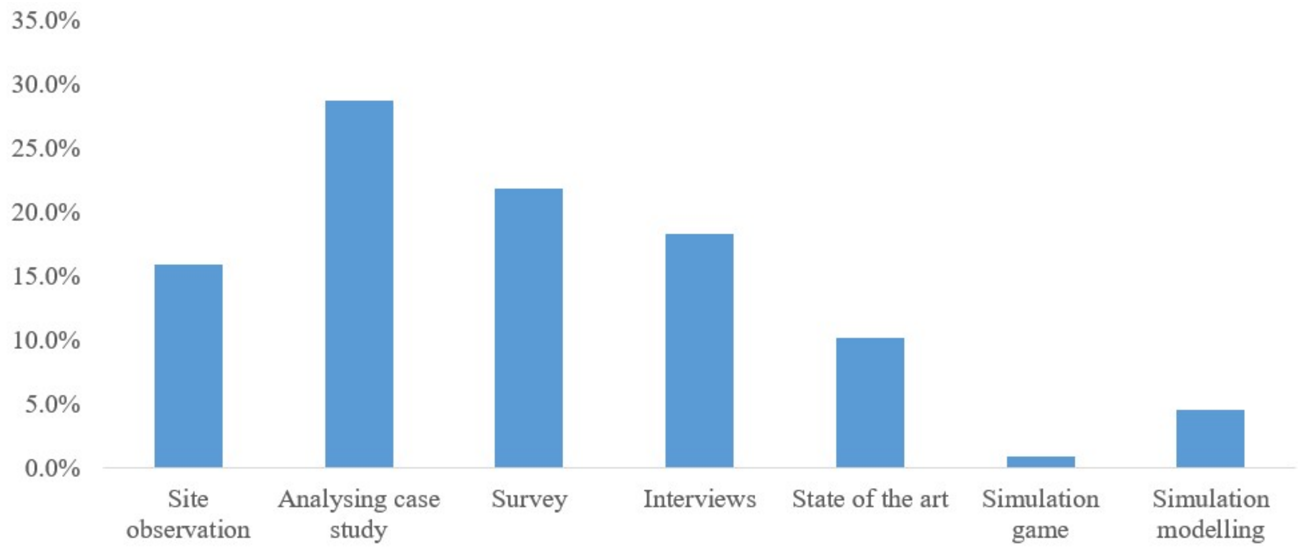


Figure 3- 14: Methodology analysis used Lean Construction (LC)

3.9 Application of Lean Construction on road project

Tables 3-40 to 3-42 summarize the studies related to Lean Construction on road and infrastructure projects. This summary is based on the country where each study is applied. The main reasons of the study are determined. The studied project sector, project type and the Lean Construction tool used are shown. Then the methodology used are listed. Finally, the results of the study are presented.

Table 3- 40: Information of Lean Construction (LC) studies on road and infrastructure projects

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
66	(Dave, 2013)	USA	Focus on applying Lean Construction and Building Information Modelling to have improvements in construction projects.	Road projects	Last Planner System (LPS)	Analysing case study, interviews, survey and applying simulation modelling.	It is concluded that the using any program with Lean Construction has a high improvement in the construction projects.
86	(Fakhimi, 2017)	USA	Determine the possibility of applying Integrated Project Delivery (IPD) system with of Lean Construction and Building Information Modelling (BIM). Identify the advantages and challenges of Integrated Project Delivery (IPD) system.	Infrastructure and building projects	Integrated Project Delivery (IPD) system	State of the art	No clear identification of the using of three tools, there are few studies on this concept. The advantages and challenges are determined, as one of the most advantages is increasing the productivity.
87	(Fullalove, 2013)	UK	Determine the achievements of highway projects in UK after applying Lean Construction.	Road projects	Lean tools in general	Analysing case studies	The identification of th projects' achievements are identified such as more wastes are determined and eliminated, increasing in the productivity and decreasing in the projects' costs.
104	(Hamdar, Kassem, Srour, & Chehab, 2015)	Lebanon	Determine the impact of applying Lean Construction in a road project.	Road projects	Lean tools in general	Site observation and analysing case study.	Improvements in road project by using Lean Construction such as decreasing in the project wastes, decreasing in the project's cost and improvemts in the quality.

Table 3- 41: Information of Lean Construction (LC) studies on road and infrastructure projects

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
111	(Heyl, 2015)	Germany	Explain the traditional approach situation and understand how to solve the seen problems (wastes). This is applied by implementing a simulation game.	Road projects	Lean tools in general	Game simulation	High improvements in the productivity is shown by eliminating the wastes.
127	(Issa, 2013)	Egypt	Apply Last Planner System to reduce the project's constraints and analyse two variables, Percent Plan Complete and the delays in the activities.	Tunnel projects	Last Planner system (LPS)	Site observation and analysing case study	By using the lean tool, the Percent Plan Complete increased while the variable of the delays in the activities is decreased. This is due to the elimination of the wastes from the studied project.
142	(Kawish, 2017)	USA	Determine the barriers of Lean Construction and identify how to overwhelm them in transportation projects.	Transportation projects	Lean tools in general	Survey	The barriers are identified and racnked. The most important barrier is the shortage in the training for the project's members. By increasing the training for the workers, this barrier's impact is reduced.
147	(Kivistö & Ohlsson, 2013)	Sweden	Determine the ways to correctly apply Lean Construction in infrastructure projects.	Transportation projects	Last Planner System (LPS)	Analysing case study, interviews and survey	It is determined that all lean principles can be adapted to infrastructure projects. The application of Last Planner System can be determined that has high improvements on the infrastructure projects.
211	(Onyango, 2016)	Sweden	Identify the integration between Lean concept and Building Information Modelling.	Road projects	Last Planner System (LPS) and Just In Time (JIT)	Survey and analysing case study	By using the two concepts together, there is high improvement in the stakeholders collaboration during the project's stages.
217	(Pasquire, Daniel, & Dickens, 2015)	UK	Identify the collaboration procedures in the road construction project.	Road projects	Last Planner System (LPS)	Survey, interviews, site observation and analysing case studies	The concept of collaboration in construction industry depends mainly on the Last Planner System. The study reconginzes that the lean tool is still not applied with details in the construction industry.

Table 3- 42: Information of Lean Construction (LC) studies on road and infrastructure projects

#	Study	Country	Aim	Project sector	Studied Lean tool	Methodology	Results
223	(Pettersen, 2017)	Norway	Determine the application of Lean Construction in Norwegian road and railroad projects.	Road and railroad projects	Lean Project Delivery System (LPDS), 5S, Last Planner System (LPS), Visual Management (VM) and Target Value Design (TVD)	Survey, interviews, site observation and analysing case studies	It is determined that the studies on the bulding projects are much more than the infrasture projects. It is also recognized that the application of Lean Construction has barriers to be applied on Norway due to the laws in public projects, regards the application of Lean Project Delivery Systems.
230	(Rodewohl, 2014)	Norway	Determine the situation of Norwegian infrastructure projects by using Lean Construction.	Roads, tunnels and bridges projects	Lean tools in general	Survey, analysing case studies, site observation and interviews	By using Lean Construction, the projects' stakeholders are more cocnerned on the wastes elimination and reducing the non-value adding activities.
275	(Tezel, Koskela, & Aziz, 2017)	UK	Determine the situation of Lean Construction in the United Kingdom's supply chain in the highway projects.	Road projects	Lean tools in general	Survey and interviews	This situation is determined and listed based on thirty one points.

3.9.1 Studies analysis

Tables 3-42 to 3-46 and Figures 3-15 to 3-18 show the analysis of the literature studies applying Lean Construction (LC) on road and infrastructure projects. Table 3-42 and Figure 3-15 show the analysis of these studies based on the country where these studies applied. The majority of this list relate to USA and UK (23.1% each). Table 3-43 and Figure 3-16 show the analysis of different project sectors. The majority is the application of Lean Construction in road projects (56.3%). Table 3-44 and Figure 3-17 show the analysis of Lean Construction tools. The majority is the application of Last Planner System (LPS) and the application of Lean Construction without specification of the exact lean tool used (33.3% each). Table 3-44 and Figure 3-18 show the application of the methodology in the studies. The majority of them is the application of analysing projects' data (29%).

Table 3- 43: Country analysis used Lean Construction (LC) on road and infrastructure projects

Country	Country quantity	Country analysis
USA	3	23.1%
UK	3	23.1%
Lebanon	1	7.7%
Germany	1	7.7%
Egypt	1	7.7%
Sweden	2	15.4%
Norway	2	15.4%
Total	**13**	**100.0%**

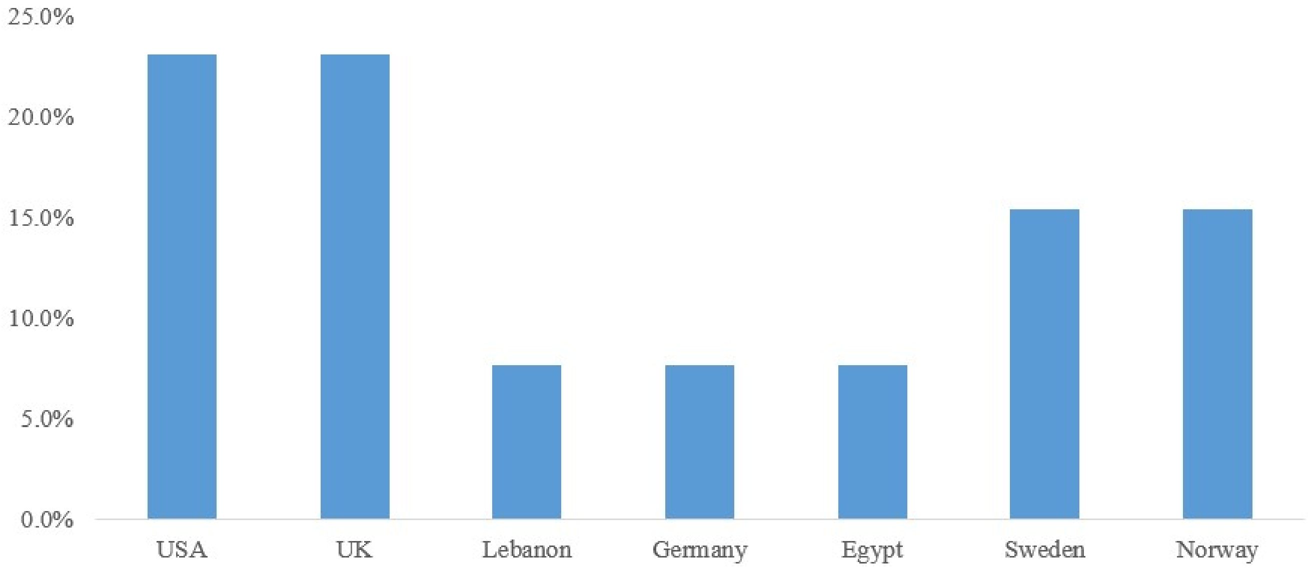


Figure 3- 15: Country analysis used Lean Construction (LC) on road and infrastructure projects

Table 3- 44: Project sector analysis used Lean Construction (LC) on road and infrastructure projects

Project sector	Project sector quantity	Project sector analysis
Road projects	9	56.3%
Infrastructure projects	1	6.3%
Tunnel projects	2	12.5%
Bridges projects	1	6.3%
Railroad projects	1	6.3%
Transportation projects	2	12.5%
Total	**16**	**100.0%**

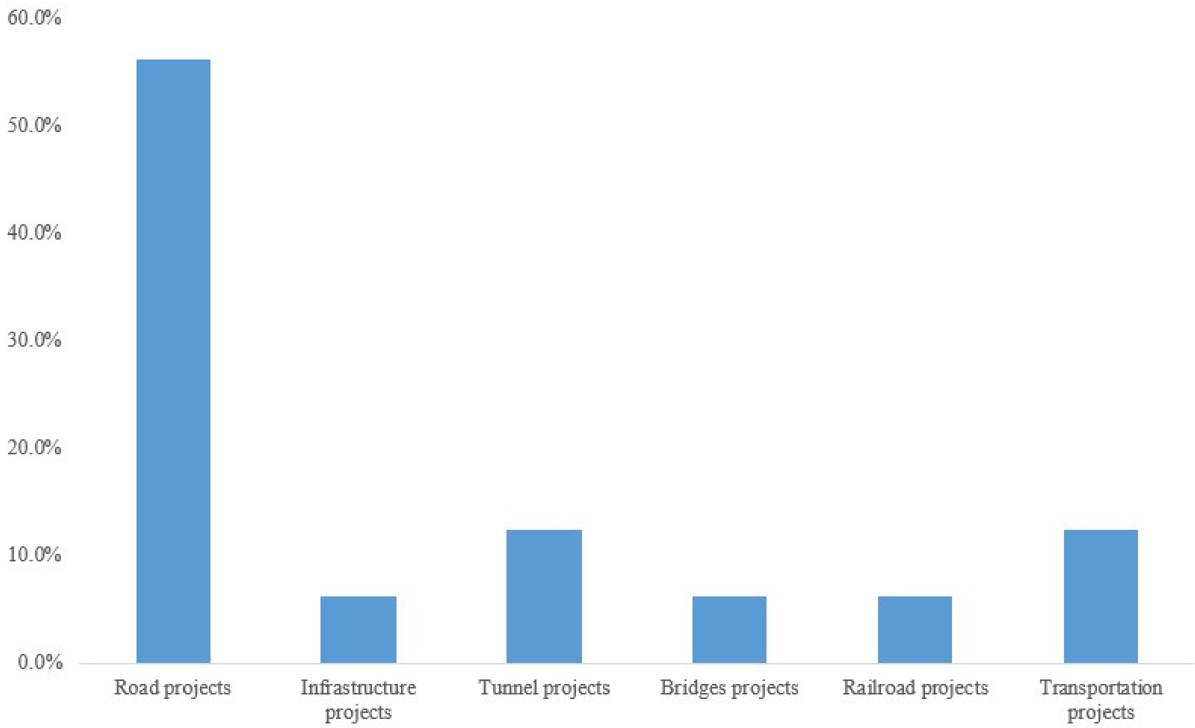


Figure 3- 16: Project sector analysis used Lean Construction (LC) on road and infrastructure projects

Table 3- 45: Lean tool analysis

Studied Lean tool	Studied Lean tools quantity	Studied Lean tools analysis
Last Planner System (LPS)	6	33.3%
Integrated Project Delivery (IPD) system	1	5.6%
Lean tools in general	6	33.3%
Just In Time (JIT)	1	5.6%
Lean Project Delivery System (LPDS)	1	5.6%
5S	1	5.6%
Visual Management (VM)	1	5.6%
Target Value Design (TVD)	1	5.6%
Total	**18**	**100.0%**

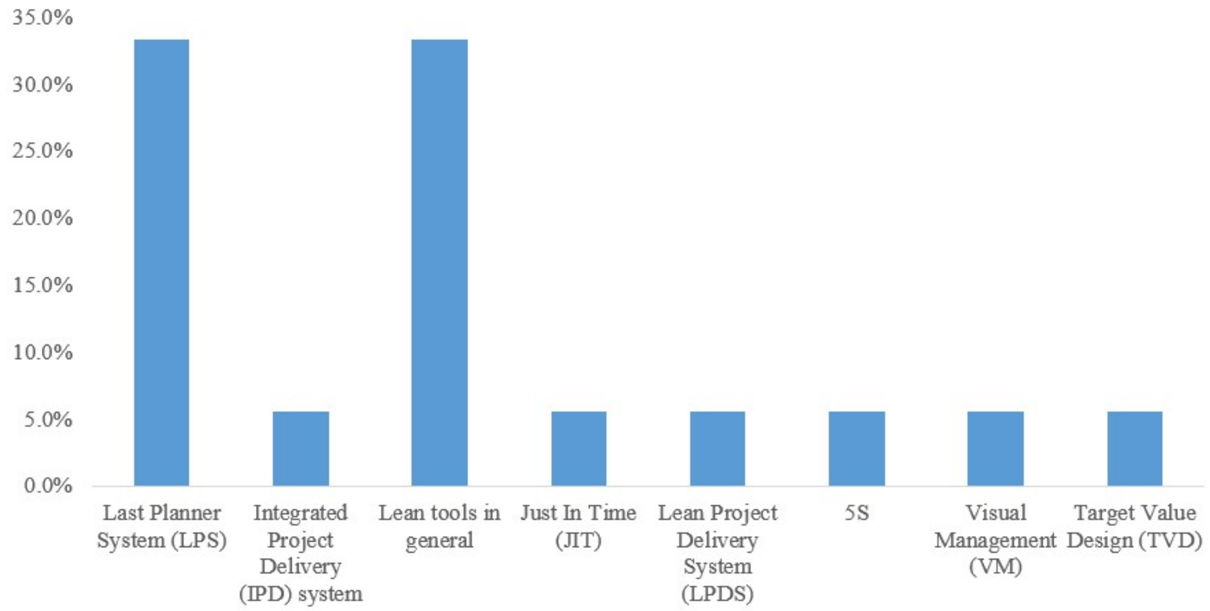


Figure 3- 17: Lean tool analysis

Table 3- 46: Methodology analysis used Lean Construction (LC)

Methodology	Methodology quantity	Methodology analysis
Site observation	5	16.1%
Interviews	6	19.4%
Analysing case study	9	29.0%
Survey	8	25.8%
Simulation modelling	1	3.2%
State of the art	1	3.2%
Game simulation	1	3.2%
Total	**31**	**100.0%**

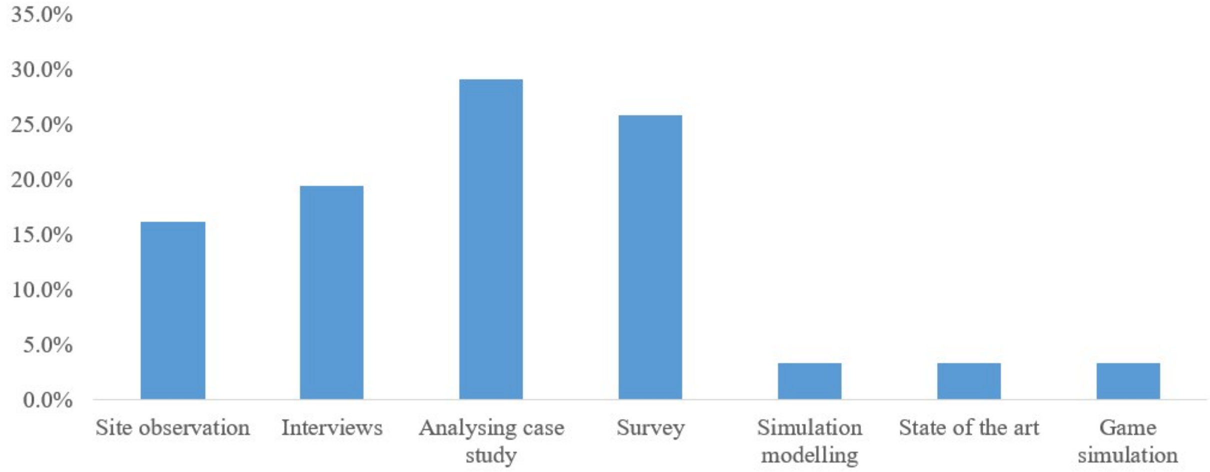


Figure 3- 18: Methodology analysis used Lean Construction (LC)

3.10 Conclusion

The invention of Lean Construction (LC) is essential because construction projects have been facing many problems. These problems eventually lead to an increase in the project's total cost and final duration, accompanied by a decrease in the quality and productivity of the project activities. Lean Construction (LC) targets to eliminate the project waste and deliver the maximum value to the customer with the best quality. This relatively new management concept requires the simultaneous use of Lean tools. Applying only one or two of these tools in the project means partial application of Lean Construction and may lead to the failure of the project. This means that if the specified Lean tools are applied to time related issues, the relevant Lean tools should be as well applied to all the other aspects of the project, that is, cost and quality. This study addresses the problem of exaggerated construction project duration while seeking to propose solutions that minimize the final duration and increase the productivity of road projects by implementing the relevant Lean tools.

If Project Management (PM) approach is considered as an eye studying the construction project from a high point, then Lean Construction (LC) is regarded as an advanced lens that provide a far more accurate perspective. As highlighted in the conclusion of the previous chapter on PM, there are three essential arguments focused on in this study; risk analysis, time management and stakeholders' collaboration. The PM approach does address the three issues in a project however still some problems persist to which solutions are provided through the LC approach tools. In the first argument related to risk analysis, PM does not address the root causes of risks in real life projects while LC targets identifying such causes to eliminate wastes or at least reduce their effects. In accordance, in the second argument related to time management, the Critical Path Method (CPM) under the PM uses buffers to address potential risks (time delays), while again LC addresses the roots of the problem through its LPS tool eliminating wastes. Finally, in the third argument related to stakeholders' collaboration, under the PM approach there is a clear lack of collaboration, while the LC approach shows keenness on involving stakeholders from the early stages of the project.

These arguments are further explicated in the empirical part of the study through the case study observed through a real life project. The methodology utilized, that is the simulation, and more details about the case study are demonstrated in the next chapter.

CHAPTER 4 CASE STUDY

4.1 Introduction

The main purpose of this chapter is to explain the case study used in this research and the application of the simulation used. Accordingly, the chapter begins by explaining and defining the studied road project; its location and characteristics. This is followed by delving into the project's activities and sub-activities as observed and based on the data collected from the site. In addition to that, the obstacles noted during the site visits are demonstrated acting as the foundation based on which the different wastes are defined.

The simulation used in this study was done by Simio Simulation; a software used as a mean to estimate the time durations. The different applications of this simulation are explained. The main target of developing such applications is to conduct a comparative analysis between using the PM and LC approaches in road projects with a special focus on eliminating time related wastes. This analysis is elaborated in the next chapter; this chapter is dedicated to explicating the fieldwork and methodology of the study.

4.2 Project definition

During the period from 16th of July until 15th of August 2016, the PhD candidate studied a highway project in Egypt -Dahshour's Connection Highway- aiming at measuring the real site ratios. It is located in a new city in Cairo called 6th of October city. It can be seen as a connection between the centre of the city and the beginning of the main highway of Alexandria (another governorate regarded as the second capital of Egypt). The length of the project is 12812 m in each of the two directions as shown in Figures 4-1 and 4-2. The project planners, before execution, plan the estimated duration for each activity. Based on this estimation, the project duration is 56 weeks as shown in Figure 4-3. The main contractor is one of the biggest public companies in Egypt called Arab Contractors. This road has existed for many years; the main target of this project is to substitute the old one with a new road besides broadening the width of each of its two directions and the total width of the road is/will be? 17m.

Accordingly, the main purpose of the conducted field observation, which occurred through regular visits to the site, was to explore the application of the Project Management (PM) approach in reality. Through such observation, the occurring and potential weaknesses were taken into account, in order to emphasize and investigate the degree of importance of Lean Construction (LC) in highway projects.

The estimated total cost of this project is about 9,700,000 Euro. Around 7,500,000 Euro is dedicated to excavations, aggregate surfaces and paving surfaces, the remaining amount, 2,200,000 Euro, is divided between pavement and landscaping. The estimated total duration of the project is eighteen months (from October 2015 to April 2017) according to data gathered from engineers from the technical office. This data is presented in GANTT chart in excel sheet Figure 4-3. This estimation was taken place by using the duration estimation tools as explained in PM chapter. The most important details of the case study are presented below, which were obtained by the PhD candidate and the main areas investigated.

Accordingly, the main target is to provide details on the case study by responding to questions such as; What are the project's main activities? How do the engineers on site implement the shop-drawings as shown in Figure 1? What were the machines used? Why were these machines used in the project?

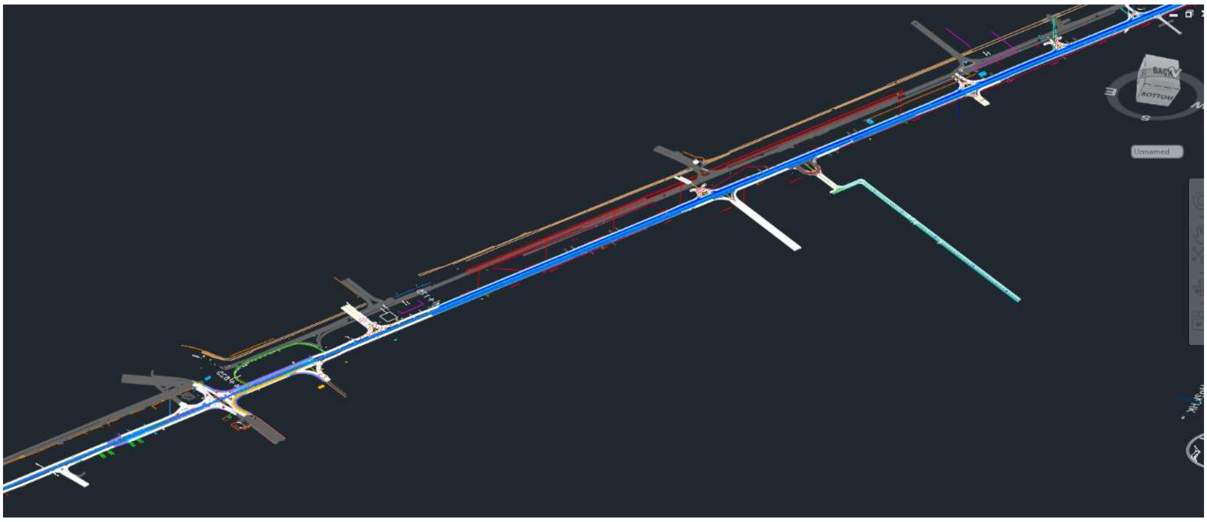


Figure 4- 1: Layout of the project

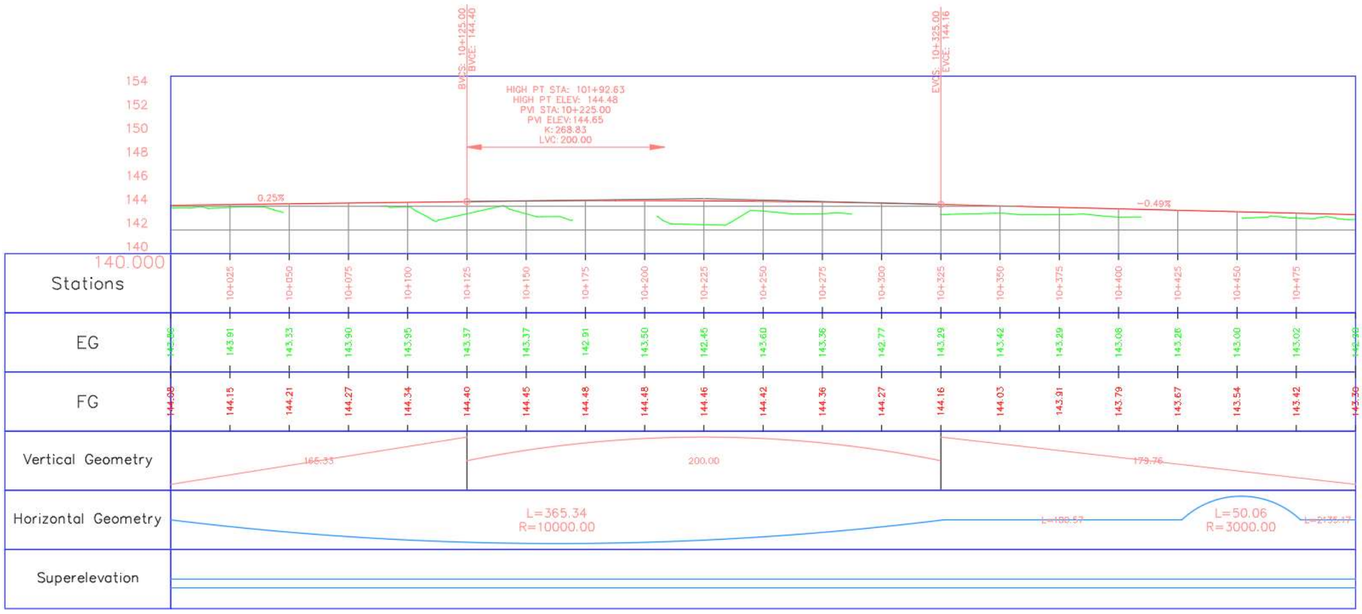


Figure 4- 2: Elevation sheet for 10.225 km

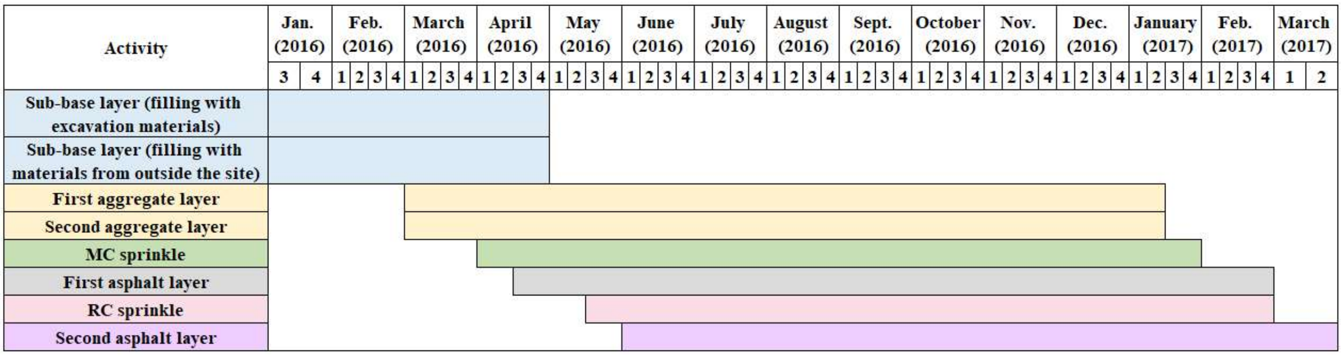


Figure 4- 3: GANTT diagram (site data)

The traffic is moving as usual on the old road during construction (the extended part that is supposed to increase the width of the road). After paving the 1st layer of asphalt, they wait for 24 hours before starting the normal traffic movement on it, and then the new extension substitutes the old road for traffic movement to give engineers and labour the opportunity to close the old one. The removal is justified by the fact that the preceding road is cracked (as shown in Figure 4-4) and they want to increase the quality of the project as a whole; taking into consideration that there are many trucks driving on it daily.

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 only one day off on Saturdays.

Figure 4- 4: Cracks of the old road

4.3 Field observation and data gathering

In the following sections, the main activities of the project are demonstrated: the sequence of execution, the definition of each activity and the equipment used for each. The main purpose of displaying this is to provide detailed information about the real life activities and sub-activities of the project, based on which the simulation used in this study is modeled. Through presenting the main findings of the field observation, the main obstacles faced during execution are put forward. These obstacles are used in the simulation as the wastes encountered in a real life project. In addition to observing the site activities, further information about the project planning and execution was gathered through documents provided by the engineers working under the contractor and through verbal communication with them. Such information has been necessary in order to have the data about each sub-activity through the oral communication with engineers, and through documents such as the shop-drawings and the time schedule of the project.

4.3.1 Main activities of the project

According to the oral communication with engineers and based on the field observation, this project is divided into the following activities:

i. Sub-base layer works

Concerning the old road, the cracked asphalt layer, as previously explained, is first removed. The remaining thin layer of asphalt is then removed by the loader. The sub-base layer of the old road is used as a foundation for construction in this part of the road.

For the new extension, they start with the excavation, then they put the aggregate for the sub-base layer with a thickness of 15cm for each of the four layers; by extending and compacting each layer. After putting the sub-base layer of the new extension, the activities are merged in both parts of the project (the old road and the new extension).

ii. 1st aggregate layer works

From this stage, both the thickness and the material of layers will be the same for the old and the new extension. The same aggregate material will be used for this layer; providing a thickness of 35cm with a total width of the road of 17m.

iii. 2nd aggregate layer works

After the previous activity the consultant inspects the levelling of the surface; if the inspection is approved, the 2nd aggregate layer begins with a thickness of 15cm for the whole width (17m) of the road. These activities (sub-base, 1st aggregate layer and 2nd aggregate layer) are important because they increase the density of the aggregate and decrease the air voids within the soil. This increases the compaction of layers resulting in better quality.

After the 2nd aggregate layer, the floor is sprinkled with a material called MC (referring to Medium Curing). This material is composed of betomine (50%) and fuel gas (50%). On the one hand, Betomine is used to prevent the ground water from transferring to the surface of the road. On the other hand, gas is used to dilute it to make it a fluid so it can be placed easily.

iv. 1st Asphalt layer works

The asphalt layers begin one day after MC sprinkling by 1st asphalt layer 7cm thick. Then another material called RC (referring to Rapid Curing) is sprinkled on top of the asphalt layer. This material has the same components as MC but with different percentage; RC consists of betomine (90%) and fuel gas (10%). For this composition with very high percentage, betomine is to work as an adhesive between the two asphalt layers.

v. 2nd Asphalt layer works

Normally, the 2nd asphalt layer activity begins after the RC sprinkle activity. It is important to note that this activity had not begun during the observation period (which ended on August 15th as previously mentioned). In addition, during the visit on site only the main activities (main activities are all the previously explained activities except MC and RC activities) were studied. The other activities (such as the removal of the old asphalt layers, MC and RC composition) were not studied as they were done after the working hours, during late night shifts.

4.3.2 Equipment information

This section focuses on the machinery used to implement the project activities and sub-activities. It is essential to note that this type of infrastructure projects depends mainly on the equipment and not on skilled (or non-skilled) labours as in the case of other kinds of projects (such as building or bridge projects). For this reason, it is necessary to demonstrate in details the different types of machines used for different purposes as shown in Figure 4-5.

Figure 4- 5: Road project machines: (a) Grader, (b) Water sprinkler, (c) Paving finisher and (d) Double Drum Roller

Secondly, Figure 4-6 shows the grader; the use of this machinery is similar to the next three machines in its usage, as all of them are used for the three following activities (sub-base, 1st aggregate layer and 2nd aggregate layer). The grader is used to spread the aggregate on the surface of the ground after the truck piles them in a mass on the ground.


Figure 4- 6: Grader

Thirdly, the water sprinkler shown in Figure 4-7. This machine worked on the three following activities (sub-base, 1st aggregate layer and 2nd aggregate layer). During the visit on site, the highest temperatures (up to 45 ºC) of the year were reached in Cairo: This high temperature, made the water sprinkler play an important role to assure adequate humidity in the ground. The importance of using water sprinkler during roads construction is to decrease the air voids in the soil by increasing the humidity of the soil. This leads to strongly compacted layers and hence better quality.

Figure 4- 7: Water sprinkle

Figure 4-8 shows the single drum rollers, which are used to compact the aggregate surface and to vibrate the soil. This task decrease the air voids in the soil, especially after water sprinkle, the soil becomes well compacted.

Figure 4- 8: Single drum rollers

Figure 4-9 shows the equipment used to sprinkle the two different materials (MC and RC). MC is sprinkled after 2nd aggregate layer while RC is sprinkled after 1st asphalt layer.

Figure 4- 9: MC & RC sprinkle machine

Figure 4-10 presents the paving finisher, which was used in two activities (1st and 2nd asphalt layers). At the beginning, the truck drops down the asphalt on the paving finisher as shown in the figure. For better quality, ideally, the asphalt's temperature on the truck should be as high as 135 ºC and after dropping down the material the temperature should be around 125 ºC.

Figure 4- 10: Paving finisher

Figure 4-11 shows the double drum rollers. This machine is used also in two activities (1st and 2nd asphalt layers) and compacts the asphalt without vibrating it.

Figure 4- 11: Double drum rollers

Table 4-1 shows the utilization of the machinery. In addition, Table 2 shows the used equipment of each sub-activity as observed on site

Table 4- 1: Equipment used and their utilization

#	Name	Utilizations	Equipment quantity
1.	Grader	Spread the aggregate on the surface of the floor.	Many
2.	Water sprinkle	Sprinkle the water on the working section.	Many
3.	Single drum rollers	Compact the aggregate surface and vibrating the soil.	Many
4.	MC & RC sprinkle machine	Sprinkle MC and RC on the working section.	1
5.	Paving finisher	Used to pave the road by asphalt.	1
6.	Double drum rollers	Compact the asphalt to the required level.	Many

Table 4- 2: 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

4.3.3 Obstacles on site and recommendations

The PM approach has been used in the construction field since the beginning of the industry. Accordingly, it is an easy to follow approach since the majority of engineers and workers are already familiar with its techniques and steps. When it comes to time planning one of the most important advantages of the PM approach is its tools that allow for time and risk planning; anticipating risks is one of its strength points. Despite so, as previously discussed there are problems that emerge while using this approach, which calls for an innovative solution; such as that provided through LC approach as argued. As highlighted, the researcher conducted the field observation with the main purpose of studying how the PM approach is applied in road projects in real life. Accordingly, demonstrating the weaknesses and obstacles that negatively affected the productivity in this project is the focus of this section. As previously mentioned, these obstacles are defined as wastes in the simulation modelling used in this study.

To collect information about the duration of the sub-activities, site observations were done for 30 days, four hours every day (six days a week). Each sub-activity under each activity was observed and its duration measured manually. 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. Value Adding (VA) activities are the activities that add value to the project. This mainly refers to all the activities on the project necessary to reach the aspired final product [188], [164], [189], [190]. The speed of each machine was determined based on the observation while calculating the duration to finish the sub-activity work in a 200 meter road section with the different machines. In case of the Non-Value Adding (NVA) activities, three durations (minimum, maximum and average) were also observed during the manoeuvring of the machine. Non-Value Adding (NVA) activities are the activities that do not add value to the project, but they should be reduced as they are considered wastes [188], [164], [189], [190]. From the VA and NVA activities duration, the total durations were calculated for each sub-activity. The wasted time was not included in the time durations calculated.

The first observed waste, W1 refers to the fact that working on the activity was finished but the following activity could not start right after. The reason goes back to the delay in inspecting the finished activities reflecting high dependency on the inspector’s comments, which affect the flow of work. Hence, this waste mainly refers to the time unnecessarily wasted during the inspection of an activity. For example, in several cases, after finishing one activity the work process stopped while waiting for the consultant to inspect the finished activity. During the site observation, this situation was detected and the consultant did not show up that day which led to the following activity being postponed till the next day after inspection. Figure 4-12 shows an example of delayed work; in this figure the machinery 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 or improving the coordination with the inspector.

Figure 4- 12: Waiting for inspecting the finished activity

The second observed waste, W2, refers to the machinery (DDR or Paving Finisher) was waiting the asphalt trucks arriving late. The problems behind the occurrence of this waste could be resolved using the Just In Time (JIT) concept, as demonstrated in Figure 4-13, where the paving finisher is shown waiting for the asphalt trucks arriving late. JIT concept is a tool mainly used to apply the pull principle; it is responsible for ensuring having the data, tasks or orders exactly when needed [192], [164], [157], [215]. The perfect occurrence is to deliver the material exactly on time, neither late nor early.

The third waste, W3, refers to the machinery having shortage of its fuel gas wasting time for it; due to lack of maintenance. However, by applying maintenance and repair this problem can be eliminated. Despite the fact that maintenance and running out of gas are two different issues, both fall under the responsibility of the technical department and hence can be grouped into one category.

The fourth waste, W4, refers to the transportation of the aggregate to the working area, for a distance farther than 5Km. This waste mainly refers to the long distance between the loading and unloading areas. The time duration of this waste is calculated per meter; minutes wasted per meter.

Figure 4- 13: Paving finisher waiting the asphalt trucks

The fifth waste, W5, which refers to the machinery stopped for mechanical problems. This waste is similar to W3 because they occurred due to lack of maintenance and repair, as shown in Figure 4-14. In this figure, the grader had mechanical problems and the mechanic had to work to solve these problems. If there were application of Total Productive Maintenance (TPM) by continuous maintenance of machines, the machines improve their efficiency and put them to use according to their maximum potential. This occurs by enabling operators to maintain their machines [146], [8], [173], [234], [169].

The sixth waste, W6, refers to double drum rollers running out of water as shown in Figure 4-15. Double drum rollers, used to mash the surface of asphalt layers, need water on the drum during rolling to facilitate the mashing process. The problem that the machinery ran out of water was identified in the middle of the work activity and the water sprinkler needed to be used to refill it. The mechanical maintenance department should regularly check on the water in the double drum rollers to prevent this waste of time and cost.

Figure 4- 14: Waiting for mechanical problems

Figure 4- 15: Double drum rollers filling with water

The seventh waste, W7, refers to the paving finisher having to make two trips to pave the road with asphalt because of the width of the road. 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. The time wasted during the two trips contributes to the overall delay in activities.

The eighth waste, W8, refers to the asphalt truck waiting until the paving finisher pave the dropped down asphalt on it. 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. The time duration of this waste is calculated per meter; minutes wasted per meter. Table 4-3 shows the explanation of the previously explained eight wastes observed on the site visits.

Table 4- 3: Wastes Explanations

Waste #	Explanations
W1	The working on the activity was finished but could not start the following activity (dependencies or waiting the consultant's comments) because the consultant should inspect the finished one first.
W2	Machinery (DDR or Paving Finisher) was waiting the asphalt trucks arriving late.
W3	The machinery had shortage of its gas these wasting time for it.
W4 (Per meter)	Transport the aggregate to the working area. For distance more than 5Km far.
W5	The equipment stopped for mechanical problems.
W6	Double drum rollers ran out of water.
W7	Paving finisher was having to make two trips to pave the road with asphalt as a result of the width of the road.
W8 (Per meter)	The asphalt truck was waiting till the paving finisher pave the dropped down asphalt on it.

4.4 Simulations explanation

This section shows the explanation of the implementation of three simulations similar to the observed conditions in the real life project. The used assumptions in these simulations are demonstrated through the definition of different equations. The process of wastes elimination is defined and the inputs of time durations, for sub-activities and wastes, are demonstrated.

The simulation was carried out by using the software Simio. This software is used to simulate any example based on the input inserted. One of its most important advantages is that it ensures accuracy of results by allowing a high number of replications; for example the researcher made 600 replications. It is a studying version, 10th edition. The target of applying this simulation is to analyse the use of Project Management (PM) approach and Lean Construction (LC) in road construction projects. In order to make it as close as possible to real life projects, the data collected from the case study and the findings of the conducted field observation are used as input according to which the PM simulation is modelled. As aforementioned, the date collected from the road project studied include obstacles which are treated as wastes in this simulation. The same simulation is modelled then to apply Last Planner System tool with the intent to compare the application of Lean Construction to PM in the same project. It is important to note that two PM simulations and one LC simulation are modelled as explained in more details below. Figure 4-16 is an illustration of the simulation software.

The comparative analysis developed through the three simulations explained below aims at highlighting how the application of LC in road projects leads to better results in terms of productivity and efficiency of accomplishing the project's activities through efficient time management. The time durations, for each; the sub-activities and the wastes, are defined by random triangular functions based on observed information (different deviation of the mean values +-20%, +-10%, +-5% and 0%).

- Simulation PM-EW, refers to Project Management with Expected Wastes: Inserting the maximum number assumed wastes for each sub-activity (theoretical assumption).
- Simulation PM-OW, refers to Project Management with Observed Wastes: In this analysis, only the wastes observed on site are considered.
- Simulation LC, refers to Lean Construction: The same assumptions in the previous simulation are considered. As in the PM-OW simulation, only the wastes observed on site are considered. The main difference with the preceding simulation is the application of the concept Last Planner System.

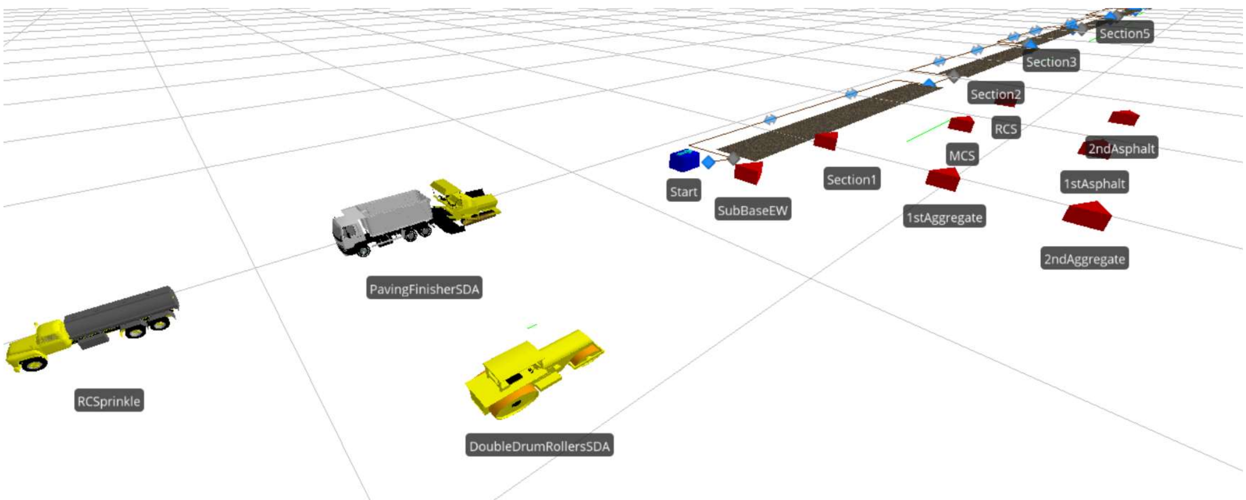


Figure 4- 16: Simio software

The next section introduces the processes done on the simulation to obtain the results. First, the assumptions are demonstrated; introducing general and specific assumptions for each of the three simulations. Second, the equations developed are demonstrated and explained. Then, the input data for every simulation is listed.

4.5 Assumptions:

The general assumptions of the three simulations (PM-EW, PM-OW and LC) are shown in Table 4-4. The studied road project in the simulations is divided into sections similar to the real life. Each section is 200 meters length and the total number of these sections is sixty four sections. The previously mentioned activities and sub-activities are inserted in the three simulations. After finishing working on each sub-activity the following sub-activity starts by sequence. There is no overlapping between any two sub-activities. For every activity, the values of PPC and PAW are calculated. Each sub-activity needs one specific machinery to be executed. This applies to all except the sub-activities related to pouring asphalt, which need two machineries; paving finisher and asphalt truck. The time durations for each of the sub-activities and the wastes are data collected during the site visits. The wastes are inserted in the simulations as delayed times; including wastes occurring during and/or after the execution of the sub-activities

Table 4-5 shows the difference between PM simulations, PM-EW and PM-OW, and LC simulation. The difference between them is only the application of Last Planner System (LPS). The time durations, for each the sub-activities and the wastes, is kept the same for the three simulations.

Table 4- 4: General assumptions for all simulations

#	**General assumptions**
1.	The road will be divided into sections (each section has the same length, 200 meter 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 PAW
6.	Every group of machinery has the same characteristics (e.g.: speed, working time, capacity, total working time).
7.	Every machinery will work in each one sub-activity (except putting asphalt layers, which needs paving finisher and a truck to work together).
8.	Triangular random expressions.
9.	The values of the total time and wastes time are obtained from observation.
10.	The wastes are simulated as delayed times among activities.
11.	No overlapping between any two sub-activities.

Table 4- 5: Specific assumptions for each simulation

#	Specific assumptions
	• **For PM-EW and PM-OW simulations**
1.	PM-EW and PM-OW simulations are considered with no application of Last Planner System (LPS) concept.
	• **For LC simulation**
1.	To apply Lean Construction ONLY the below mentioned waste will be removed. The total time for all the sub-activities will be kept as same as in PM-EW and PM-OW simulations.

4.6 Definition of parameters:

Having presented the assumptions, which represent part of the input inserted to the simulations. It is crucial to explicate the parameters and their equations. Hence, this section is a demonstration of how the three simulations were implemented. Besides explaining the parameters and equations used, a sample of how the simulations work is given through displaying one of the activities as an example.

Equation 1 is used for measuring the activity's productivity on site. While equations 2 and 3 are related to a new variable named Percentage Plan Complete (PPC) and Percentage Activity Waste (PAW), which are considered as outputs from the simulation for each activity. PPC is related to the efficiency of each activity on the project. While PAW is related to the identification of the percentage of the waste in each activity. Equation 4 is related to the process efficiency for each waste observed in the site visit. Process efficiency is used to differentiate between the wastes due to its times of occurrence. For illustrative purposes, an example for the calculation of the activity's productivity applied on the 2nd Aggregate layer is presented below:

Equation 2:

$$Productivity\ of\ activity\ I\ per\ week\ (As\ observed)\ in\ Simio\ simulateon\ \left[\frac{m2}{week}\right] = \left(\frac{Total\ quantity\ of\ activity\ I\ [m2]}{\frac{Total\ Time\ for\ activity\ I\ [hour]\#}{Number\ used\ in\ the\ activity\ I} + Total\ waste\ time\ in\ activity\ I\ [hours]\# * Process\ efficiency\ (PE)}\right) * 7\frac{hours}{day} * 6\frac{days}{week}$$

\# Random values with triangular distribution

Equation *3*: PPC% =

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

Equation 4: $PAW\% = \frac{\text{Waste time ONLY during an activity} * 100}{\text{Total time of an activity WITHOUT WASTE TIME}}$

Equation 5: $\text{Process efficiency} = \frac{\text{Time of a waste observed}}{\text{Maximum occurrence of the waste}}$

- **Example of application on 2nd Aggregate layer:**

- Analysed activities: ONLY the 2nd Aggregate layer. Total quantity= 120,000 m^2
- Analysed road project: 64 sections of 200ml
- Thickness per layer = 15cm
- Width per layer = 17m
- Total duration of sub base layer activity: 42 weeks (project data)
  - **Productivity for 2nd Aggregate layer as scheduled from the project information for all simulations (PM-EW, PM-OW and LC):**

Productivity per week (As scheduled from the project information) = $\frac{120{,}000}{42} = 2{,}857.14\ m2/week$

  - **Productivity for 2nd Aggregate layer as observed in site visiting for simulation PM-OW:**

Process efficiency (PE) for W1 = $\frac{35}{39} * 100$ = 89.74%

Process efficiency (PE) for W4 = $\frac{11}{11} * 100 = 100.00\%$

Process efficiency (PE) for W5 = $\frac{11}{39} * 100$ = 28.21%

Duration for unloading 2nd Aggregate layer per section (in hours) = Random triangular values (1.821, 3.125, 4.875) OVER number of machines used

W4 during the unloading (in hours) = Random triangular values (15.150, 27.188, 43.200)

W4 is per meter the random triangular values multiply by $\frac{120{,}000}{64} = 1{,}875\ m2/section$

W4 multiplies by its process efficiency (PE), which is 100%

Total duration for unloading 2nd Aggregate layer (in hours) = Summations of the duration values for the 64 sections

Duration for levelling 2^{nd} Aggregate layer per section (in hours) = Random triangular values (0.650, 1.172, 1.875) OVER number of machines used

W5 during the levelling (in hours) = Random triangular values (0.293, 0.367, 0.440)

W5 multiplies by its process efficiency (PE), which is 28.21%

W1 after the levelling (in hours) = Random triangular values (0.347, 3.575, 8.060)

W1 multiplies by its process efficiency (PE), which is 89.74%

Total duration for levelling 2^{nd} Aggregate layer (in hours) = Summations of the duration values for the 64 sections

Duration for water sprinkle 2^{nd} Aggregate layer per section (in hours) = Random triangular values (1.750, 2.875, 4.500) OVER number of machines used

W1 after the water sprinkle (in hours) = Random triangular values (0.347, 3.575, 8.060)

W1 multiplies by its process efficiency (PE), which is 89.74%

Total duration for water sprinkle 2^{nd} Aggregate layer (in hours) = Summations of the duration values for the 64 sections

Duration for compact 2^{nd} Aggregate layer per section (in hours) = Random triangular values (2.375, 3.750, 5.625) OVER number of machines used

W1 after the compact (in hours) = Random triangular values (0.347, 3.575, 8.060)

W1 multiplies by its process efficiency (PE), which is 89.74%

Total duration for compact 2^{nd} Aggregate layer (in hours) = Summations of the duration values for the 64 sections

Total duration for 2^{nd} Aggregate layer for all sections (in hours) = Summations of the total duration values (with the wastes duration values) of all the sub-activities for the 64 sections

Productivity for 2nd Aggregate layer as observed in site visiting for simulation PM-OW as in equation 1 (per week) =

$$\frac{\text{Total quantity for 2nd Aggregate layer}}{\text{Total duration for 2nd Aggregate layer for all sections with wastes duration}} * 7 * 6$$

PPC for 2nd Aggregate layer as in equation 2 (per week) =

$$\frac{\text{Productivity for 2nd Aggregate layer as observed in site visiting for simulation PM}-\text{OW}}{\text{Productivity for 2nd Aggregate layer as scheduled from the project information}} * 100$$

PAW for 2nd Aggregate layer as in equation 3 =

$$\frac{\text{W4}*\text{W4 PE} + \text{W5}*\text{W5 PE}+\text{W} \quad *\text{W1 PE}+ \qquad *\text{W1 PE}+\text{W} \quad *\text{W1 PE}}{\text{Duration for unloading} + \text{duration for levelling} + \text{duration for water sprinkle} + \text{duration for compact}} * 100$$

4.7 Simulations input data

The studied road project is divided into some categories as shown in Table 4-6. The whole project is identified as *Mountain*, which refers to something bulky or huge. This category is broken-down to sections from the first to the sixty-fourth section; referring to the total number of sections in the real life project. The sections are identified as *Boulders*. These sections are broken-down further into project activities, which is referred to as *Rocks*. The project activities are broken-down more into the smallest category – sub-activities, which is identified as *Pebbles*. Some scholars [119] illustrate dividing projects in this manner into the mentioned categories. Table 4-7 shows the wastes observed during the site visits and the maximum occurrence.

Table 4- 6: Breakdown of the studied road project

Mountain (Whole project)	**Boulders (For the two directions of the road)**	**Rocks -m2-(Activities)**	**Pebbles (sub-activities)**
Road construction	1st section to 64th section	***For example:*** Sub-base (Filling with excavation material)	***For example:*** Unloading

Table 4- 7: Wastes occurrence during every sub-activity (Observed and Assumed)

Rocks (Activities)	Pebbles (sub-activities)	Resource	Pebbles wastes (As observed)								Pebbles wastes (Maximum occurrence)							
			W1	W2	W3	W4	W5	W6	W7	W8	W1	W2	W3	W4	W5	W6	W7	W8
Sub-base Layers	Unloading	Aggregate truck				X								X				
	Levelling	Grader	X				X				X		X		X			
	Sprinkle	Water sprinkle	X								X		X		X			
	Compact	Single drum roller	X								X		X		X			
1st and 2nd aggregate layer	Unloading	Aggregate truck				X								X				
	Levelling	Grader	X				X				X		X		X			
	Sprinkle	Water sprinkle	X								X		X		X			
	Compact	Single drum roller	X								X		X		X			
MC and RC	Sprinkle	MC sprinkle	X								X		X		X			
1st and 2nd asphalt	1st and 2nd asphalt layers	Asphalt truck		X	X				X	X	X	X	X		X		X	X
		Paving finisher																
	Compact	Double drum roller		X	X			X			X	X	X		X	X		

Table 4-8 shows the observed frequency of occurrence for each waste and the maximum number of occurrences. From this, data the percentage of occurrence of each waste was calculated. These percentages are multiplied by the wastes duration to get the actual duration time of each activity.

Table 4- 8: Wastes times observed and maximum occurrence percentage

Waste #	Time observed (As observed in the site visiting)	Maximum occurrence of the waste
W1	35	39
W2	4	4
W3	4	39
W4 (Per meter)	11	11
W5	11	39
W6	2	2
W7	2	2
W8 (Per meter)	2	2

4.8 Process for each waste elimination

Table 4-9 shows the eight wastes that have been observed during the site-visiting period and their similarities in previous studies. The seventh and eighth wastes could not be found in the analyzed previous studies, due to their specificity. Meaning, the seventh waste refers to the paving finisher making two trips to pave the road with asphalt due to the lack of compatibility between the width of the road and that of the paving finisher. The eighth waste refers to a time gap between the moment when the asphalt was dropped and the time needed by the paving finisher to pave it resulting from the driver's rush to drop the asphalt too early.

Table 4- 9: Wastes similarities on previous studies

Wastes	Waste similarities on literature	References
W1	Inspection delays	[146], [165], [147], [2], [152], [151], [190], [178], [187], [204], [181], [145], [186], [166]
W2 & W4	Transportation of materials	[146], [187], [186]
	Transport time	[147]
	Raw materials moving	[150]
	Waiting materials	[200]
	Lack of materials	[224], [189], [117], [262], [138], [193]
	Materials shortage	[145], [188], [257], [3], [298]
	Delay in material availability	[247], [160], [218]
	Transportation of materials	[190], [239]
	Moving of materials	[152]
	Materials not delivering	[6]
	Late delivery of material	[176], [170], [220], [148]
	Resources unavailability	[177], [229], [185]
	Delay in material supply	[55], [184]
W3, W5 & W6	Equipment breakdown	[146], [147], [172], [244], [230]
	Poor installation of equipment	[222]
	Failure of the machine	[8], [4]
	Machine breakdowns	[187], [176], [298]
	Unreliable equipment	[170]
	Equipment downtime	[177]
	Equipment failure	[186], [234], [247]
	Machine deterioration	[235]
W7 & W8	-	-

In the table below, Table 4-10, the tools used to eliminate the different types of wastes are demonstrated. Reaching the conclusion about which tool is best to use for each of the wastes is based on the reviewed literature also shown in Table 10. These tools are used to eliminate the wastes while at the same time applying the main tool; Last Planner System (LPS). By applying the principles of Last Planner System, which is mainly focusing on eliminating wastes before starting the required activity, the project efficiency improves. As shown, some wastes have been merged in the elimination process due to their similar nature that makes them fall under the same category.

As shown in Table 10, W1, referring to wastes as a result of inspection delays, which come as a consequence of the lack of collaboration between stakeholders. The tool used to eliminate this type of waste is Integrated Project Delivery (IPD), as previously explained in the Literature review. However, it is worth noting that a direct link between inspection delays and IPD could not be found in the reviewed literature. W2 and W4 were merged because fall under the category of material transportation related wastes, and accordingly could be addressed using the same tool – Just in Time (JIT). W3, W5 and W6 are all related to mechanical maintenance problems which result in machinery failure, and hence the same tool can be used to eliminate them – Total Productive maintenance (TPM). As previously explained, W7 and W8 are too specific and accordingly the researcher could not find the adequate tools to address them; they were also not mentioned in previous studies.

Table 4- 10: Wastes modified based on previous studies (By using Lean tools)

Wastes	Lean tool used from literature	References
W1	Integrated Project Delivery (IPD)	
W2 & W4	Just in Time (JIT)	[145],[186], [184], [160], [6], [146], [147], [176], [2], [220], [159], [177], [229], [241], [226], [293], [173], [272], [192], [157], [232], [139], [215]
W3, W5 & W6	Total Productive Maintenance (TPM)	[146], [147], [226], [169], [174]
W7 & W8	-	-

4.9 Duration Inputs

In this section, it is intended to deliver the picture of how a real life project activities work in sequence and where exactly the different types of wastes occur. As shown in the tables 11-29 below, the time average for each sub-activity and the wastes occurring in the middle of execution (or after) are demonstrated in sequence. This is applied for each of the three simulations as explained in section 4.3. The sections below are dedicated to explain the aforementioned inputs in the three simulations. In the first simulation, PM-EW, the maximum occurrence of wastes is displayed. In the second simulation, PM-OW, the observed wastes are shown. While in the third simulation, LC, the minimum wastes are demonstrated after applying Lean Construction tools as explained in the literature review. It is important to note that the upcoming sections show the inputs data inserted in each simulation, while the results of each simulation are demonstrated in details in the next chapter

4.9.1 Simulation PM-EW

Tables 4-11 to 4-18 show the time and wastes duration inserted as inputs in the simulation PM-EW. The wastes durations are inserted where they are expected to most likely occur; within the time duration of the activity. The inputs are based on the maximum occurrence times of wastes as explained in section 4.3.3. These durations are represented as random triangle distributions (ranging with a deviation from the mean value of +-20%, +-10%, +-5% and 0%). Some wastes are inserted during the sub-activities and others are inserted after the activities depending on where and when they occurred in the observed real life project. The reason why they are inserted this way is to assure that the simulation reproduces the observed reality on site. The total quantities of each activity are represented on these tables (the quantity unit is m^2). For example, W4, referring to time wasted during the transportation of the aggregate to the working area, was observed *during* the unloading sub-activity. On the other hand, W1, inspection delays, occurred *after* the levelling sub-activity in the observed site, and hence was placed in the same manner in the simulation.

Table 4- 11: Time and wastes duration Simulation PM-EW (Sub-base 1st and 2nd Layers filling with excavation material)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)-	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
sub-base 1st Layer (Filling with excavation material	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	W4 during Unloading		5.260	5.918	6.247	6.576	9.440	12.500	13.125	13.750	15.000
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
sub-base 2nd Layer (Filling with excavation material	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	W4 during Unloading		5.260	5.918	6.247	6.576	9.440	12.500	13.125	13.750	15.000
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 12: Time and wastes duration Simulation PM-EW (Sub-base 3rd and 4th Layers filling with excavation material)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)-	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
sub-base 3rd Layer (Filling with excavation material	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	W4 during Unloading		5.260	5.918	6.247	6.576	9.440	12.500	13.125	13.750	15.000
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
sub-base 4th Layer (Filling with excavation material	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	W4 during Unloading		5.260	5.918	6.247	6.576	9.440	12.500	13.125	13.750	15.000
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 13: Time and wastes duration Simulation PM-EW (Sub-base 1st and 2nd Layers filling with outside material)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)-	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
sub-base 1st Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	W4 during Unloading		1.578	1.775	1.874	1.973	2.832	3.750	3.938	4.125	4.500
	Levelling		0.068	0.076	0.080	0.085	0.122	0.163	0.171	0.179	0.195
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
sub-base 2nd Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	W4 during Unloading		1.578	1.775	1.874	1.973	2.832	3.750	3.938	4.125	4.500
	Levelling		0.182	0.205	0.216	0.228	0.122	0.163	0.171	0.179	0.195
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 14: Time and wastes duration Simulation PM-EW (Sub-base 3rd and 4th Layers filling with outside material)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)-	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
sub-base 3rd Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	W4 during Unloading		1.578	1.775	1.874	1.973	2.832	3.750	3.938	4.125	4.500
	Levelling		0.068	0.076	0.080	0.085	0.122	0.163	0.171	0.179	0.195
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
sub-base 4th Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	W4 during Unloading		1.578	1.775	1.874	1.973	2.832	3.750	3.938	4.125	4.500
	Levelling		0.068	0.076	0.080	0.085	0.122	0.163	0.171	0.179	0.195
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 15: Time and wastes duration Simulation PM-EW (1st Aggregate for the two Layers)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)-	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
1st aggregate 1st Layer	Unloading	1,328.125 m2	1.290	1.451	1.532	1.613	2.214	2.878	3.021	3.165	3.453
	W4 during Unloading		10.731	12.073	12.743	13.414	19.258	25.500	26.775	28.050	30.600
	Levelling		0.460	0.518	0.547	0.576	0.830	1.107	1.162	1.217	1.328
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		1.240	1.395	1.472	1.549	2.036	2.656	2.789	2.922	3.188
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		1.682	1.893	1.998	2.103	2.656	3.320	3.486	3.652	3.984
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
1st aggregate 2nd Layer	Unloading	1,328.125 m2	1.290	1.451	1.532	1.613	2.214	2.878	3.021	3.165	3.453
	W4 during Unloading		10.731	12.073	12.743	13.414	19.258	25.500	26.775	28.050	30.600
	Levelling		0.460	0.518	0.547	0.576	0.830	1.107	1.162	1.217	1.328
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		1.240	1.395	1.472	1.549	2.036	2.656	2.789	2.922	3.188
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		1.682	1.893	1.998	2.103	2.656	3.320	3.486	3.652	3.984
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 16: Time and wastes duration Simulation PM-EW (2nd Aggregate and MC activities)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)-	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
2nd aggregate	Unloading	1,875.000 m2	1.821	2.049	2.163	2.277	3.125	4.063	4.266	4.469	4.875
	W4 during Unloading		15.150	17.044	17.991	18.938	27.188	36.000	37.800	39.600	43.200
	Levelling		0.650	0.731	0.772	0.813	1.172	1.563	1.641	1.719	1.875
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		1.750	1.969	2.078	2.188	2.875	3.750	3.938	4.125	4.500
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		2.375	2.672	2.820	2.969	3.750	4.688	4.922	5.156	5.625
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
MC	Sprinkle MC	5,781.250 m2	5.396	6.070	6.408	6.745	8.865	11.563	12.141	12.719	13.875
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 17: Time and wastes duration Simulation PM-EW (1st Asphalt layer and RC activities)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)-	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
1st asphalt layer (Paving process)	1st asphalt layer	3,125.000 m2	8.042	9.047	9.549	10.052	16.719	29.688	31.172	32.656	35.625
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	W2 after Paving process		0.893	1.005	1.061	1.117	2.058	3.000	3.150	3.300	3.600
	W3 after Paving process		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W7 after Paving process		0.373	0.420	0.443	0.467	0.467	0.467	0.490	0.513	0.560
	W8 after Paving process		2.038	2.292	2.420	2.547	2.547	2.547	2.674	2.802	3.056
	Compact		3.958	4.453	4.701	4.948	6.250	7.813	8.203	8.594	9.375
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	W2 after Paving process		0.893	1.005	1.061	1.117	2.058	3.000	3.150	3.300	3.600
	W3 after Paving process		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W6 after Paving process		0.093	0.105	0.111	0.117	0.117	0.117	0.123	0.128	0.140
RC	Sprinkle RC	8,437.500 m2	7.875	8.859	9.352	9.844	12.938	16.875	17.719	18.563	20.250
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W3 during Levelling		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 18: Time and wastes duration Simulation PM-EW (2nd Asphalt Layer)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)-	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
2nd asphalt layer (Paving process)	2nd asphalt layer	5,312.500 m2	13.671	15.380	16.234	17.089	28.422	50.469	52.992	55.516	60.563
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	W2 after Paving process		0.893	1.005	1.061	1.117	2.058	3.000	3.150	3.300	3.600
	W3 after Paving process		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W7 after Paving process		0.373	0.420	0.443	0.467	0.467	0.467	0.490	0.513	0.560
	W8 after Paving process		3.464	3.897	4.113	4.330	4.330	4.330	4.546	4.763	5.196
	Compact		6.729	7.570	7.991	8.411	10.625	13.281	13.945	14.609	15.938
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	W2 after Paving process		0.893	1.005	1.061	1.117	2.058	3.000	3.150	3.300	3.600
	W3 after Paving process		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W6 after Paving process		0.093	0.105	0.111	0.117	0.117	0.117	0.123	0.128	0.140

4.9.2 Simulation PM-OW

Table 4-19 to table 4-25 show the time and wastes duration inserted as inputs in the simulation PM-OW. The wastes durations are inserted where they are observed on site visits; within the time duration of the activity. The inputs are based on the observation time of wastes as explained in section 4.3.3. These durations are represented as random triangle distributions (ranging with a deviation from the mean value of +-20%, +-10%, +-5% and 0%). Some wastes are inserted during the sub-activities and others are inserted after the activities depending on where and when they occurred in the observed real life project. The reason why they are inserted this way is to assure that the simulation reproduces the observed reality on site. The total quantities of each activity are represented on these tables (the quantity unit is m^2). For example, W4, referring to time wasted during the transportation of the aggregate to the working area, was observed during the unloading sub-activity. On the other hand, W1, inspection delays, occurred after the levelling sub-activity in the observed site, and hence was placed in the same manner in the simulation

Table 4- 19: Time and wastes duration Simulation PM-OW (Sub-base 1st and 2nd Layers filling with excavation material)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.* 1.00	Av.*1.00	Max.* 1.00	*1.05	*1.10	*1.20
sub-base 1st Layer (Filling with excavation material)	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	W4 during Unloading		5.260	5.918	6.247	6.576	9.440	12.500	13.125	13.750	15.000
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
sub-base 2nd Layer (Filling with excavation material)	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	W4 during Unloading		5.260	5.918	6.247	6.576	9.440	12.500	13.125	13.750	15.000
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 20: Time and wastes duration Simulation PM-OW (Sub-base 3rd and 4th Layers filling with excavation material)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.* 1.00	Av.*1.00	Max.* 1.00	*1.05	*1.10	*1.20
sub-base 3rd Layer (Filling with excavation material)	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	W4 during Unloading		5.260	5.918	6.247	6.576	9.440	12.500	13.125	13.750	15.000
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
sub-base 4th Layer (Filling with excavation material)	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	W4 during Unloading		5.260	5.918	6.247	6.576	9.440	12.500	13.125	13.750	15.000
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 21: Time and wastes duration Simulation PM-OW (Sub-base 1st and 2nd Layers filling with outside material)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.* 1.00	Av.*1.00	Max.* 1.00	*1.05	*1.10	*1.20
sub-base 1st Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	W4 during Unloading		1.578	1.775	1.874	1.973	2.832	3.750	3.938	4.125	4.500
	Levelling		0.068	0.076	0.080	0.085	0.122	0.163	0.171	0.179	0.195
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
sub-base 2nd Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	W4 during Unloading		1.578	1.775	1.874	1.973	2.832	3.750	3.938	4.125	4.500
	Levelling		0.182	0.205	0.216	0.228	0.122	0.163	0.171	0.179	0.195
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 22: Time and wastes duration Simulation PM-OW (Sub-base 3rd and 4th Layers filling with outside material)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.* 1.00	Av.*1.00	Max.* 1.00	*1.05	*1.10	*1.20
sub-base 3rd Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	W4 during Unloading		1.578	1.775	1.874	1.973	2.832	3.750	3.938	4.125	4.500
	Levelling		0.068	0.076	0.080	0.085	0.122	0.163	0.171	0.179	0.195
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
sub-base 4th Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	W4 during Unloading		1.578	1.775	1.874	1.973	2.832	3.750	3.938	4.125	4.500
	Levelling		0.068	0.076	0.080	0.085	0.122	0.163	0.171	0.179	0.195
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 23: Time and wastes duration Simulation PM-OW (1st Aggregate for the two layers)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.* 1.00	Av.*1.00	Max.* 1.00	*1.05	*1.10	*1.20
1st aggregate 1st Layer	Unloading	1,328.125 m2	1.290	1.451	1.532	1.613	2.214	2.878	3.021	3.165	3.453
	W4 during Unloading		10.731	12.073	12.743	13.414	19.258	25.500	26.775	28.050	30.600
	Levelling		0.460	0.518	0.547	0.576	0.830	1.107	1.162	1.217	1.328
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		1.240	1.395	1.472	1.549	2.036	2.656	2.789	2.922	3.188
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		1.682	1.893	1.998	2.103	2.656	3.320	3.486	3.652	3.984
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
1st aggregate 2nd Layer	Unloading	1,328.125 m2	1.290	1.451	1.532	1.613	2.214	2.878	3.021	3.165	3.453
	W4 during Unloading		10.731	12.073	12.743	13.414	19.258	25.500	26.775	28.050	30.600
	Levelling		0.460	0.518	0.547	0.576	0.830	1.107	1.162	1.217	1.328
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		1.240	1.395	1.472	1.549	2.036	2.656	2.789	2.922	3.188
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		1.682	1.893	1.998	2.103	2.656	3.320	3.486	3.652	3.984
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 24: Time and wastes duration Simulation PM-OW (2nd Aggregate layer and MC activities)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.* 1.00	Av.*1.00	Max.* 1.00	*1.05	*1.10	*1.20
2nd aggregate	Unloading	1,875.000 m2	1.821	2.049	2.163	2.277	3.125	4.063	4.266	4.469	4.875
	W4 during Unloading		15.150	17.044	17.991	18.938	27.188	36.000	37.800	39.600	43.200
	Levelling		0.650	0.731	0.772	0.813	1.172	1.563	1.641	1.719	1.875
	W5 during Levelling		0.293	0.330	0.348	0.367	0.367	0.367	0.385	0.403	0.440
	W1 after Levelling		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Sprinkle		1.750	1.969	2.078	2.188	2.875	3.750	3.938	4.125	4.500
	W1 after Sprinkle		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
	Compact		2.375	2.672	2.820	2.969	3.750	4.688	4.922	5.156	5.625
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
MC	Sprinkle MC	5,781.250 m2	5.396	6.070	6.408	6.745	8.865	11.563	12.141	12.719	13.875
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060

Table 4- 25: Time and wastes duration Simulation PM-OW (1st Asphalt layer, RC activities and 2nd Asphalt layer activities)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.* 1.00	Av.*1.00	Max.* 1.00	*1.05	*1.10	*1.20
1st asphalt layer (Paving process)	1st asphalt layer	3,125.000 m2	8.042	9.047	9.549	10.052	16.719	29.688	31.172	32.656	35.625
	W2 after Paving process		0.893	1.005	1.061	1.117	2.058	3.000	3.150	3.300	3.600
	W3 after Paving process		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W7 after Paving process		0.373	0.420	0.443	0.467	0.467	0.467	0.490	0.513	0.560
	W8 after Paving process		2.038	2.292	2.420	2.547	2.547	2.547	2.674	2.802	3.056
	Compact		3.958	4.453	4.701	4.948	6.250	7.813	8.203	8.594	9.375
	W2 after Paving process		0.893	1.005	1.061	1.117	2.058	3.000	3.150	3.300	3.600
	W3 after Paving process		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W6 after Paving process		0.093	0.105	0.111	0.117	0.117	0.117	0.123	0.128	0.140
RC	Sprinkle RC	8,437.500 m2	7.875	8.859	9.352	9.844	12.938	16.875	17.719	18.563	20.250
	W1 after Compact		0.347	0.390	0.412	0.433	3.575	6.717	7.053	7.388	8.060
2nd asphalt layer (Paving process)	2nd asphalt layer	5,312.500 m2	13.671	15.380	16.234	17.089	28.422	50.469	52.992	55.516	60.563
	W2 after Paving process		0.893	1.005	1.061	1.117	2.058	3.000	3.150	3.300	3.600
	W3 after Paving process		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W7 after Paving process		0.373	0.420	0.443	0.467	0.467	0.467	0.490	0.513	0.560
	W8 after Paving process		3.464	3.897	4.113	4.330	4.330	4.330	4.546	4.763	5.196
	Compact		6.729	7.570	7.991	8.411	10.625	13.281	13.945	14.609	15.938
	W2 after Paving process		0.893	1.005	1.061	1.117	2.058	3.000	3.150	3.300	3.600
	W3 after Paving process		0.200	0.225	0.238	0.250	2.217	4.183	4.392	4.602	5.020
	W6 after Paving process		0.093	0.105	0.111	0.117	0.117	0.117	0.123	0.128	0.140

4.9.3 Simulation LC

Table 4-26 to table 4-29 show the time and wastes duration inserted as inputs in the simulation LC. The wastes durations are inserted where they are expected to most likely occur; within the time duration of the activity. The inputs are based on the application of Lean Construction (LC) tools as explained in section 4.3.4. These durations are represented as random triangle distributions (ranging with a deviation from the mean value of +-20%, +-10%, +-5% and 0%).

Table 4- 26: Time and wastes duration Simulation LC (Sub-base for the four layers filling with excavation material)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
sub-base 1st Layer (Filling with excavation material)	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
sub-base 2nd Layer (Filling with excavation material)	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
sub-base 3rd Layer (Filling with excavation material)	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953
sub-base 4th Layer (Filling with excavation material)	Unloading	651.043 m2	0.632	0.711	0.751	0.791	1.085	1.411	1.481	1.552	1.693
	Levelling		0.226	0.254	0.268	0.282	0.407	0.543	0.570	0.597	0.651
	Sprinkle		0.608	0.684	0.722	0.760	0.998	1.302	1.367	1.432	1.563
	Compact		0.825	0.928	0.979	1.031	1.302	1.628	1.709	1.790	1.953

Table 4- 27: Time and wastes duration Simulation LC (Sub-base for the four layers filling with outside material)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
sub-base 1st Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	Levelling		0.068	0.076	0.080	0.085	0.122	0.163	0.171	0.179	0.195
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
sub-base 2nd Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	Levelling		0.068	0.076	0.080	0.085	0.122	0.163	0.171	0.179	0.195
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
sub-base 3rd Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	Levelling		0.068	0.076	0.080	0.085	0.122	0.163	0.171	0.179	0.195
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586
sub-base 4th Layer (Filling with outside material)	Unloading	195.313 m2	0.190	0.213	0.225	0.237	0.326	0.423	0.444	0.465	0.508
	Levelling		0.068	0.076	0.080	0.085	0.122	0.163	0.171	0.179	0.195
	Sprinkle		0.182	0.205	0.216	0.228	0.299	0.391	0.410	0.430	0.469
	Compact		0.247	0.278	0.294	0.309	0.391	0.488	0.513	0.537	0.586

Table 4- 28: Time and wastes duration Simulation LC (1st Aggregate two layers, 2nd Aggregate and MC activities)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
1st aggregate 1st Layer	Unloading	1,328.125 m2	1.290	1.451	1.532	1.613	2.214	2.878	3.021	3.165	3.453
	Levelling		0.460	0.518	0.547	0.576	0.830	1.107	1.162	1.217	1.328
	Sprinkle		1.240	1.395	1.472	1.549	2.036	2.656	2.789	2.922	3.188
	Compact		1.682	1.893	1.998	2.103	2.656	3.320	3.486	3.652	3.984
1st aggregate 2nd Layer	Unloading	1,328.125 m2	1.290	1.451	1.532	1.613	2.214	2.878	3.021	3.165	3.453
	Levelling		0.460	0.518	0.547	0.576	0.830	1.107	1.162	1.217	1.328
	Sprinkle		1.240	1.395	1.472	1.549	2.036	2.656	2.789	2.922	3.188
	Compact		1.682	1.893	1.998	2.103	2.656	3.320	3.486	3.652	3.984
2nd aggregate	Unloading	1,875.000 m2	1.821	2.049	2.163	2.277	3.125	4.063	4.266	4.469	4.875
	Levelling		0.650	0.731	0.772	0.813	1.172	1.563	1.641	1.719	1.875
	Sprinkle		1.750	1.969	2.078	2.188	2.875	3.750	3.938	4.125	4.500
	Compact		2.375	2.672	2.820	2.969	3.750	4.688	4.922	5.156	5.625
MC	Sprinkle MC	5,781.250 m2	5.396	6.070	6.408	6.745	8.865	11.563	12.141	12.719	13.875

Table 4- 29: Time and wastes duration Simulation LC (1st Asphalt, RC and 2nd Asphalt activities)

Rocks (Activities) -Per Layer-	Pebbles (sub-activities)	Total quantity per section	Time observed -per section- (hr.) (Per Machinery)								
			Total Time								
			*0.8	*0.90	*0.95	Min.*1.00	Av.*1.00	Max.*1.00	*1.05	*1.10	*1.20
1st asphalt	1st asphalt layer	3,125.000 m2	8.042	9.047	9.549	10.052	16.719	29.688	31.172	32.656	35.625
	W7 after		0.373	0.420	0.443	0.467	0.467	0.467	0.490	0.513	0.560
	W8 after		2.038	2.292	2.420	2.547	2.547	4.712	4.947	5.183	5.654
	Compact		3.958	4.453	4.701	4.948	6.250	7.813	8.203	8.594	9.375
RC	Sprinkle RC	8,437.500 m2	7.875	8.859	9.352	9.844	12.938	16.875	17.719	18.563	20.250
2nd asphalt	2nd asphalt layer	5,312.500 m2	13.671	15.380	16.234	17.089	28.422	50.469	52.992	55.516	60.563
	W7 after		0.373	0.420	0.443	0.467	0.467	0.467	0.490	0.513	0.560
	W8 after		3.464	3.897	4.113	4.330	4.330	4.330	4.546	4.763	5.196
	Compact		6.729	7.570	7.991	8.411	10.625	13.281	13.945	14.609	15.938

4.10 Conclusion

In this chapter, the data of the studied road project and its use as input in the utilized simulation software has been explained. The simulation application stands on two main pillars: the input data (time related input – activities and wastes durations – and materials quantity), and parameters equations. Accordingly, three applications of the simulation were developed in order to set base for comparative analysis between using PM and LC approaches in road projects. Hence, two simulations feature applying the PM approach; one running based on the expected wastes and the other based on the actual observed wastes. The third simulation only features applying the LC approach. since there is no margin of difference between the expected and observed wastes in case of applying LC, as a result of wastes elimination under this approach. In light of the presented work, the following chapter addresses the results of the simulations, the analysis and implications of such findings.

CHAPTER 5 ANALYSIS RESULTS

5.1 Introduction

In the previous chapter, the input of the three simulations were explained. This includes the information that were entered into the simulations regarding the time duration of each sub-activity and waste (referring to time delays) duration that occurs during each one. In this chapter, the output that resulted from the simulations is explained, and analysed. The results displayed include: a) Percentage Plan Complete (PPC); the value that reflects the performance of each activity with regards to the actual productivity divided by the expected productivity based on the data collected from the site. b) The results also include Percentage Activity Waste (PAW); introduced by the researcher to measure the extent to which the time waste duration affects each activity, by dividing the time waste duration for each by the Total duration of the same activity as presented below in equations 1, 2, 3 and 4. After demonstrating the mentioned results, analysis and discussion the implications and significance of the findings are included.

Equation 6:

$$Productivity\ of\ activity\ i\ per\ week\ (As\ observed)\ in\ Simio\ simulation\ [\frac{m2}{week}] =$$

$$\left(\frac{Total\ quantity\ of\ activity\ i\ [m2]}{\frac{Total\ Time\ for\ activity\ i\ [hour]\#}{Number\ used\ in\ the\ activity\ i} + Total\ waste\ time\ in\ activity\ i\ [hour\ \ ]\# * Process\ efficienc\ \ (PE)}\right) *$$

$$7\frac{hours}{day} * 6\ days/week$$

\# Random values with triangular distribution

Equation 7: PPC% =

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

Equation 8: PAW% = $\frac{\text{Waste time ONLY during an activity} * 100}{\text{Total time of an activity WITHOUT WASTE TIME}}$

Equation 9: Process efficiency (PE) = $\frac{Time\ of\ a\ waste\ observed}{Maximum\ occurrence\ of\ the\ waste}$

5.2 Results

The results of the road project activities analysis are presented below after applying the three simulations (Project Management for Expected Wastes PM-EW, Project Management for Observed Wastes PM-OW and Lean Construction LC). Every simulation is run 600 times to increase the accuracy of the results. These results are summarized in tables 5-3 to 5-10 and figures 5-2 to 5-33.

In order to reach the most accurate results, the researcher includes four standard deviation scenarios in each of the three simulations. The scenarios are based on random triangular distribution, where there is a minimum value, a maximum value and a mean [1], [112], [110], [175], [286]. In each of these scenarios, different minimum and maximum time duration values for the activities are introduced with the same mean value. This occurs by increasing the minimum and maximum values with the same percentage. The last (fourth) one 'scenario 0%' represents the values measured on site in the studied road project during the observation period. The other three scenarios assume gradual increases in the observed minimum and maximum values by ±5%, ±10% and ±20% while maintaining the same mean value. By doing this, the PhD candidate intends to be as much inclusive as possible to the potential scenarios that can occur in real life projects by presenting this wide range of variations in the minimum and maximum time values. This comes as a result of not being able to cover all the different variations in values during the site visits which lasted for one month not the whole project. Accordingly, as aforementioned scenario 0% represent the variation measured on site based on which the other scenarios are developed. Hence, the results that are based on these scenarios are as much accurate as possible.

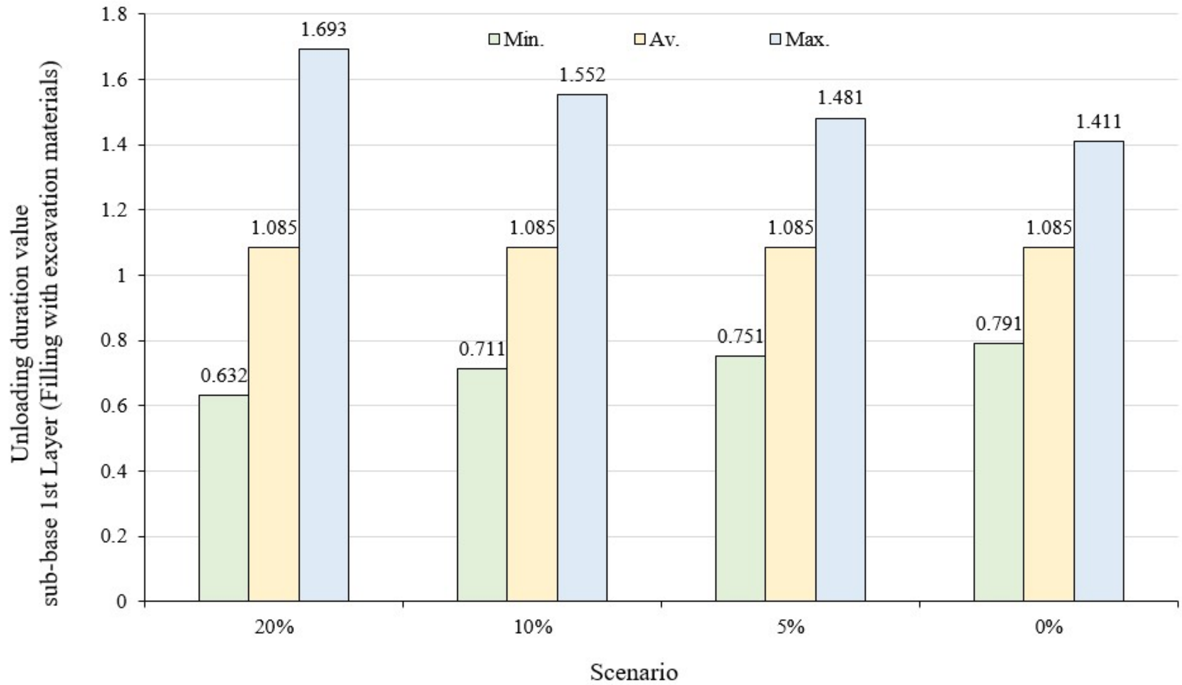


Figure 5- 1: The four scenarios used in the simulations for Unloading sub-activity

The following four scenarios were applied to the duration of each activity and waste, as shown in Figure 5-1; for each scenario the minimum, maximum and mean are displayed. For example in scenario 5%, the minimum value is 0.751 hours, the maximum value is 1.481 hours and the mean value is 1.085 hours; the same order of bars applies to the other scenarios. As noted the mean value in all four scenarios is the same due to the simultaneous increase in the minimum and maximum values. The figure demonstrates the scenarios for the unloading sub-activity under the activity sub-base first layer (filling with excavation material).

a) Scenario ±20%; based on the actual measured values introduced in scenario 0%, the duration values are varied by 20% for the maximum and the minimum (Highest standard deviation).
b) Scenario ±10%; based on the actual measured values introduced in scenario 0%, the duration values are varied by 10% for the maximum and the minimum.
c) Scenario ±5%; based on the actual measured values introduced in scenario 0%, the duration values are varied by 5% for the maximum and the minimum.
d) Scenario 0%: Minimum and maximum time duration values for activities measured during site visits (lowest standard deviation).

The two main parameters studied are: (i) Percentage Plan Complete (PPC) [217], [85], [66], [219] and (ii) Percentage Activity Waste (PAW) – created by the PhD candidate. Every activity is summarised with one table (as shown below in tables 5-3 to 5-10); showing the percentage of the results of PPC and PAW. These parameters were analysed for each simulation (PM-EW, PM-OW and LC) based on all four scenarios; as previously explained, the time duration of the activities introduced in three scenarios are adjusted based on the actual information (values in the fourth scenario - scenario 0%) and updated with a statistical approach as explained above. The following graphs (from Figure 5-2 to Figure 5-33) are used to summarise the simulation of the activities; four graphs for each activity. These graphs include information and their analysis of (i) PPC and (ii) PAW.

The value of each of the two parameters is separately calculated for each scenario in the simulation based on which the final Ratio between each scenario and scenario 0% is calculated as shown in Table 5-1 below. Table 5-1 explains how the Ratio between PPC value for each scenario and scenario 0% is obtained. Table 5-2 gives an example for calculating the ratio of the analysed PPC, for the activity Sub-base first layer (filling with excavation material). This applies to each of the three simulations for the two parameters. The results (ratio) for each parameter (PPC and PAW) are calculated as the result of the value in each scenario over the value of scenario 0% (of the simulation PM-EW). For example, the value of PPC in simulation PM-OW, scenario 20% (9.2811%) is divided by the value of PPC in simulation PM-EW, scenario 0% (9.5654%) to obtain the PPC ratio (0.9703%). Each PPC value in the different scenarios and different simulations is divided by the same value used in the example (9.5654%) to analyse the PPC values. The choice of this specific value to use as a denominator in the process goes back to the fact that it is one of two possible values to occur in reality in the studied project (the other value is PM-OW, scenario 0%). The chosen value reflects the worst case of the two values related to the studied project since it refers to the expected wastes.

Table 5- 1: Analysed equation for PPC ratios

Scenario	PPC		
	PM-EW	**PM-OW**	**LC**
±20%	PM-EW Scen. 20% / PM-EW Scen. 0%	PM-OW Scen. 20% / PM-EW Scen. 0%	LC Scen. 20% / PM-EW Scen. 0%
±10%	PM-EW Scen. 10% / PM-EW Scen. 0%	PM-OW Scen. 10% / PM-EW Scen. 0%	LC Scen. 10% / PM-EW Scen. 0%
±5%	PM-EW Scen. 5% / PM-EW Scen. 0%	PM-OW Scen. 5% / PM-EW Scen. 0%	LC Scen. 5% / PM-EW Scen. 0%
0%	PM-EW Scen. 0% / PM-EW Scen. 0%	PM-OW Scen. 0% / PM-EW Scen. 0%	LC Scen. 0% / PM-EW Scen. 0%

Table 5- 2: Sub-base first layer (filling with excavation material) example for analyzed PPC ratios

Scenario	PPC					
	PM-EW	**PM-OW**	**LC**	**PM-EW**	**PM-OW**	**LC**
±20%	8.9266	9.2811	57.2770	0.9332	0.9703	5.9879
±10%	9.2365	9.5999	58.1792	0.9656	1.0036	6.0823
±5%	9.3991	9.7671	58.6386	0.9826	1.0211	6.1303
0%	9.5654	9.9396	59.0965	1.0000	1.0391	6.1782

The studied project activities are eight (the activities are named a and b) under four categories, the activities are as follows:

1. Sub-base Layer
    a. Sub-base layers based on filling with excavation material.
    b. Sub-base layers based on filling with external material.
2. 1st and 2nd Aggregate Layer
    a. First aggregate layers.
    b. Second aggregate layer.
3. MC sprinkle and 1st asphalt paving
    a. Medium Curing sprinkle (MC).
    b. First asphalt paving.
4. RC sprinkle and 2nd asphalt paving
    a. Rapid Curing sprinkle (RC).
    b. Second asphalt paving.

In the next sections, the detailed results for each of the mentioned activities and sub-activities are demonstrated. The three parameters' results (PPC and PAW) are presented for each activity under each of the three simulations.

In general, the values of PPC are very low because the planned productivity (obtained based on the site information) are optimistic compared to the actual productivity -observed on the site visited and are calculated based on the first equation). Additionally the values of PAW (this variable is created by PhD candidate) are high because the time wastes observed for the activities are very close in value to the total time of these activities.

5.2.1 Sub-base Layers

Figures 5-2 to 5-9 and Tables 5-3 and 5-4 show the results for the three variables PPC and PAW on each simulation PM-EW, PM-OW and LC. These values were for the two sub-base layers activities (filling with excavation material and filling with material from outside).

a) **Sub-base Layers filling with excavation material**

The results for the sub-base layer filling with excavation material, concerning PPC and PAW, are shown in Table 5-3 and Figures 5-2 to 5-5, respectively.

Table 5- 3: PPC and PAW for Sub-base layers filling with excavation material [%]

Scenario	PPC [%]			PAW [%]		
	PM-EW	PM-OW	LC	PM-EW	PM-OW	LC
±20%	8.93	9.28	57.28	84.45	83.73	0.00
±10%	9.24	9.60	58.18	84.16	83.44	0.00
±5%	9.40	9.77	58.64	84.01	83.29	0.00
0%	9.57	9.94	59.10	83.94	83.20	0.00

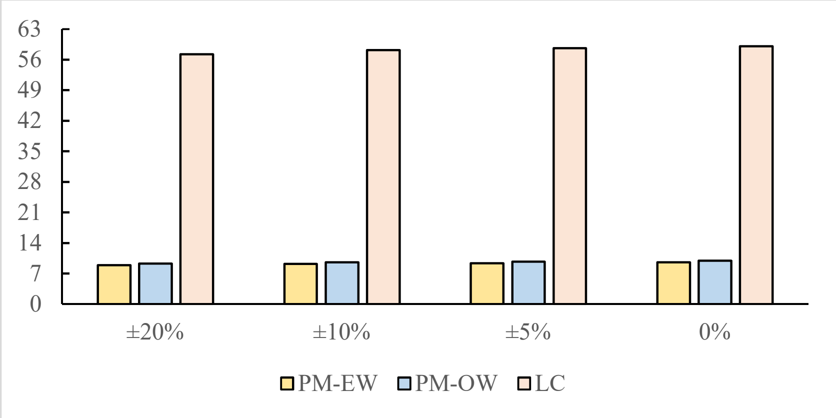


Figure 5- 2: PPC for the sub-base layer filling with excavation material

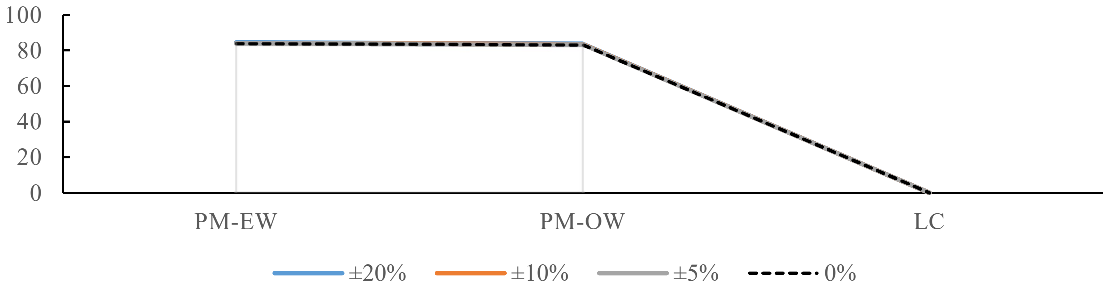


Figure 5- 3: Analyzed PPC ratio for Sub-base layers filling with excavation material

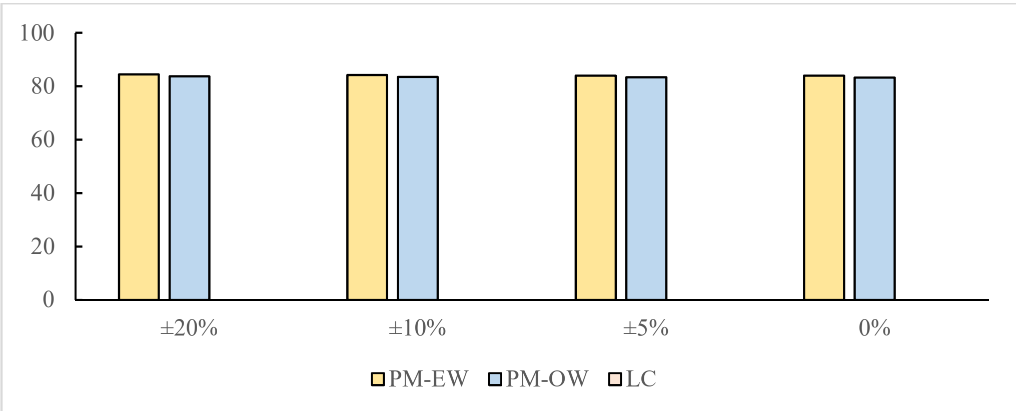


Figure 5- 4: PAW for Sub-base layers filling with excavation material

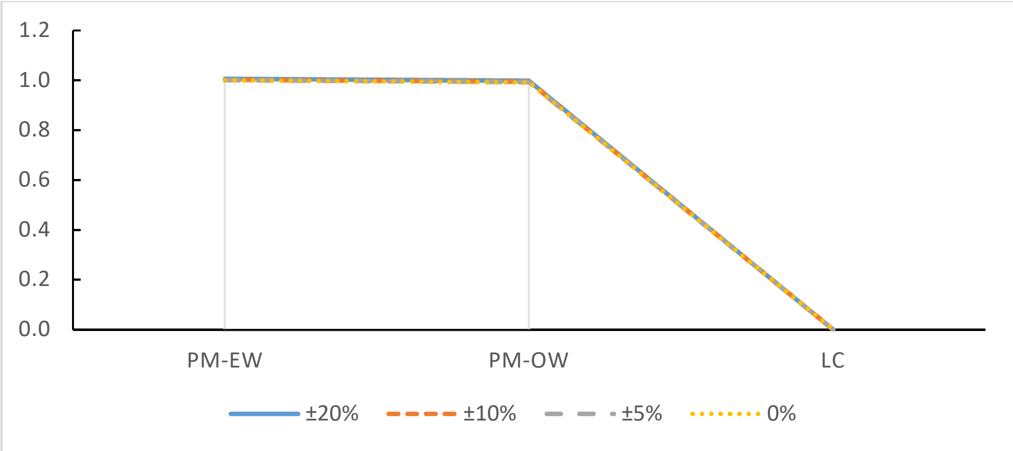


Figure 5- 5: Analyzed PAW ratio for Sub-base layers filling with excavation material

b) **Sub-base Layers filling with material not from the site**

The results for Sub-base layers filling with material that was not available on site, concerning PPC and PAW, are shown in Table 5-4 and Figures 5-6 to 5-9.

Table 5- 4: PPC and PAW for Sub-base layers filling with material not from the site [%]

Scenario	PPC [%]			PAW [%]		
	PM-EW	PM-OW	LC	PM-EW	PM-OW	LC
±20%	14.36	15.28	192.35	92.25	92.26	0.00
±10%	15.00	15.96	195.73	92.06	92.03	0.00
±5%	15.34	16.33	197.40	91.96	91.91	0.00
0%	15.71	16.73	199.05	92.21	91.60	0.00

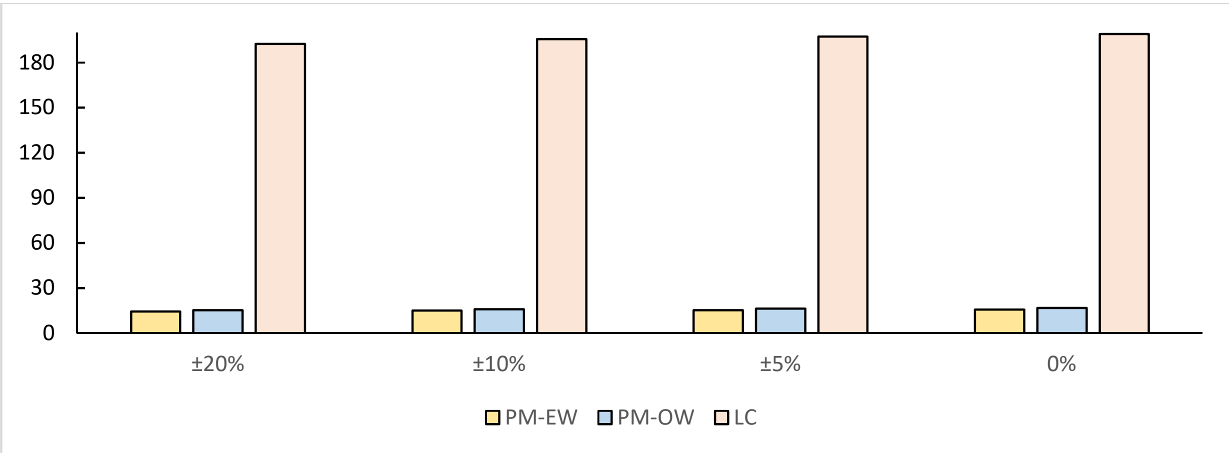


Figure 5- 6: PPC for Sub-base layers filling with material not from the site

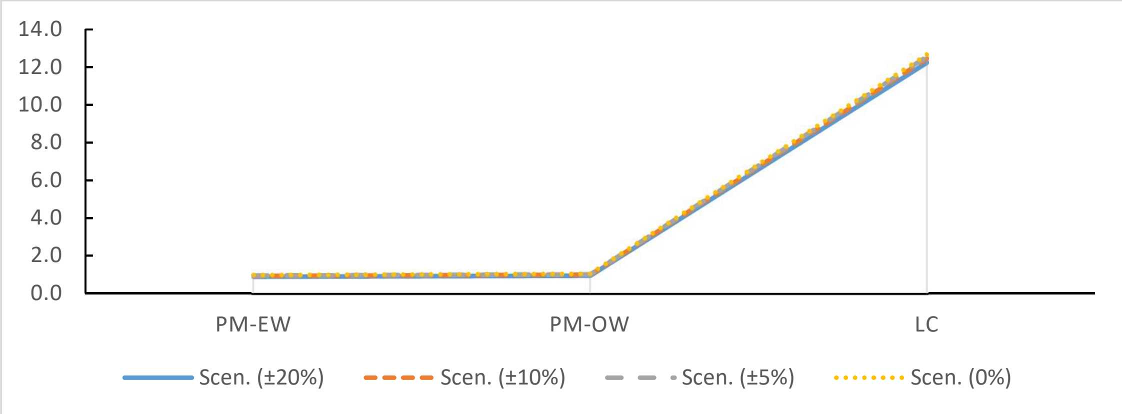


Figure 5- 7: Analyzed PPC ratio for Sub-base layers filling with material not from the site

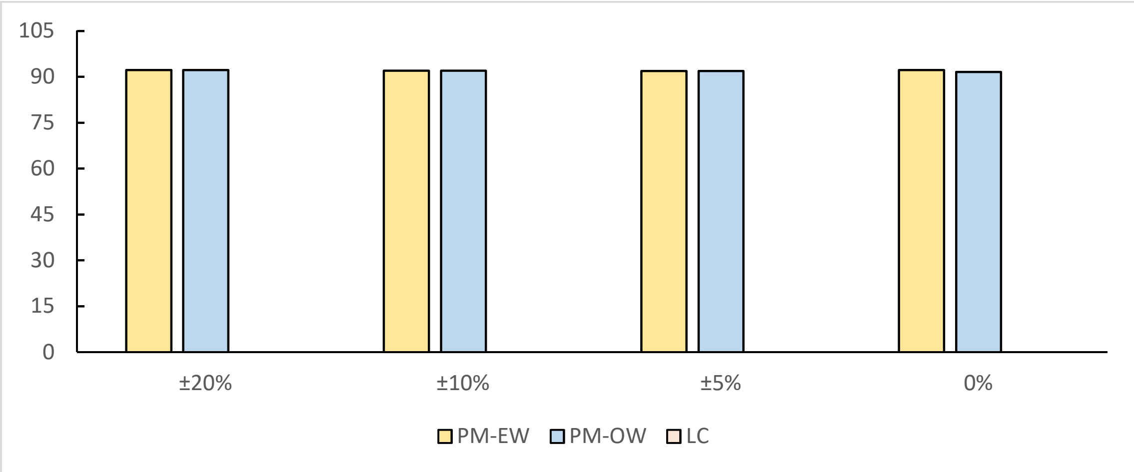


Figure 5- 8: PAW for Sub-base layers filling with material not from the site

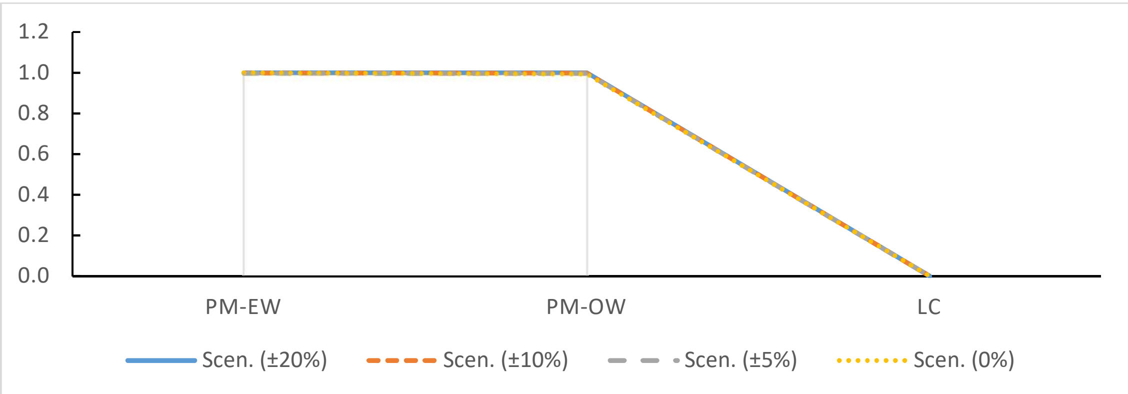


Figure 5- 9: Analyzed PAW ratio for Sub-base layers filling with material not from the site

For the sub-base layer activities (filling with excavation material and filling with material not from the site) and for Simulations PM-OW and PM-EW, the values of PPC are less than 10% for the first activity and did not reach 17% for the second activity. This is illustrated by the fact that these two activities have high values of PAW, more than 80% for the first and more than 90% for the second. From these results, it can be seen that the second activity (sub-base layers filling with material not from the site) has higher values of PPC, however, its PAW values are also higher. This is due to the fact that the material quantity (166,667 m^2) of the second activity is only 30% of the total material quantity (50,000 m^2) of the first one. Moreover, the expected duration for the second activity is the same as the first activity, based on the planning done by engineers working on the project. This is regarded as an unrealistic expectation due to the different quantities of material required for each activity; here the time plan for both activities is the same despite requiring different material quantities.

Results obtained by the PM approach (PM-OW and PM-EW) are very similar in terms of PPC because the wastes duration values are almost the same. This can be seen in the results of PAW; obtained by dividing time waste durations over the actual activity duration. It is essential to note here that the two mentioned simulations (PM-OW and PM-EW) refer to observed wastes and expected wastes respectively. The summation of the time waste duration values in these two simulations is also highly close, which led to an almost similar PAW value for both.

By eliminating the wastes (Non-Value Adding activities, NVA) in the last simulation (LC), the results of PPC increase and the results of PAW are zero. However, the results of PPC in the first sub-base activity (filling with excavation material) are between 57.28% and 59.10% while the results of PPC in the second activity (filling with material not from the site) are between 192.35% and 199.05%.

5.2.2 First and Second Aggregate Layers

Figures 5-10 to 5-17 and Tables 5-5 and 5-6 show the results for the two variables PPC and PAW in each of the three simulations PM-EW, PM-OW and LC. These values are for the two activities 1st and 2nd aggregate layer activities.

c) **First Aggregate Layers**

The results for 1st aggregate layers, concerning PPC and PAW, are shown in Table 5-5 and Figures 5-10 to 5-13.

Table 5- 5: PPC and PAW for 1st aggregate layers [%]

Scenario	PPC [%]			PAW [%]		
	PM-EW	PM-OW	LC	PM-EW	PM-OW	LC
±20%	34.31	35.21	169.68	79.76	79.29	0.00
±10%	35.32	36.22	172.60	79.53	79.05	0.00
±5%	35.84	36.75	174.10	79.40	78.93	0.00
0%	36.41	37.28	175.62	79.34	78.81	0.00

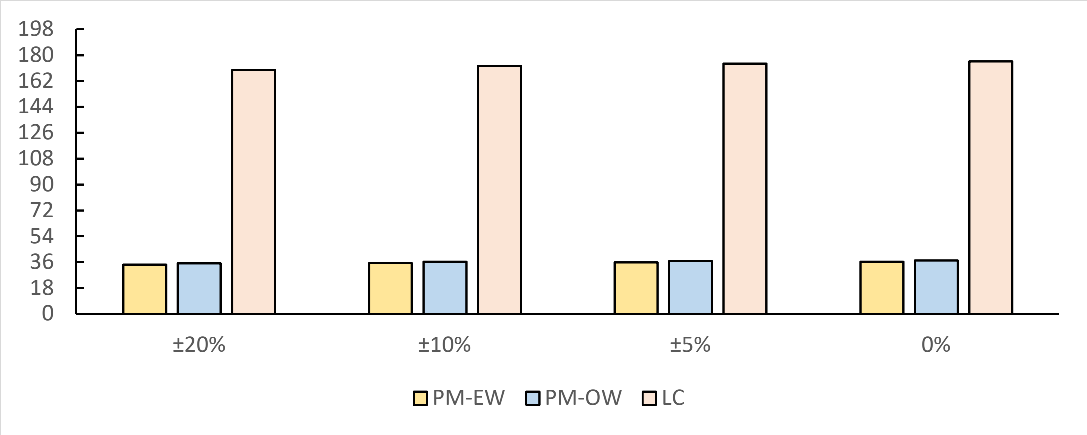


Figure 5- 10: PPC for 1st aggregate layers

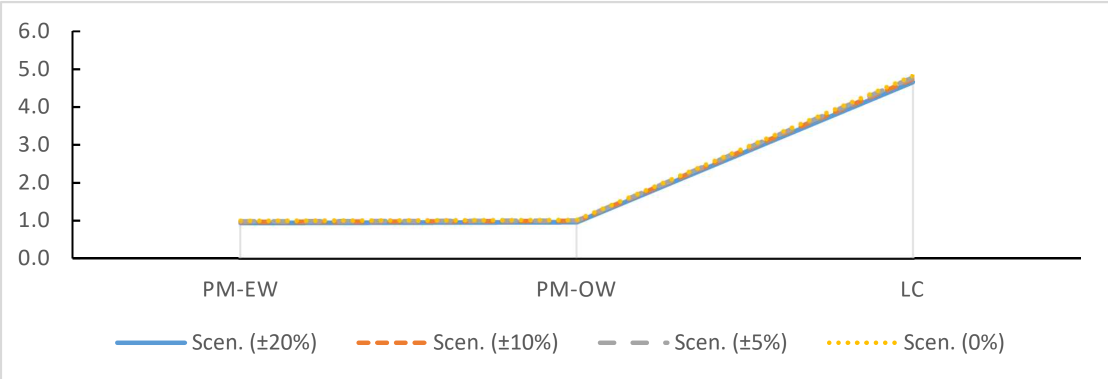


Figure 5- 11: Analyzed PPC ratio for 1st aggregate layers

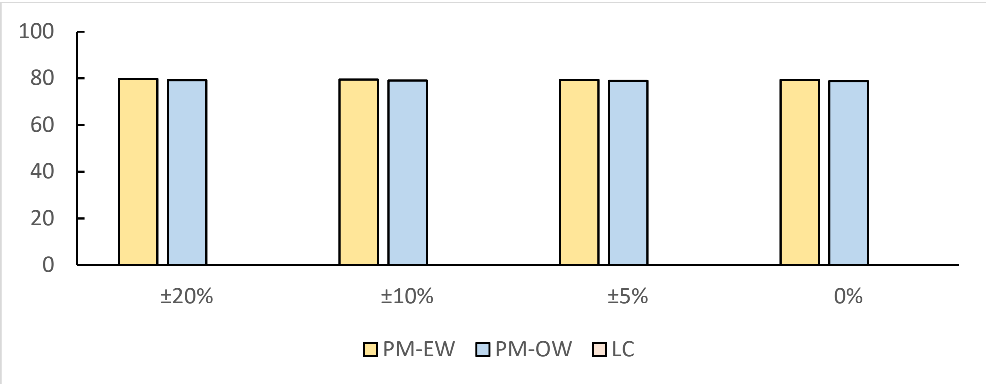


Figure 5- 12: PAW for 1st aggregate layers

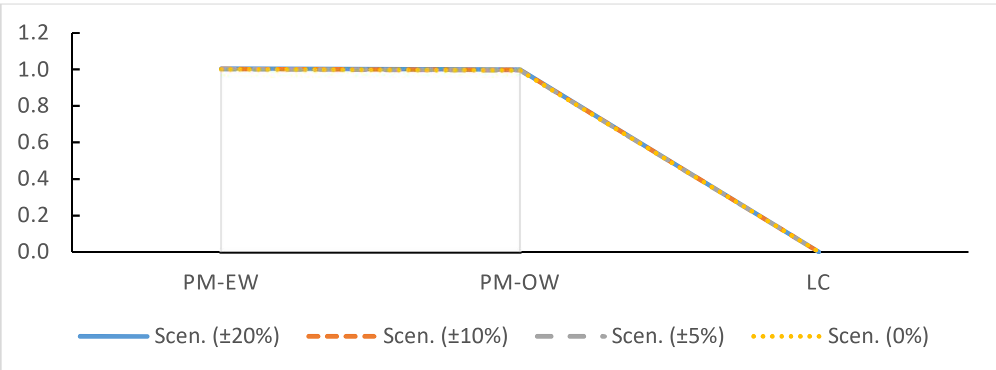


Figure 5- 13: Analyzed PAW ratio for 1st aggregate layers

d) **Second Aggregate Layer**

The results for 2nd aggregate layer, concerning PPC and PAW are shown in Table 5-6 and Figures 5-14 to 5-17.

Table 5- 6: PPC and PAW for 2nd aggregate layer [%]

Scenario	PPC [%]			PAW [%]		
	PM-EW	PM-OW	LC	PM-EW	PM-OW	LC
±20%	53.24	54.23	240.53	77.88	77.56	0.00
±10%	54.68	55.67	244.63	77.66	77.33	0.00
±5%	55.42	56.43	246.73	77.55	77.21	0.00
0%	56.19	57.26	248.86	77.40	77.02	0.00

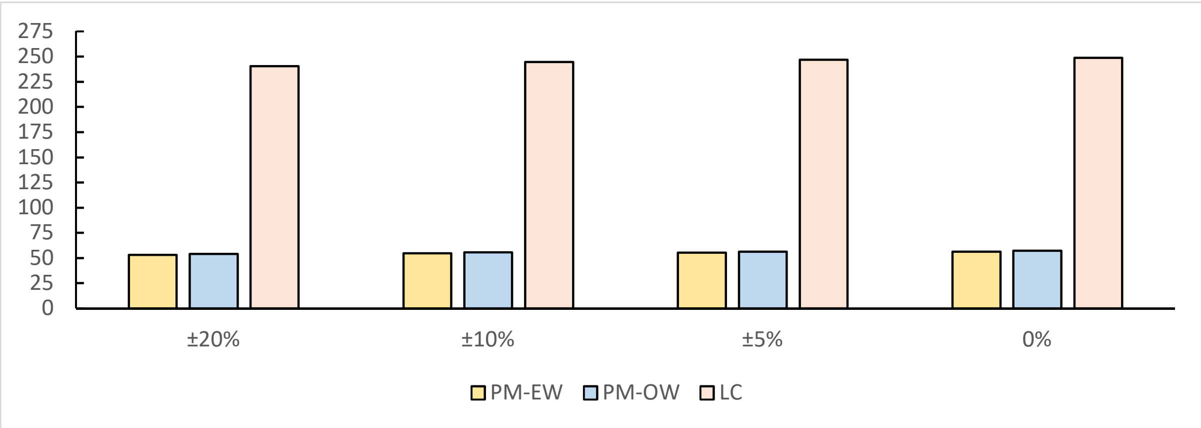


Figure 5- 14: PPC for 2nd aggregate layer

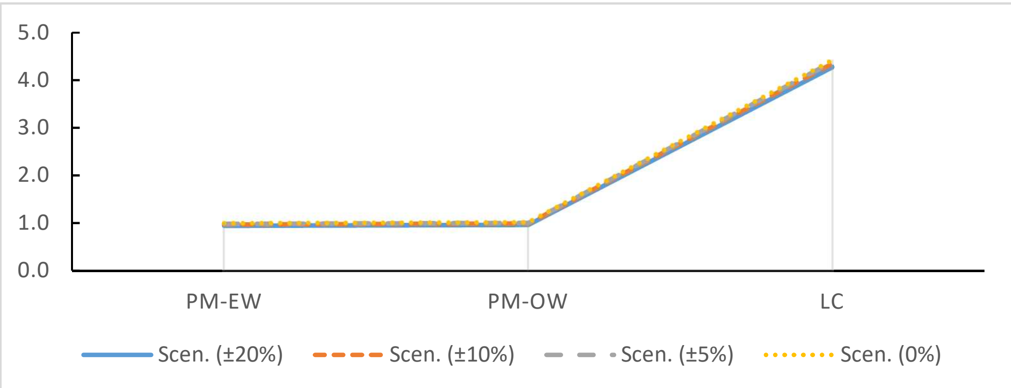


Figure 5- 15: Analyzed PPC ratio for 2nd aggregate layer

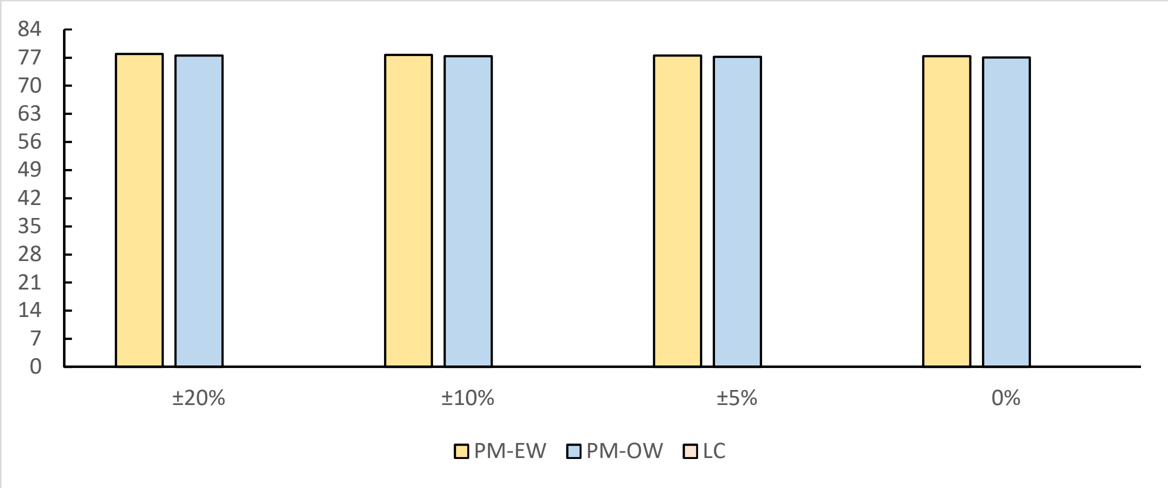


Figure 5- 16: PAW for 2nd aggregate layer

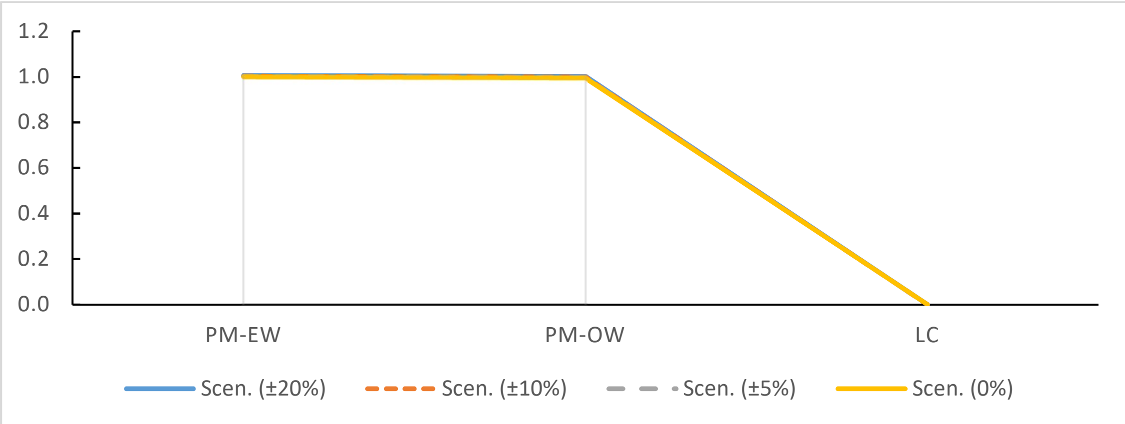


Figure 5- 17: Analyzed PAW ratio for 2nd aggregate layer

For the two aggregate layers (1st and 2nd aggregate layers) similar results were obtained for the two activities; the values of PPC range between 34.31% and 37.28% for the first activity and 53.24% and 57.26% for the second one, in the two PM simulations. This can be explained by the fact that these two activities have high PAW values; between 78.81% and 79.61% for first activity and between 77.02% and 77.88% for second one. From these results, it can be seen that the second activity (2nd aggregate layers) has higher values of PPC; despite the fact that the results of PAW are close in the two activities. The reason behind this is that the total material quantity of the second activity is 70% of the total quantity of the first one. Despite this, the expected duration for the second activity is same as the first activity. This is regarded as an unrealistic expectation due to the different quantities of material required for each activity.

Results obtained in the PM approach (PM-OW and PM-EW) are very similar in terms of PPC because the wastes duration values are almost the same. This can be seen in the results of PAW; obtained by dividing time waste durations over the actual activity duration. It is essential to note here that the two mentioned simulations (PM-OW and PM-EW) refer to observed wastes and expected wastes respectively. By eliminating the wastes in the Lean Construction (LC) simulation, the results of PPC increase and the results of PAW become zero. The results of PPC is between 169.68% and 175.62% for the first activity and between 240.53% and 248.86% for the second activity. As noted the values in the LC simulations are high due to the fact that in the PM simulations, the percentage of wastes in these activities is high, which is not the case in LC simulations since these wastes are eliminated. It is also worth mentioning that the value of PAW is high in the PM simulations and is zero in the LC simulations.

5.2.3 MC sprinkle and First asphalt paving

Figures 5-18 to 5-25 and Tables 5-7 and 5-8 show the results of the two variables PPC and PAW in each of the three simulations PM-EW, PM-OW and LC. These values are for the MC sprinkle and 1st asphalt paving activities.

e) **MC sprinkle**

The results for MC sprinkle, concerning PPC and PAW, are shown in Table 5-7 and Figures 5-18 to 5-21.

Table 5- 7: PPC and PAW for MC sprinkle [%]

Scenario	PPC [%]			PAW [%]		
	PM-EW	PM-OW	LC	PM-EW	PM-OW	LC
±20%	197.17	203.19	280.14	29.61	27.75	0.00
±10%	202.65	208.70	284.95	28.88	27.01	0.00
±5%	205.50	211.56	287.41	28.50	26.63	0.00
0%	208.48	214.00	289.93	28.13	26.02	0.00

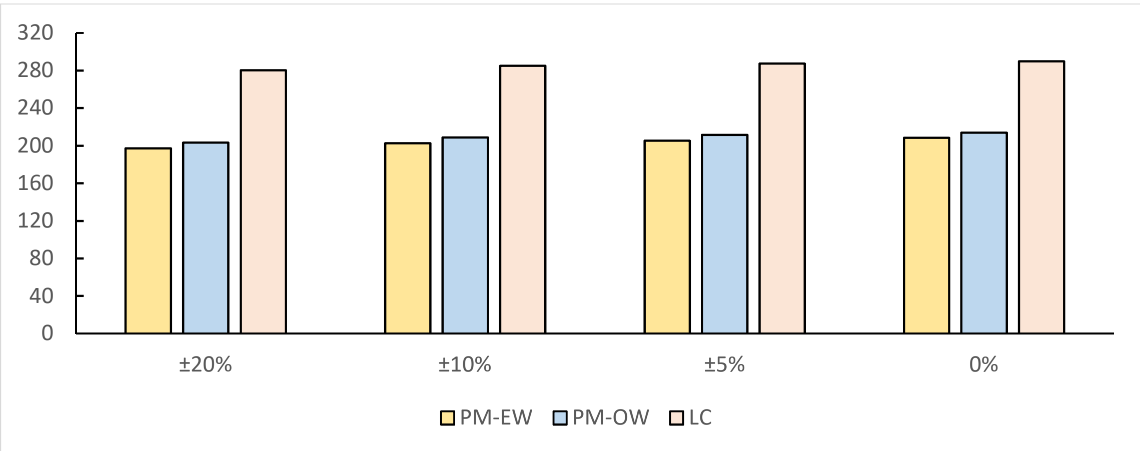


Figure 5- 18: PPC for MC sprinkle

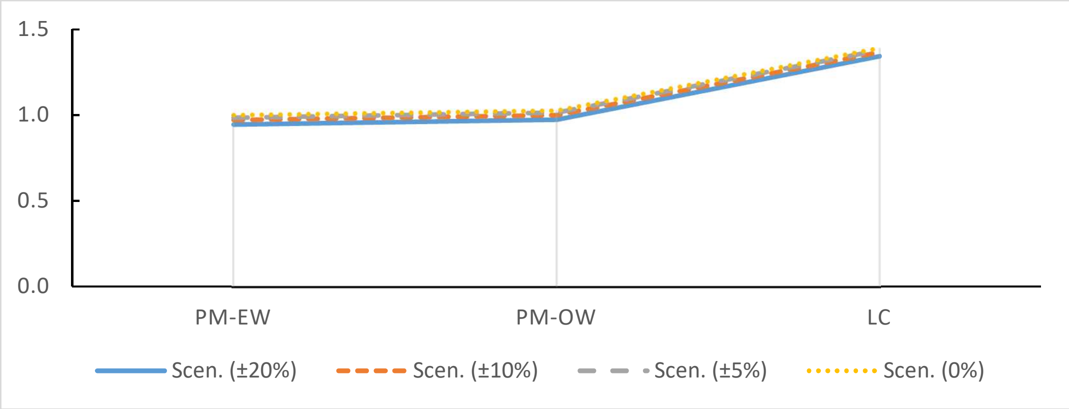


Figure 5- 19: Analyzed PPC ratio for MC sprinkle

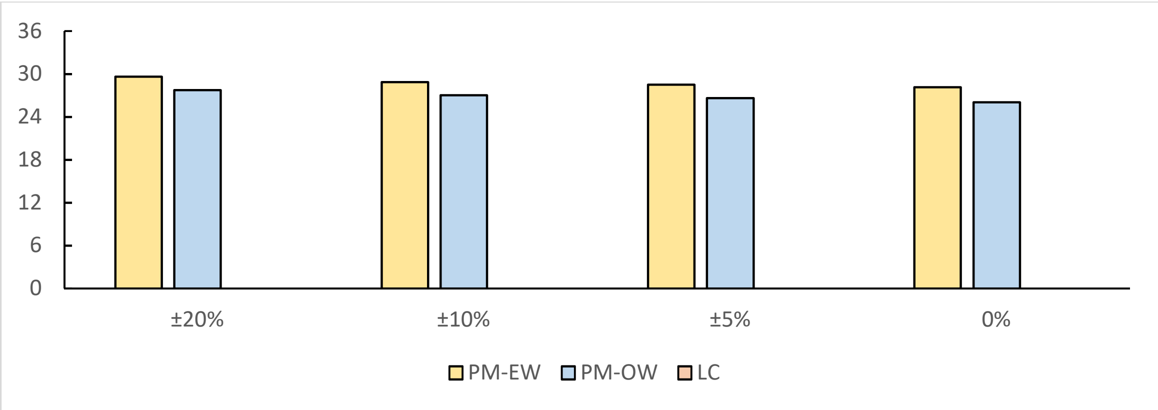


Figure 5- 20: PAW for MC sprinkle

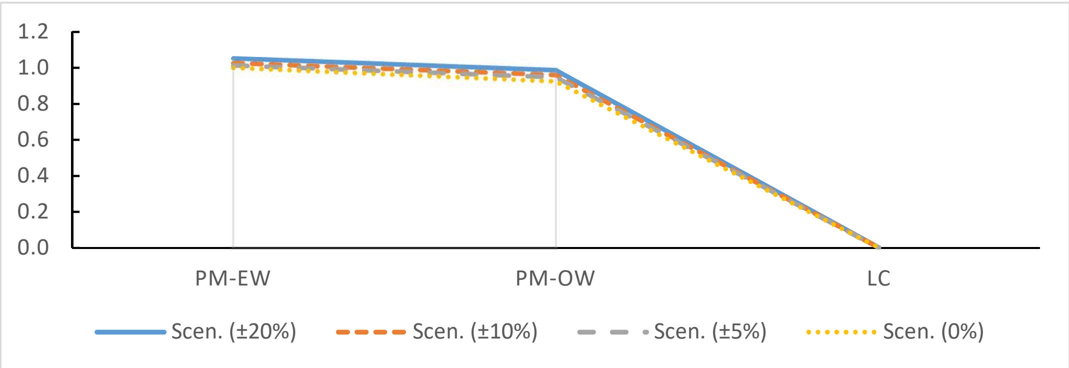


Figure 5- 21: Analyzed PAW ratio for MC sprinkle

f) **First asphalt paving**

The results for 1st asphalt paving, concerning PPC and PAW, are shown in Table 5-8 and Figures 5-22 to 5-25.

Table 5- 8: PPC and PAW for 1st asphalt paving [%]

Scenario	PPC			PAW		
	PM-EW	PM-OW	LC	PM-EW	PM-OW	LC
±20%	65.58	79.61	92.94	36.63	23.09	10.18
±10%	67.64	81.73	95.34	36.48	23.25	10.43
±5%	68.71	82.83	96.58	36.40	23.33	10.57
0%	69.84	83.90	97.92	36.27	23.45	10.69

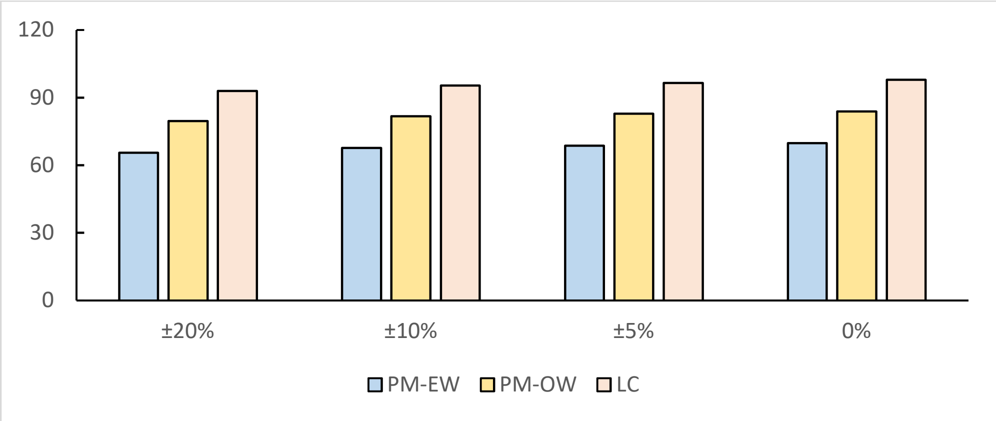


Figure 5- 22: PPC for 1st asphalt paving

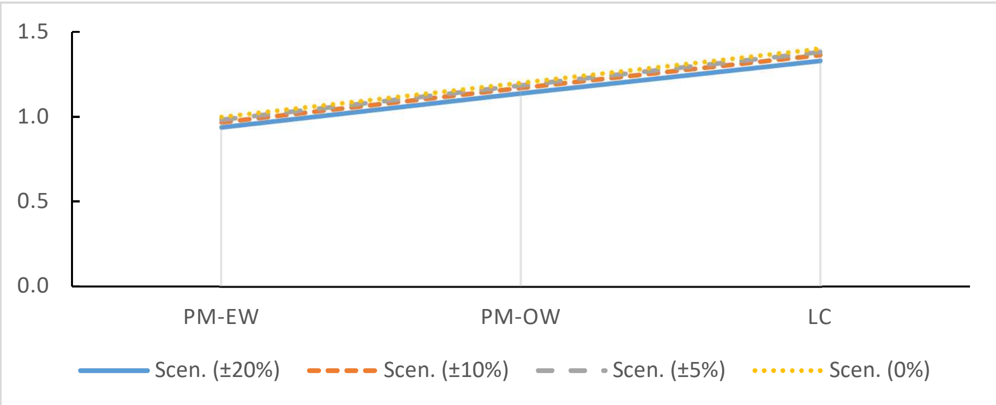


Figure 5- 23: Analyzed PPC ratio for 1st asphalt paving

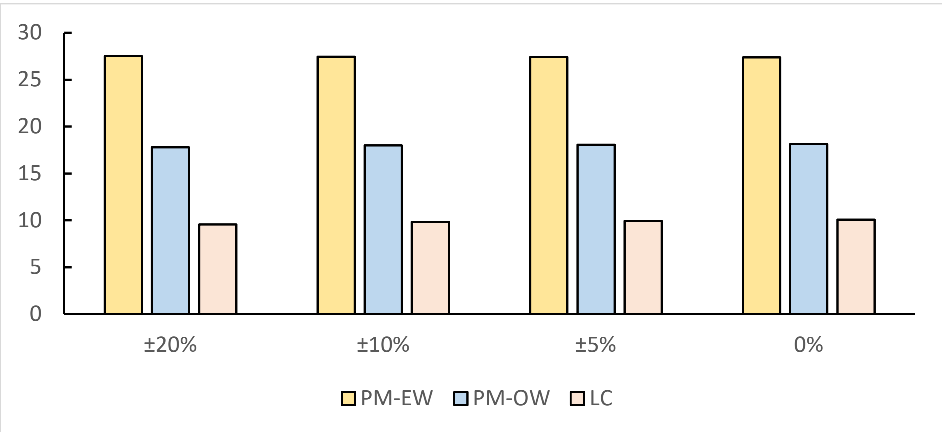


Figure 5- 24: PAW for 1st asphalt paving

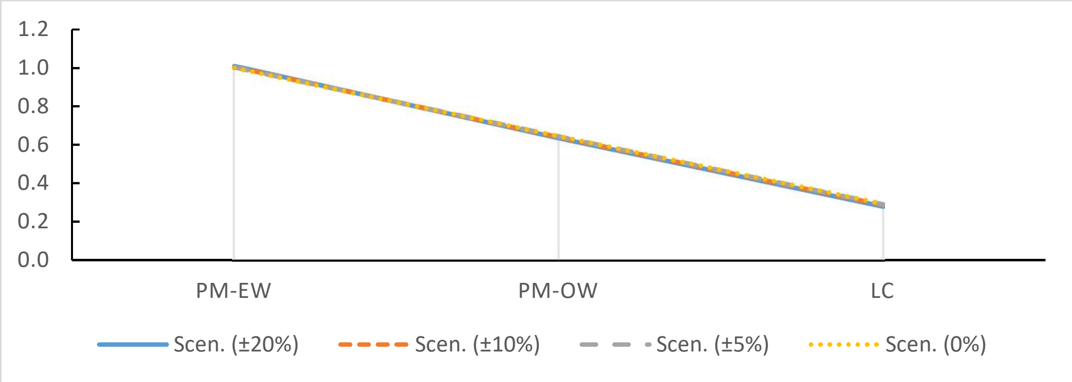


Figure 5- 25: Analyzed PAW ratio for 1st asphalt paving

Regarding the two activities, MC sprinkle and First asphalt paving, as all other activities they were applied in Simulations PM-OW, PM-EW and LC. The results of PPC for MC sprinkle are very high before and after reducing the wastes. This is the case because the expected duration for this activity is much higher than the actual duration. While for the other activity, First asphalt paving, the PPC results are between 65.58% and 69.84% in the simulations PM-EW, between 79.61% and 83.90% in the simulations PM-OW and between 92.94% and 97.92% in the simulations LC. For the first two simulations (PM-OW and PM-EW), the results of PPC are between 65.58% and 83.90%, which is regarded as a high value, due to the fact that the percentage of wastes is low. It is also worth mentioning that the value of PAW is high in the PM simulations and is between 10.18% and 10.69% in the LC simulations. For the simulation LC, the results of PPC for the First asphalt paving activity increased to become between 92.94% and 97.92%. As noted the values in the LC simulations are high due to the fact that in the PM simulations, the percentage of wastes in these activities is high, which is not the case in LC simulations since these wastes are reduced.

5.2.4 RC sprinkle and Second asphalt paving

Figures 5-26 to 5-33 and Tables 5-9 and 5-10 show the results for the two variables PPC, PAW and on each simulation PM-EW, PM-OW and LC. These values were for the RC sprinkle and 2nd asphalt paving activities.

g) **RC sprinkle**

The results for RC sprinkle, concerning PPC and PAW, are shown in Table 5-9 and Figures 5-26 to 5-29.

Table 5- 9: PPC and PAW for RC sprinkle [%]

Scenario	PPC [%]			PAW [%]		
	PM-EW	PM-OW	LC	PM-EW	PM-OW	LC
±20%	141.59	144.37	182.33	22.37	20.80	0.00
±10%	145.16	147.98	185.46	21.77	20.20	0.00
±5%	147.01	149.85	187.07	21.45	19.88	0.00
0%	148.77	151.83	188.71	21.12	19.56	0.00

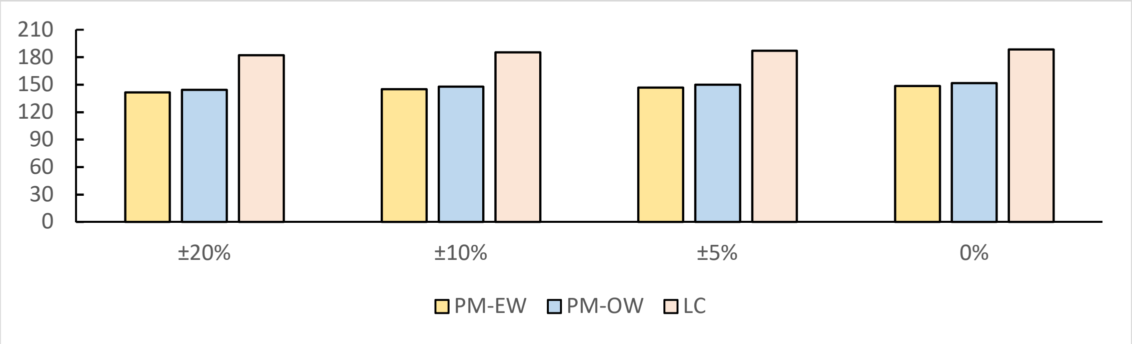


Figure 5- 26: PPC for RC sprinkle

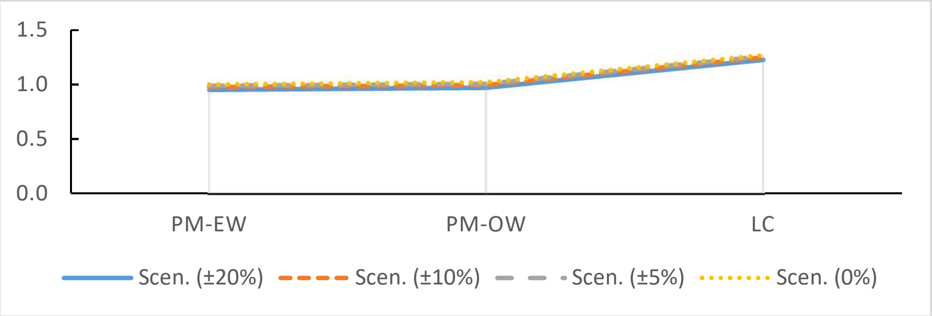


Figure 5- 27: Analyzed PPC ratio for RC sprinkle

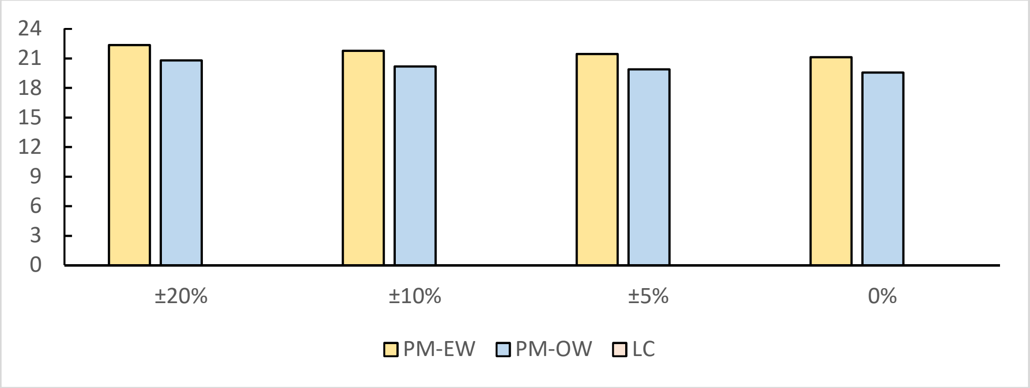


Figure 5- 28: PAW for RC sprinkle

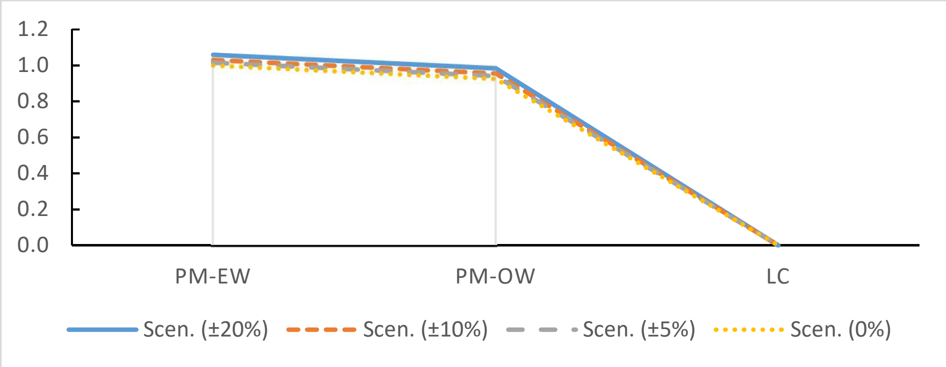


Figure 5- 29: Analyzed PAW ratio for RC sprinkle

h) **Second asphalt paving**

The results for 2nd asphalt paving, concerning PPC and PAW, are shown in Tables 5-10 and Figures 5-30 to 5-33.

Table 5- 10: PPC and PAW for 2nd asphalt paving [%]

Scenario	PPC			PAW		
	PM-EW	PM-OW	LC	PM-EW	PM-OW	LC
±20%	39.92	45.32	49.86	27.52	17.81	9.58
±10%	41.11	46.52	51.15	27.46	17.99	9.83
±5%	41.73	47.14	51.82	27.42	18.08	9.96
0%	42.37	47.78	52.39	27.37	18.15	10.08

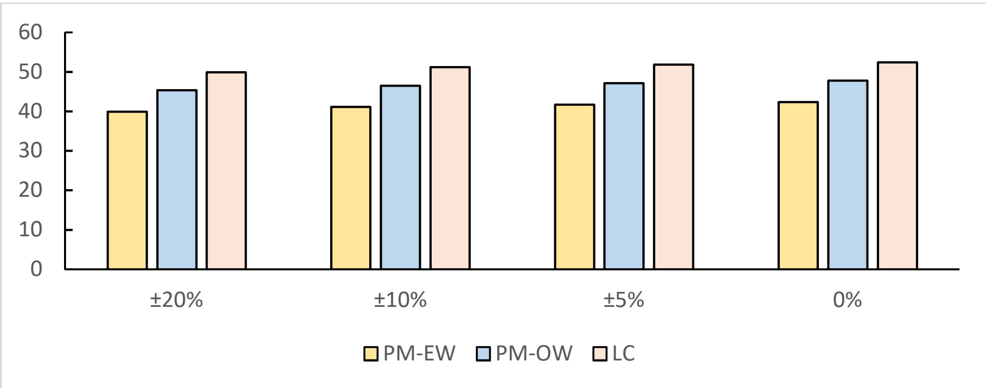


Figure 5- 30: PPC for 2nd asphalt paving

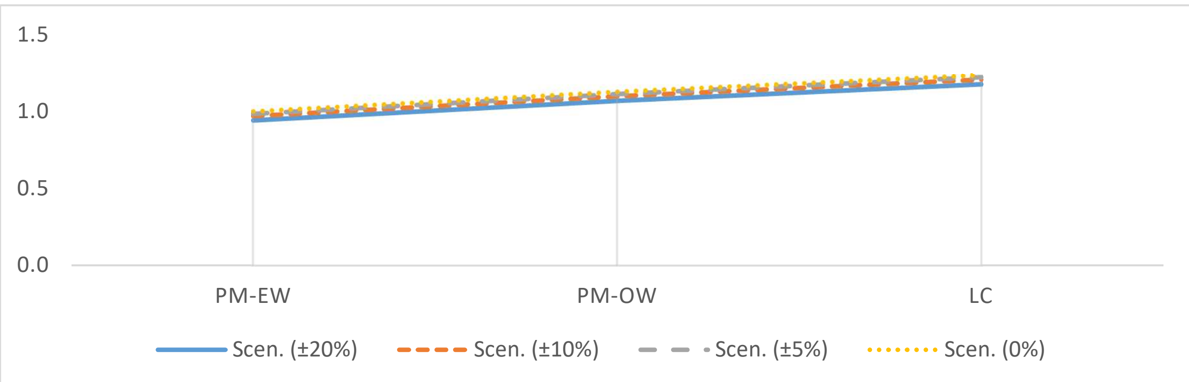


Figure 5- 31: Analyzed PPC ratio for 2nd asphalt paving

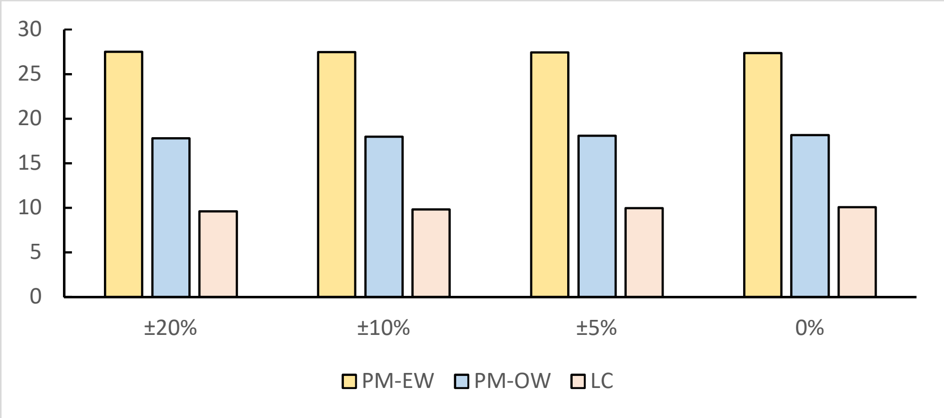


Figure 5- 32: PAW for 2nd asphalt paving

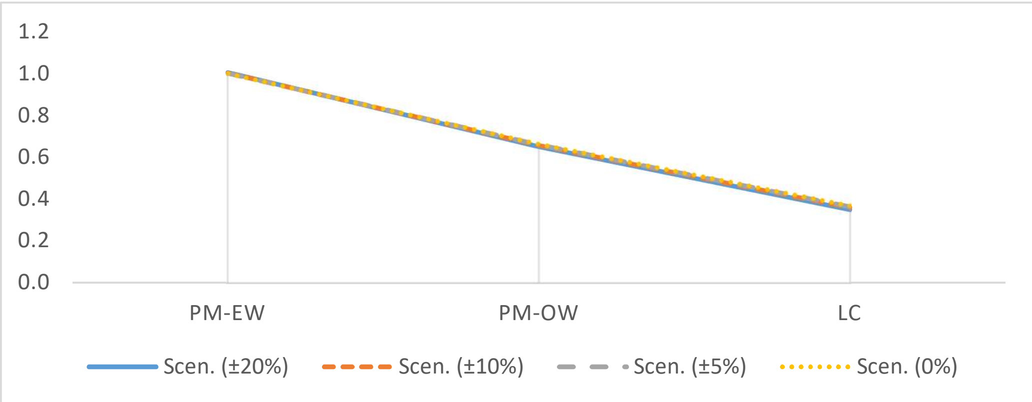


Figure 5- 33: Analyzed PAW ratio for 2nd asphalt paving

Regarding the RC sprinkle and Second asphalt paving activities, when applied in the Simulations PM-OW, PM-EW and LC, similar results analysis emerged. The results of PPC for RC sprinkle is very high before and after reducing the wastes. This is due to the fact that the expected duration (duration values estimated by engineers on site) for this activity is much higher than the actual duration. While for the other activity, Second asphalt paving, PPC results are between 45.32% and 47.78% in the simulation PM-OW, between 39.92% and 42.37% in the simulation PM-EW and between 49.86% and 52.39% in the simulation LC. For the first three simulations, PM-EW, PM-OW and LC, the results of PPC are lower than 50% because the–expected duration for this activity was very low. There is not high improvement after reducing some wastes in the Second asphalt paving; however, more improvement could be noted after reducing the same wastes in the First asphalt paving. The reason behind this is that the First asphalt paving's total material quantity is lower by 60% of the Second asphalt paving's total quantity. However, the First asphalt paving's expected duration is 110% more than the Second asphalt paving's expected duration. This is regarded as an unrealistic expectation due to the different quantities of material required for each activity; here the time plan for the activity (First asphalt paving) with less material is higher than the activity (Second asphalt paving) with more material.

5.3 Analysis

Scholars [284], [25], [136], [39], [48], [62], [251], [95] identified the results of Percentage Plan Complete (PPC) explaining the schedule performance. Higher values of PPC means higher productivity. For example, as shown in the findings, in Sub-base layers filling with material that were not from the site the PPC values in LC simulation increased between 192.35% to 199.05%, reflecting higher values than those in the PM simulation. It was stated that [103], [278], [139], [142], [129], [277], [236], [111], [121], [173], [147] the main aim for Lean Construction is avoiding wastes which lead to reducing the activity duration. In the first aggregate layers activity, after eliminating the wastes, the values of PPC increased between 169.68% to 175.62% in LC simulation. Additionally, the PAW in this activity ranges between 78.81% to 79.76% in the two PM simulations. This means, as scholars agree, that Lean Construction (LC) improves the process of eliminating the wastes from construction projects, which leads to increase in the productivity of each activity [103], [278], [139], [142], [129], [277], [236], [111], [121], [173], [147]. These improvements are shown in the values of PPC and PAW in all the studied project activities. Applied to all activities, the values of PPC in the LC simulation are higher than the PPC values in the PM simulations as demonstrated in the results. In contrast, the values of PAW in the LC simulation are lower than the PAW values in the PM simulations. The elimination of the wastes from the activity increases the values of PPC. This also results in a reduction of the final project duration. Consequently, the customer satisfaction increases as a result of reduced costs, higher quality and shorter total duration. The application of Lean Construction (LC) is based on the utilization of the lean tools (such as Last Planner System (LPS), Integrated Project Delivery (IPD), Total Productive Maintenance (TPM), etc.; the Lean Construction (LC) tools used in the study). These tools are used under Last Planner System (LPS), which is considered as a shield saving the project duration from the delays when used together with other tools. In other words, the reason behind the improvements in Lean Construction (LC) is its advanced tools which lead to overall improvements in time, cost and quality, [103], [278], [139], [142], [129], [277], [236], [111], [121], [173], [147], [284], [25], [136], [39], [48], [62], [251], [95], [1], [191], [196], [201], [2]. The results of PPC are calculated by using the Last Planner System (LPS) in the end of every week during the project execution. Additionally, the PhD candidate present a new variable –

PAW- which can be used in real projects to determine the time wasted in each activity. The PAW values can be calculated with PPC values at the end of each week.

5.4 Conclusion: Implications and Significance of the Findings

The main objective of conducting this case study and applying the input to the utilized simulation software is to highlight the merits of using the Lean Construction approach in road projects. The research focuses on one of the iron triangle sides; time, regarded as highly impactful on the other two; quality and cost. After running the three different simulations, findings reveal how using Lean tools has a positive influence over time planning in road projects. This has been demonstrated through focusing on the results of the two parameters; PPC and PAW.

The Rationale behind reflecting the results through these two parameters is how each relates to time planning of the different activities and sub-activities in the project. Percentage Plan Complete (PPC), on a weekly basis, reflects the efficiency of accomplishing each activity, productivity wise. In other words, it examines the accuracy of a time plan and its ability to detect potential wastes and eliminate them as stipulated by the Lean Construction approach. Percentage Activity Wastes (PAW), a parameter introduced by the researcher, which aims at detecting the percentage of time wasted during each activity. Through this parameter the effect of time wastes on the productivity in each activity is revealed. Hence, based on the findings demonstrated, the results of the two parameters support the essentiality of eliminating time wastes in order for productivity and efficiency to improve. Lean Construction emphasises on accurate planning of a project time schedule, mainly based on the elimination of wastes through utilizing specified Lean tools.

Running three different simulations gave the researcher a comparative view between Project Management and Lean Construction approaches in light of the observed road project. The results from the simulation PM-EW is regarded as the poorest when judging time planning. This comes as a result of the findings showing PPC at its lowest levels in all activities, while PAW values are at their highest levels. Moderate values resulted from the simulation PM-OW, since the wastes in this simulation are less than the wastes in PM-EW, leading to better results when it comes to PPC (higher) and PAW (lower). Findings show that the simulation LC achieves the best results when it comes to values of the two parameters; PPC reaching its highest value with PAW reaching its lowest values. In light of the wastes observed on site, and based on the reviewed literature, the researcher highlights Lean Construction tools - IPD, JIT and TPM – each tackling different types of wastes leading to their elimination. Hence, the findings from the simulation LC support these results.

Findings of this study support the statement that applying Lean Construction approach to road projects leads to tangible improvements in time planning. This is attained through addressing the root cause of the problem, in these case delays, by eliminating time wastes. The significance of this approach of management lies in its ability to predict the problem and avoid it through innovative tools designed specifically to address the different types of wastes. Applying this to the day-to-day site activities in road projects, boosting productivity and efficiency, reflects on the final result; the total project duration.

CHAPTER 4 CONCLUSION

6.1 Introduction

During the literature review phase, the PhD candidate was not able to find any comparison between Project Management (PM) approach and Lean Construction (LC) in an infrastructure project in previous studies. Accordingly, it is regarded as a research gap in the field addressing these topics. The aim of this research is exploring how different/similar PM and LC are when specifically applied to road projects, with the attempt to contribute to filling the research gap in this area. In this chapter the main conclusions of the research are presented through the summary of research findings. This is followed by displaying the most important contributions of this research to the academic body of knowledge and the construction industry. Accordingly, recommendations for the industry and for future studies are presented. Limitations of the study are also presented.

6.2 Summary of research findings

Highlighting the merits of applying the Lean Construction approach in road projects has been one of the main objectives of conducting the case study in this research. Based on the reviewed literature, the study put forward the hypothesis that the application of Lean Construction (LC) improves the overall performance in road projects. The research focuses on one of the iron triangle sides; time, regarded as highly impactful on the other two; quality and cost. After running the three different simulations, findings support the research hypothesis by revealing how using Lean tools has a positive influence over time planning in road projects. It is essential to mention that the simulations input is based on data collected from the observed road project. The research hypothesis was tested through focusing on results from the two parameters; PPC and PAW.

The simulation application stands on two main pillars: the input data (time related input – activities and wastes durations – and materials quantity), and parameters equations. Accordingly, three applications of the simulation were developed in order to set base for comparative analysis between using PM and LC approaches in road projects. Hence, two simulations feature applying the PM approach; one running based on the expected wastes and the other based on the actual observed wastes. The third simulation only features applying the LC approach, since there is no margin of difference between the expected and observed wastes in case of applying LC, as a result of wastes elimination under this approach.

The rationale behind reflecting the results through these two parameters is how each one relates to time planning of the different activities and sub-activities in the project. Percentage Plan Complete (PPC), on a weekly basis, reflects the efficiency of accomplishing each activity, productivity wise. In other words, it examines the accuracy of a time plan and its ability to detect potential wastes and eliminate them as stipulated by the Lean Construction approach. Percentage Activity Wastes (PAW), a parameter introduced by the researcher, which aims at detecting the percentage of time wasted during each activity. Through this parameter the effect of time wastes on the productivity in each activity is revealed.

Hence, based on the findings demonstrated, the results of the PPC and the PAW support the essentiality of eliminating time wastes in order for productivity and efficiency to improve. Lean Construction emphasises on accurate planning of a project time schedule, mainly based on the elimination of wastes through utilizing specified Lean tools.

Running three different simulations gave the researcher a comparative view between Project Management and Lean Construction approaches in light of the observed road project. The results from the simulation PM-EW are regarded as the poorest when judging time planning. This comes as a result of the findings showing PPC at its lowest levels in all activities, while PAW is at the highest levels. Moderate values resulted from the simulation PM-OW, since the wastes in this simulation are less than the wastes in PM-EW, leading to better results when it comes to PPC (higher) and PAW (lower). Findings show that the simulation LC achieves the best results when it comes to values of the two parameters; PPC reaching its highest value with PAW reaching its lowest values. In light of the wastes observed on site, and based on the reviewed literature, the researcher highlights Lean Construction tools - IPD, JIT and TPM – each tackling different types of wastes leading to their elimination. Hence, the findings from the simulation LC support these results.

Findings of this study support the statement that applying Lean Construction approach to road projects leads to tangible improvements in time planning. This is attained through addressing the root cause of the problem, in this case delays, by eliminating time wastes. The significance of this approach of management lies in its ability to predict the problem and avoid it through innovative tools designed specifically to address the different types of wastes. Applying this to the day to day site activities in road projects, boosting productivity and efficiency, reflects on the final result; the total project duration.

Project Management (PM) approach focuses on analysing the risks that can take place in the construction projects. An example of these risks is the delay in the project duration. These risks are not the root of the problem, while the main issue is the huge number of different time wastes, eventually leading to the risks. Hence, eliminating these wastes will consequently eliminate the risks. The Project Management approach does provide the tools to analyse potential risks like project delay, however it does not address the root causes of such risks; the time wastes. Although, scholars [233], [271] emphasize that a project will be successful by managing the projects' risks, still the quantitative risk analysis is rarely developed in many construction projects. The reason behind this is that in order to conduct such analysis, experience and data from previous projects is necessary, which is unfortunately not available in many instances. Three main arguments all related to risk emerged from the PM literature analysis; how the PM approaches risk analysis, time management and stakeholders' collaboration.

The first and most importance argument for the purpose of this study, is related to the PM not addressing the root causes of risks in real life projects as elaboratively explained in Chapter 2. Scholars [263], [151], [23], [164], [287] agree that, thanks to the fact that it is nearly impossible to find two similar construction projects, the construction industry has a higher number of risks than other industries. The second argument is concerned with the time management tool the Project Management (PM) approach; Critical Path Method (CPM). This tool helps in managing risks through using time buffers for the different activities on the project as explained before. It is essential to highlight that in the planning phase risks are a possibility that might or might not occur. This means that introducing buffers to the different activities result in time wastes in case that the anticipated risks did not occur. The third argument is concerned with lack of stakeholders collaboration under the PM approach. As a result of this lack of collaboration, risk transfer is resorted to; transferring the responsibility of risk occurrence from one stakeholder to another as elaboratively explained in Chapter 2. These arguments are further explicated in the empirical part of the study through the case study observed through a real life project as presented.

On the other hand, Lean Construction (LC) is regarded as a vital addition to the field as a potential solution to the many problems faced by construction projects. These problems eventually lead to an increase in the project's total cost and final duration, accompanied by a decrease in the quality and productivity of the project activities. Lean Construction (LC) targets to eliminate the project waste and deliver the maximum value to the customer with the best quality. This relatively new management concept requires the simultaneous use of Lean tools. Applying only one or two of these tools in the project means partial application of Lean Construction and may lead to the failure of the project. As demonstrated by this study's findings, Lean Construction seeks to propose solutions that minimize the final duration and increase the productivity of road projects by implementing the relevant Lean tools.

If Project Management (PM) approach is considered as an eye studying the construction project from a high point, then Lean Construction (LC) is regarded as an advanced lens that provide a far more accurate perspective.

6.3 Contribution and future recommendations

As aforementioned, this study is regarded as a contribution to the body of knowledge, considering that it presents a comparison between the PM approach and LC approach when applied to road projects. Based on the reviewed literature such comparative analysis, focusing on road projects is missing. A new variable, Percentage Activity Waste (PAW) is introduced in this study aiming at measuring the wastes duration in each activity in the project.

Accordingly, the study invites academics and those in the industry of construction to consider project planning from a different perspective focusing on addressing root causes of the problem rather than only anticipating risks. Two conference papers were presented and published from this study (Elkherbawy, Lozano, Ramos & Turmo, 2018a[1], Elkherbawy, Lozano, Ramos & Turmo, 2018b[2])

In light of the presented findings which support the positive impact of applying LC approach on time planning, the following recommendations are put forward:

- Future studies:

This study addresses time as one of three most essential factors in any project. Due to time limitation, the PhD candidate could not include cost and quality in the study. Accordingly, addressing these factors in a comparison between PM and LC approach is recommended for future research. As the case is with time, there are obstacles that stand in the way of efficiently planning for cost and quality in construction projects under the PM approach. Hence, investigating the impact of applying LC is important.

[1] ELKHERBAWY, A., LOZANO, J. A., RAMOS, G., & TURMO, J. (2018). Comparison of project management and lean construction in a real road project.

[2] ELKHERBAWY, A., LOZANO, J. A., RAMOS, G., & TURMO, J. (2018). Lean construction in road projects.

Further, the study develops the comparison between the two approaches (PM and LC) when applied on road projects. Research investigating this comparison in other types of construction project needs to be developed.

- Industry recommendations

As previously highlighted, among the obstacles of integrating LC to construction projects is the fear of change and lack of knowledge. Accordingly, it is essential to:

- conduct LC orientation and training programs to the policy and decision makers in order to spread knowledge about the approach
- shed light on best practices; projects that successfully applied LC to motivate the stakeholders to adopt it
- position LC as an innovative method of project planning that results in higher efficiency and productivity

6.4 Research limitations

- As aforementioned due to time limitation, the PhD candidate could not include cost and quality in the study. Integrating them to study requires a longer investigation period.
- Some activities in the studied project (such as MC, RC sprinkles and 2nd Asphalt layers) were not observed. The reason for that is the fact that some activities were scheduled for the far future (after the observation period, which lasted for 30 days), and others were executed in times that were not convenient for the PhD candidate to attend.
- Last Planner System (LPS) tool was used only theoretically – based on literature - in the study's simulations due to time limitation. Results might differ with real implementation.

6.5 Conclusion

This research supports and demonstrates that the application of lean concept on infrastructure road projects decreases the project duration, increases productivity and decreases the percentage of the waste duration. These improvements eventually lead to an increased reliability between project stakeholders, resulting in customer satisfaction with the results regarding the project duration.

Concerned with addressing the root causes of the problem, the PhD candidate introduced a new variable as previously mentioned; Percentage Activity Waste (PAW) is introduced in this study aiming at measuring the waste duration in each activity in the project. As demonstrated, PAW can be used in future studies for its utility in reflecting the waste percentage by dividing the time wasted in an activity by the Total duration of the activity, and hence extracting the wasted time. This variable meets the main aim of lean concept; the elimination of wastes. PAW is an effective parameter to use on a weekly basis of assess the percentage of wastes.

Bibliography

1. Abbasian-Hosseini, S., Nikakhtar, A., & Ghoddousi, P. (2014). Verification of Lean Construction Benefits through Simulation Modeling: A Case Study of Bricklaying Process. Civil Engineering, 18(5), 1248-1260.

2. Adamu, I., & Howell, G. (2012). Applying Last Planner in the Nigerian construction industry. Twentieth Annual Conference of the International Group for Lean Construction (IGLC-20), 2, 731-740. San Diego, California.

3. Adamu, S., & Adulhamid, R. (2016). Lean Construction Techniques for Transforming Nigeria Project Delivery Process - A Case Study Report. Indian Journal of Science and Technology, 9(48), 1-4.

4. Adekunle, O., & Ajibola, K. (2015). Factorial Causative Assesments and Effects of Building Construction Project Delays in Osun State, Nigeria, 4(3), 1-8. Journal Architectural Engineering Technology.

5. Adio-Moses, D., & Asaolu, O. (2016). Artificial intelligence for sustainable development of intelligent buildings, 446-454. 9th cidb Postgraduate Conference. Cape Town, South Africa.

6. Adio-Moses, D., & Oladiran, O. (2016). Smart City Strategy and sustainable Development Goals for building Construction Framework in Lagos, 1(1). The 5th International Conference on Infrastructure Development in Africa.

7. Adnan, H., Bachik, F., Supardi, A., & Marhani, M. (2012). Success Factors of Design and Build Projects in Public Universities. Asia Pacific International Conference on Environment-Behaviour Studies, 35, (pp. 170 – 179).

8. Adnan, H., Hashim, N., Marhani, M., & Johari, M. (2013). Project Management Success for Contractors, 7(2), 398-402. International Journal of Economics and Management Engineering.

9. Adnan, H., Yusuwan, N., Yusof, F., & Bachik, F. (2014). Critical Success Factors for Contractors, 2(2), 107-113. International Journal of Engineering and Technical Research.

10. Agyeman, S., Asare, E., & Ankomah, E. (2016). The Effects of Design Information on Reliability of Progress and Cost Estimates of Construction Projects: The Case of Two Civil Engineering Projects. American Journal of Civil Engineering, 4(6), 326-336.

11. Ahmed, M., Georgy, M., & Osman, H. (2014). Ontology-based Investigation of Construction Delay Analysis Methodologies in Egypt, 1428-1437. Construction Research Congress.

12. Ahuja, R., Sawhney, A., & Arif, M. (2016). Driving lean and green project outcomes using BIM: A qualitative comparative analysis, (6)1, 69-80. International Journal of Sustainable Built Environment.

13. Al Hattab, M., & Hamzeh, F. (2015). Using social network theory and simulation to compare traditionalversus BIM–lean practice for design error management. Automation in Construction, 52, 59–69.

14. Al Nasseri, H., & Aulin, R. (2016). Understanding Management Roles and Organisational Behaviours in Planning and Scheduling Based on Construction Projects in Oman. Journal of Construction in Developing Countries, 21(1), 1–18.

15. Al-Aomar, R. (2012a). A lean construction framework with Six Sigma rating. International Journal of Lean Six Sigma, 3(4), 299 - 314.

16. Al-Aomar, R. (2012b). Analysis of lean construction practices at Abu Dhabi construction industry, 105-121. Lean Construction Journal.

17. Alashwal, A., Abdul-Rahman, H., & Radzi, J. (2016). Knowledge Utilization Process in Highway Construction Projects, 32(4), 05016006. Journal of Management in Engineering.

18. Albogamy, A., Scott, D., & Dawood, N. (2013). Dilemma of Saudi Arabian Construction Industry, 3(4), 35-40. Journal of Construction Engineering and Project Management.

19. Albogamy, A., Scott, D., Dawood, N., & Bekr, G. (2013). Addressing crucial risk factors in the Middle East construction industries: a comparative study of Saudi Arabia and Jordan, 118-128. Sustainable Building Conference.

20. Almuharib, T. (2014). Service Quality Improvement Through Lean Management at King Khalid International Airport in Saudi Arabia. PhD thesis.

21. Alptekin, O., & Alptekin, N. (2017). Analysis of Criteria Influencing Contractor Selection Using TOPSIS Method, 245(6), 062003. IOP Conference Series: Materials Science and Engineering.

22. Alsendi, M. (2015). Studying the effect of decision making on delayed construction projects. Master thesis.

23. Aminbakhsh, S., Gunduz, M., & Sonmez, R. (2013). Safety risk assessment using analytic hierarchy process (AHP) during planning and budgeting of construction projects. Journal of Safety Research, 46, 99–105.

24. Andesen, B., Belay, A., & Seim, E. (2012). Lean construction practices and its effects: A case study, Norway. Lean construction journal, 122-149.

25. Andreu, G. (2016). Del Lean Thinking a la Lean Construction. Estudi de la filosofia i aplicació a un projecte constructiu. Bachelor thesis. Barcelona, Spain.

26. Anifowose, M., Ola-awo, W., & Mohammed, T. (2013). Assessment of Cost Management Functions of Quantity Surveyors with Lean Methodology, 4(2), 67-81. International Journal of Sustainable Construction Engineering & Technology.

27. Ankomah, E., Ayarkwa, J., & Agyekum, K. (2017). A theoretical review of lean implementation within construction SMEs. International conference on infrastructure development in Africa 7(1), (pp. 1675-1688). Kumasi, Ghana.

28. Ansah, R., Sorooshian, S., Mustafa, S., & Duvvuru, G. (2016a). Advancing Towards Delay-Free Construction Project: A Review. International Conference on Industrial Engineering and Operations Management, 744-751. Michigan, USA.

29. Ansah, R., Sorooshian, S., Mustafa, S., & Duvvuru, G. (2016b). Lean Construction Tools. International Conference on Industrial Engineering and Operations Management, (pp. 784-793). Michigan.

30. Arditi, D., Nayak, S., & Damci, A. (2017). Effect of organizational culture on delay in construction. International Journal of Project Management, 35(2), 136–147.

31. Arroyo, P., & Gonzalez, V. (2016). Rethinking Waste Definition to Account for Environmental and Social Impacts. The 24th Annual Conference of the International Group for Lean Construction, (pp. 13-22). Boston, USA.

32. Artto, K., Ahola, T., & Vartiainen, V. (2015). From the front end of projects to the back end of operations: Managing projects for value creation throughout the system lifecycle, 34(2), 258-270. International Journal of Project Management.

33. Asim, M., Deep, S., & Ahmad, S. (2017). Time Impact Study of Real Estate Sector Construction Projects Post Application of Lean Principles for Delay Resolutions. International Journal of Civil Engineering and Technology, 8(2), (pp. 89–99).

34. Asri, M., Nawi, M., Saad, R., Osman, W., & Anuar, H. (2016). Exploring lean construction component for Malaysian industrialized building system logistics management—A literature review. Advanced Science Letters, 22(5/6), 1593-1596.

35. Ayalew, M., Dakhli, M., & Lafhaj, Z. (2016). The future of lean construction in Ethiopian construction industry, 5(2), 107-113. International Journal of Engineering Research & Technology.

36. Ayarkwa, J., Agyekum, K., Adinyira, E., & Osei-Asibey, D. (2012). Perspectives for the implementation of Lean Construction in the Ghanaian construction industry, 2(2), 345-359. Construction Project Management and Innovation.

37. Azhar, N., Kang, Y., & Ahmad, I. (2015). Critical Look into the Relationship between Information and Communication Technology and Integrated Project Delivery in Public Sector Construction, 31(5), 04014091. Management in Engineering.

38. Aziz, R., & Abdel-Hakam, A. (2016). Exploring delay causes of road construction projects in Egypt. Alexandria Engineering Journal, 55, 1515–1539.

39. Aziz, R., & Hafez, S. (2013). Applying lean thinking in construction and performance improvement. Alexandria Engineering Journal, 52, 679–695.

40. Bajjou, M., Chafi, A., Ennadi, A., & El Hammoumi, M. (2017). The Practical Relationships between Lean Construction Tools and Sustainable Development: A literature review. Journal of Engineering Science and Technology, 10(4), 170-177.

41. Baladrón, C., & Alarcón, L. (2017). Assessing the Impact of Lean Methods in Mining Development Projects. The 25th Annual Conference of the International Group, 2, (pp. 137–144). Heraklion, Greece.

42. Balashova, E., & Gromova, E. (2017). Lean construction as an effective organization model in Arctic, 117, 00011. Theoretical Foundation of Civil Engineering.

43. Baroudi, B. (2014). Designing Postgraduate Project Management Programs for Success. Th fifth International Conference on Engineering, Project, and Production Management, (pp. 105-115). Port Elizabeth, South Africa.

44. Batool, A., & Abbas, F. (2017). Reasons for delay in selected hydro-power projects in Khyber Pakhtunkhwa (KPK), Pakistan. Renewable and Sustainable Energy Reviews, 73, 196–204.

45. Becker, T., Shane, J., & Jalselskis, E. (2012). Comparative Analysis of Lean Construction with Design-Build Using a Framework of Contractual Forms of Agreement. Journal of architectural engineering, 18(2), 187-191.

46. Bekdik, B., Hall, D., & Aslesen, S. (2016). Off-Site Prefabrication: What Does It Require from the Trade Contractor? 24th Ann. Conf. of the Int'l. Group for Lean Construction, (pp. 43–52). Boston, MA, USA.

47. Berroir, F., Harbouche, L., & Boton, C. (2015). Top down vs. Bottom up approaches regarding the implementation of lean construction through a French case study. 23rd Ann. Conf. of the Int'l. implementation of lean construction through a French case study. (pp. 29-31). Perth, Australia,: Research Gate.

48. Bhatla, A., & Leite, F. (2012). Integration Framework of Bim with the Last Planner System. The 20th Annual Conference of the International Group for Lean Construction.

49. Bodkhe, A., Waghamare, A., & Patil, S. (2017). Investigation and Minimization of Construction Wastage Using Lean Technology in Construction . International Research Journal of Engineering and Technology (IRJET), 4(5), 2408-2412.

50. Bolzan, W., Formoso, C., & Tzortzopoulos, P. (2017). Planning and controlling design in engineered-to-order prefabricated building systems, 25(2), 134-152. Engineering, Construction and Architectural Management.

51. Brady, D. (2014). Using visual management to improve transparency in planning and control in construction. PhD thesis.

52. Braimah, N. (2013). Construction delay analysis techniques—A review of application issues and improvement needs. Building, 3, 506-531.

53. Brioso, X., & Humero, A. (2016). Incorporating Lean Construction agent into the Building Standards: Act the Spanish case study, 8(1), 1511-1517. Organization, Technology and Management in Construction.

54. Brioso, X., Humero, A., Murguia, D., Corrales, J., & Aranda, J. (2017). Using post-occupancy evaluation of housing projects to generate value for municipal governments, 57(2), 885-896. Alexandria Engineering Journal.

55. Burger, M. (2013). Project management in the built environment: the need for industry specific knowledge. PhD thesis.

56. Chedas Fàbregas, A. (2012). To Introduce the Lean Management philosophy as a way of thinking and acting to minimize waste in planning, organization and implementation processes, focusing in basic building constructions. Master thesis. Barcelona, Spain: Universitat Politècnica de Catalunya.

57. Chiarini, A. (2014). Sustainable manufacturing-greening processes using specific Lean Production tools: an empirical observation from European motorcycle component manufacturers85, 226-233. Cleaner Production.

58. Chiu, B., & Lai, J. (2017). Project delay: key electrical construction factors in Hong Kong, 23(7), 847-857. Journal of Civil Engineering and Management, 847–857.

59. Chowdhury, M. (2016). Simulation Of Value Stream Mapping And Discrete Optimization Of Energy Consumption In Modular Construction. Master thesis.

60. Cristóba, J. (2014). Cost allocation between activities that have caused delays in a project using game theory. International Conference on Project Management, 16, (pp. 1017 – 1026).

61. Cserháti, G., & Szabó, L. (2014). The relationship between success criteria and success factors in organisational event projects. International Journal of Project Management, 32(4), 613–624.

62. Ćwik, K., & Rosłon, J. (2017). Last planner system in construction, 117, 00032. Theoretical Foundation of Civil Engineering.

63. Daniel, E., & Pasquire, C. (2017). Last Planner System Path Clearing Approach (LPS-PCA): an approach to guide; clients, main contractors and subcontractors in the implementation of the LPS. Nottingham, UK: Nottingham Trent University.

64. Daniel, E., Pasquire, C., & Ameh, O. (2014). The magic of the Last Planner® System for Nigerian construction, 605-616. The 20th Annual Conference of the International Group on Lean Construction. Oslo, Norway.

65. Daniel, E., Pasquire, C., & Dickens, G. (2015). Exploring the implementation of the Last Planner® System. The 20th Annual Conference of the International Group on Lean Construction, (pp. 153-162). Perth, Australia.

66. Dave, B. (2013). Developing a construction management system based on Lean Construction and Building Information Modelling. PhD thesis.

67. Dave, B., Hämäläinen, J.-P., & Koskela, L. (2015). Exploring the Recurrent Problems in the Last Planner Implementation on Construction Projects. Proceedings of the Indian Lean Construction Conference (ILCC 2015).

68. Desai, M., & Dhawale, A. (2017). Review of application of Six Sigma in the construction industry. International Journal of Engineering Sciences & Research Technology.

69. Dias, M., Tereso, A., Braga, A., & Fernandes, A. (2014). The Key Project Managers' Competences for Different Types of Projects, 1, 359-368. New Perspectives in Information Systems and Technologies.

70. Dinesh, S., Sethuraman, R., & Sivaprakasam, S. (2017). The review on Lean Construction an effective approach in construction industry, 119-123. International Journal of Engineering Research and Modern Education.

71. Ding, Z., Zuo, J., Wu, J., & Wang, J. (2015). Key factors for the BIM adoption by architects: a China study, 22(6), 732-748. Engineering, Construction and Architectural Management.

72. Dinis-Carvalho, J., & Fernandes, S. (2016). Student´ s role in the Implementation of a Lean Teaching and Learning Model, 6, 284-293. 8th International Symposium on Project Approaches in Engineering Education (PAEE) and 14th Active Learning in Engineering Education Workshop (ALE). Guimarães: Project Approaches in Engineering Education Association and Department of Production and Systems, School of Engineering of University of Minho.

73. Dixit, S., Mandal, S., Sawhney, A., & Singh, S. (2017). Area of Linkage Between Lean Construction and Sustainability in Indian Construction Industry, 8(8), 623-636. International Journal of Civil Engineering and Technology (IJCIET).

74. Doloi, H. (2013). Cost Overruns and Failure in Project Management: Understanding the Roles of Key Stakeholders in Construction Projects. Journal of Management in Engineering, 139(3), 267-279.

75. Doloi, H., Sawhney, A., Iyer, K., & Rentala, S. (2012). Analysing factors affecting delays in Indian construction projects. International Journal of Project Management, 30(4), 479–489.

76. Dos Santos, G., & Tokede, O. (2016). Last Planner System - from theory to implementation, 305-318. The 10th Cost Engineering, Quantity Surveying & Project Management World Congress. Research Gate.

77. Drevland, F., Lohne, J., & Klakegg, O. (2017). Ethical Dilemmas in Value Delivery: Theoretical Conditions. 25th Annual Conference of the International Group for Lean Construction (IGLC) (pp. 145–152). Heraklion, Greece: Research Gate.

78. Drohomeretski, E., Costa, S., Lima, E., & Garbuio, P. (2013). Lean, Six Sigma and Lean Six Sigma: an analysis based on operations strategy. Production Research, 52(3), 804-824.

79. Durdyev, S., Omarov, M., & Ismail, S. (2017). Causes of delay in residential construction projects in Cambodia, 4(1), 121117. Cogent Engineering.

80. Dziadosz, A., & Rejment, M. (2017). Risk analysis in construction project - chosen methods. Operational Research in Sustainable Development and Civil Engineering - meeting of EURO working group and 15th German-Lithuanian-Polish colloquium, 122, (pp. 258 – 265).

81. El Asmar, M., Hanna, A., & Loh, W.-Y. (2013). Quantifying Performance for the Integrated Project Delivery System as Compared to Established Delivery Systems. 139(11), 04013012, Construction Engineering and Management.

82. El Asmar, M., Hanna, A., & Loh, W.-Y. (2015). Evaluating Integrated Project Delivery Using the Project Quarterback Rating, 142(1), 04015046. Journal of Construction Engineering and Management.

83. Elhaniash, F., & Stevovic, S. (2016). Towards factors affecting delays in construction projects: A case of Libya. International Journal of Applied Research, 2(5), 1078-1081.

84. Emam, H., Farrell, P., & Abdelaal, M. (2015). Causes of Delay on Large Infrastructure Projects in Qatar. 31st Annual ARCOM Conference, (pp. 773-782). Lincoln, UK.

85. Emdanat, S., & Azambuja, M. (2016). Aligning Near and Long Term Planning for LPS Implementations: A Review of Existing and New Metrics. Lean Construction Journal, 90-101.

86. Fakhimi, A. (2017). Is IPD made adequate infrastructure for utilizing LC AND BIM? The 1st International & 3rd National Conference of Construction & Project Management.

87. Fullalove, L. (2013). Examples of Lean techniques and methodology applied to UK road schemes, 1057-1066. International Group for Lean Construction (IGLC). Fortaleza, Brazil.

88. Gade, R. (2016). A Proposed Solution to the Problem of Construction Industry Overruns: Lean Construction Techniques and Linear Programming, 9(25). Indian Journal of Science and Technology.

89. Gambo, N., Said, I., & Ismail, R. (2016). Influences of Cost Factors Affecting Technical Performance of Local Government Projects in Nigeria: A Partial Least Square-StructuralEquation Modeling (PLS-SEM) Approach. Journal of Construction in Developing Countries, 21(1), 85–111.

90. Ghadamsi, A. (2016). Investigating the Influence of Procurement Method Selection on Project Performance in Libya. PhD thesis.

91. Ghoddousi, P., Ansari, R., & Makui, A. (2016). An improved robust buffer allocation method for the project scheduling problem, 49(4), 718-731. Engineering optimization.

92. Ghoddousi, P., Ansari, R., & Makui, A. (2017). A Risk-Oriented Buffer Allocation Model Based on Critical Chain Project Management, 21(5), 1536-1548. Journal of Civil Engineering.

93. Giuda, G., Villa, V., Giana, P., Tagliabue, L., & Ciribini, A. (2017). Lean construction applied to a BIM process: how to control point attribution in MEAT tender process. Technology, Engineering, Materials and Architecture, 3(1), 35-44.

94. Glenn, S. (2015). Public and private sectors preferences with regard to the briefing process. Master thesis.

95. Gomes, D., Koskela, L., Biotto, C., Talebi, S., & Pikas, E. (2017). Shared understanding in construction: a conceptual synthesis. 5th Workshop When Social Sciences meet Lean and BIM.

96. Gowtham, R., & Sivakumar, A. (2017). A review on the implementation of Last Planner System, 4(3), 88-90. International Journal of Engineering Technology Science and Research.

97. Gudienė, N., Banaitis, A., & Banaitienė, N. (2013). Evaluation of critical success factors for construction projects – an empirical study in Lithuania. International Journal of Strategic Property Management, 17(1), 21-31.

98. Gudienė, N., Banaitis, A., Podvezko, V., & Banaitienė, N. (2014). Identification and evaluation of the critical success factors for construction projects in Lithuania: AHP approach, 20(3), 350–359. Journal of Civil Engineering and Management.

99. Guerrero, M., Villacampa, Y., & Montoyo, A. (2014). Modeling construction time in Spanish building projects. International Journal of Project Management, 32(5), 861–873.

100. Gustafsson, A., Vessby, J., & Rask, L.-O. (2012). Identification of potential improvement areas in industrial housing: A case study of waste, 61-71. Lean Construction Journal.

101. Gutierrez-Bucheli, L., Caldarón, M., Londoño-Acevedo, M., & Ponz-Tienda, J. (2016). BIM and IPD as vehicle in the teaching and learning process of Project delivery in civil engineering, 192-201. The 9th annual International Conference of Education, Research and Innovation. Seville, Spain.

102. Gutierrez-Bucheli, L., Romero-Cortes, J., Calderón, M., Londoño-Acevedo, M., & Ponz-Tienda, J. (2017). Senda matrix software as a control and planning tool for project delivery in civil engineering, 3315-3322. INTED2017 Conference. Valencia, Spain: ResearchGate.

103. Haarr, K., & Drevland, F. (2016). A Mandated Lean Construction Delivery System In a Rehab Project – A Case Study. The 24th Ann. Conf. of the Int'l. Group for Lean Construction, (pp. section 3, 3-12). Boston, MA, USA.

104. Hamdar, Y., Kassem, H., Srour, I., & Chehab, G. (2015). Performance-Based Specifications for Sustainable Pavements: A Lean Engineering Analysis. International Conference on Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES15 (74, pp. 453 – 461). Elsevier Ltd.

105. Hamzeh, F. (2009). Improving Construction Workflow- The Role of Production Planning and Control. PhD thesis. CALIFORNIA, USA: Research Gate.

106. Hamzeh, F., & Aridi, O. (2013). Modeling the Last Planner System metrics: a case study of an aec company, 599-608. International Group for Lean Construction . Fortaleza, Brazil.

107. Hamzeh, F., Ballard, G., & Tommelein, I. (2012). Rethinking Lookahead Planning to Optimize Construction Workflow. Lean Construction, 15-34.

108. Hamzeh, F., Kallassy, J., Lahoud, M., & Azar, R. (2016). The First Extensive Implementation of Lean and LPS in Lebanon: Results and Reflections. 24th Ann. Conf. of the Int'l. Group for Lean Construction (pp. section 6, 33–42). Boston, MA, USA: Research Gate.

109. Hamzeh, F., Morshed, F., Jalwan, H., & Saab, I. (2012). Is Improvisation Compatible with Lookahead Planning? An Exploratory Study, 20. Annual Conference of the International Group for Lean Construction. Research Gate.

110. Hamzeh, F., Zankoul, E., & El Sakka, F. (2016). Removing Constraints to Make Tasks Ready in Weekly Work Planning. Creative Construction Conference, (164, pp. 68 – 74).

111. Heyl, J. (2015). Lean Simulation in Road Construction: Teaching of basic Lean Principles. 23rd Ann. Conf. of the Int'l. Group for Lean Construction., (pp. 403-412). Perth.

112. Hosseini, S., Nikakhtar, A., & Ghoddousi, P. (2012). Flow Production of Construction Processes through Implementing Lean Construction Principles and Simulation, 4(4), 475-479. International Journal of Engineering and Technology.

113. Hossen, M., Kang, S., & Kim, J. (2015). Construction schedule delay risk assessment by using combined AHP-RII methodology for an international NPP project. Nuclear Engineering and Technology, 47, 362-379.

114. Hsu, P.-Y., Aurisicchio, M., & Angeloudis, P. (2017). Investigating Schedule Deviation in Construction Projects through Root Cause Analysis. International Conference on Project Management, (121, pp. 732–739). Barcelona, Spain.

115. Hui, J., Abdul-Rahman, H., & Chen, W. (2017). Design Change Dynamics in Building Project: From Literature Review to A Conceptual Framework Formulation, 8(1), 13-33. Journal of Surveying, Construction and Property.

116. Hussain, S., Krishna, B., & Kumar, V. (2014). Application and analysis of Last Planner System in the construction industry. International Journal of Research in Engineering & Technology, 2(6), 33-44.

117. Hussain, S., Nama, A., & Fatima, A. (2016). Barriers to Implement Lean Principles in the Indian Construction Industry, 3(1), 1-6. International Journal of Innovative Research in Advanced Engineering.

118. Ibrahim, M. (2016). Modeling, Benchmarking, and Maximizing Project Delivery Performance. Master thesis.

119. Idiake, J. (2014). The effects ofproductivityand work flow variability on construction jobsite labour performance in Nigeria. PhD thesis. NIGERIA.

120. Ihuah, P., Kakulu, I., & Eaton, D. (2014). A review of Critical Project Management Success Factors (CPMSF) for sustainable social housing in Nigeria. International Journal of Sustainable Built Environment, 3, 62–71.

121. Ingle, A., & Waghmare, A. (2015). Advances in Construction: Lean Construction for Productivity enhancement and waste minimization, 2(11), 19-23. International Journal of Engineering and Applied Sciences (IJEAS).

122. Iram, N., Khan, B., & Sherani, A. (2016). Critical factors influencing the project success: an analysis of projects in manufacturing and construction in Pakistan, 6(2), 20-24. Arabian Journal of Business and Management Review (Oman Chapter).

123. Islam, M., & Khadem, M. (2013). Productivity determinants in Oman construction industry, 12(4), 426-448. International Journal of Productivity and Quality Management.

124. Islam, M., & Trigunarsyah, B. (2017). Construction Delays in Developing Countries: A Review, 7(1), 1-12. Journal of Construction Engineering and Project Management.

125. Islam, M., Nepal, M., Skitmore, M., & Attarzadeh, M. (2017). Current research trends and application areas of fuzzy and hybrid methods to the risk assessment of construction projects. Advanced Engineering Informatics, 33, 112–131.

126. Islam, M., Trigunarsyah, B., Hassanain, M., & Assaf, S. (2015). Causes of Delay in Construction Projects in Bangladesh, 82-86. The 6th International Conference on Construction Engineering and Project Management. Busan, Korea.

127. Issa, U. (2013). Implementation of lean construction techniques for minimizing the risks effect on project construction time, 52, 697-704. Alexandria Engineering Journal.

128. Jalal, M., & Koosha, S. (2015). Identifying organizational variables affecting project management office characteristics and analyzing their correlations in the Iranian project-oriented organizations of the construction industry. International Journal of Project Management, 33, 458–466.

129. Jeong, W., Chang, S., Son, J., & Yi, J.-S. (2016). BIM-Integrated Construction Operation Simulation for Just-In-Time Production Management, 8(11), 1106. Multidisciplinary Digital Publishing Institute (MDPI).

130. Jin, Z., Deng, F., Li, H., & Skitmore, M. (2013). Practical Framework for Measuring Performance of International Construction Firms. Journal of Management in Engineering, 139(9), 1154-1167.

131. Johansson, M., & Silversten, T. (2016). Collaboration between Design and Construction. Master thesis. Gothenburg, Sweden: Chalmers university of technology.

132. Johnsen, C., & Drevland, F. (2016). Lean and sustainability: three pillar thinking in the production process. 24th Ann. Conf. of the Int'l. Group for Lean Construction, (24, pp. 23–32). Boston, MA, USA.

133. Jones, B. (2014). Integrated project delivery (IPD) for maximizing design and construction considerations regarding sustainability, 95, 528-538. 2nd International Conference on Sustainable Civil Engineering Structures and Construction Materials, (pp. 528 – 538).

134. Joseph, N. (2017). Conceptualising a multidimensional model of information communication and technology project complexity, 19(1), 1-14. South African Journal of Information Management.

135. Joslin, R., & Müller, R. (2015). Relationships between a project management methodology and project success in different project governance contexts. International Journal of Project Management, 33(6), 1377–1392.

136. Juarez, J., & Erichsen, E. (2016). A Supplier-Oriented LPS Framework. Master thesis.

137. Jung, W., Ballard, G., Kim, Y.-W., & Han, S. (2012). Understanding of Target Value Design for Integrated Project Delivery with the Context of Game Theory, 556-563. Construction Research Congress.

138. Kahvandi, Z., Saghatforoush, E., Alinezhad, M., & Noghli, F. (2017). Integrated Project Delivery (IPD) Research Trends. Journal of Engineering, Project, and Production Management, 7(2), 99-114.

139. Kaipainen, A. (2017). Developing resource-efficient aggregate stone use with lean thinking: case study of an urban area development project. Master thesis.

140. Kalsaas, B. (2012). The Last Planner System Style of Planning: Its Basis in Learning Theory. Engineering, Project, and Production Management, 2(2), 88-100.

141. Kalu, U., Lew, T., & Sim, A. (2013). Relationship between leadership style and project success among IT Professionals in Nigeria: Implications to Project Management. Australian Journal of Basic and Applied Sciences, 7(12), 74-83.

142. Kawish, S. (2017). Identifying and prioritizing barriers and overcoming strategies in implementing Lean Construction principles and methods within transportation projects. Master thesis.

143. Kerosuo, H., Mäki, T., Codinhoto, R., Koskela, L., & Miettinen, R. (2012). In Time at Last – Adoption of Last Planner tools for the Design Phase of a Building Project. The 20th Annual Conference of the International Group for Lean Construction, (pp. 1031-1041).

144. Khan, K., Turner, R., & Maqsood, T. (2013). Factors that influence the success of public sector projects in Pakistan, 1-25. In Proceedings of IRNOP 2013 Conference.

145. Khanh, H., & Kim, S. (2016). A Survey on Production Planning System in Construction Projects Based on Last Planner System, 20(1), 1-11. Journal of Civil Engineering.

146. Khodeir, L., & Othman, R. (2016). Examining the interaction between lean and sustainability principles in the management process of AEC industry. Ain Shams Engineering Journal.

147. Kivistö, G., & Ohlsson, H. (2013). Expanding Lean into Transportation Infrastructure Construction. Master thesis. Gothenburg, Sweden.

148. Knotten, V., Svalestuen, F., Lædre, O., & Hansen, G. (2016). Improving Design Management with Mutual Assessment. 24th Ann. Conf. of the Int'l. Group for Lean Construction, (pp. section 4, 173-182). Boston, MA, USA.

149. Kuklare, P., & Hedaoo, M. (2017). Feasibility of Application of 5'S Methodology in Construction Industry. International Journal of Scientific Research in Science and Technology, 3(1), 144-147.

150. Kumar, D. (2016). Causes and Effects of Delays in Indian Construction Projects, 3(4), 1831-1837. International Research Journal of Engineering and Technology.

151. Kuo, Y.-C., & Lu, S.-T. (2013). Using fuzzy multiple criteria decision making approach to enhance risk Using fuzzy multiple criteria decision making approach to enhance risk. International Journal of Project Management, 31, 602–614.

152. Kyere, P. (2016). Enablers of Lean Construction Concept to Affordable Housing Schemes in Ghana. Master thesis. Kumasi, Ghana.

153. Lagos, C., Herrera, R., & Alarcón, L. (2017). Contribution of Information Technologies to Last Planner System Implementation. The 25th Annual Conference of the International Group for Lean Construction (IGLC), (1, pp. 87–94). Heraklion, Greece.

154. Larsen, J., Shen, G., Lindhard, S., & Brunoe, T. (2016). Factors Affecting Schedule Delay, Cost Overrun, and Quality Level in Public Construction Projects, 32(1), 04015032. Journal of Management in Engineering.

155. Laurent, J. (2017). Cross-functional project teams in construction: a case study. Master thesis.

156. Lee, H. (2012). Application of Target Value Design to Energy Efficiency Investments. PhD thesis.

157. Lee, H., Anderson, S., Kim, Y.-W., & Ballard, G. (2014). Advancing Impact of Education, Training, and Professional Experience on Integrated Project Delivery, 19(1), 8-14. Practice Periodical on Structural Design and Construction.

158. Lee, H., Tommelein, I., & Ballard, G. (2013). Energy-Related Risk Management in Integrated Project Delivery, 139(12), A4013001. Construction Engineering and Management .

159. Lehtiranta, L. (2014). Risk perceptions and approaches in multi-organizations: A research review 2000–2012. International Journal of Project Management, 32(4), 640–653.

160. Lessing, B., Thurnell, D., & Durdyev, S. (2017). Main Factors Causing Delays in Large Construction Projects: Evidence from New Zealand. Journal of Management, Economics, and Industrial Organization, 1(2), 63-82.

161. Li, H., Al-Hussein, M., Lei, Z., & Ajweh, Z. (2013). Risk identification and assessment of modular construction utilizing fuzzy analytic hierarchy process (AHP) and simulation, 40(12), 1184-1195. Canadian Journal of Civil Engineering.

162. Li, S., Wu, X., Zhouc, Y., & Liu, X. (2017). A study on the evaluation of implementation level of lean construction in two Chinese firms. Renewable and Sustainable Energy Reviews, 71, 846–851.

163. Liu, J., Xie, Q., Xia, B., & Bridge, A. (2017). Impact of Design Risk on the Performance of Design-Build Projects, 143(6), 04017010. Journal of Management in Engineering.

164. Liu, J., Zhao, X., & Yan, P. (2016). Risk Paths in International Construction Projects: Case Study from Chinese Contractors, 142(6), 05016002. Journal of Construction Engineering and Management.

165. Liu, R., & Chua, V. (2016). Theoretical digitalization of information flow in the construction supply chain, 5(1), 10-27. International Journal of Management Research and Business Strategy.

166. Locatelli, G., Mancini, M., Gastaldo, G., & Mazza, F. (2013). Improving Projects Performance With Lean Construction: State Of The Art, Applicability And Impacts. Organization, technology and management in construction, 5, 775 - 783.

167. Locatelli, G., Mikic, M., Brookes, N., & Kovačević, M. (2017). The Successful Delivery of Megaprojects: A Novel Research Method, 48(5), 78-94. Project Management Journal.

168. Ma, T., & Voo, M. (2014). A Comparative Study of Construction Joint Ventures in Australia and Malaysia. The fifth International Conference on Engineering, Project, and Production Management, (pp. 45-54). Port Elizabeth, South Africa.

169. Ma, T., Luong, C., & Zuo, J. (2014). A Study of the Skills of Construction Project Managers in Australia and Their Needs for Training and Certification. The fifth International Conference on Engineering, Project, and Production Management, (pp. 55-73). Port Elizabeth, South Africa.

170. Mandujano, M., Alarcón, L., Kunz, J., & Mourgues, C. (2016). Identifying waste in virtual design and construction practice from a Lean Thinking perspective: A meta-

analysis of the literature. Red de Revistas Científicas de América Latina y el Caribe, 107-118.

171. Mante, J., Ndekugri, I., Ankrah, N., & Hammond, F. (2012). The influence of procurement methods on dispute resolution mechanism choice in construction, 979-988. 28th annual association of researchers in construction management. Edinburgh, UK.

172. Marhani, M., Jaapar, A., & Bari, N. (2012). Lean Construction: Towards enhancing sustainable construction in Malaysia. ASIA Pacific International Conference on Environment-Behaviour Studies (68, pp. 87 – 98). Cairo, Egypt: Science Direct.

173. Marhani, M., Jaapar, A., Bari, N., & Zawawi, M. (2013). Sustainability through Lean Construction Approach: A literature review. AMER International Conference on Quality of Life, (101, pp. 90 – 99). Langkawi, Malaysia.

174. Marzouk, M., & El-Rasas, T. (2014). Analyzing delay causes in Egyptian construction projects. Journal of Advanced Research, 5(1), 49–55.

175. Marzouk, M., Bakry, I., & El-Said, M. (2012). Assessing design process in engineering consultancy firms using lean principles. Simulation, 88(12), 1522-1536.

176. Marzouk, M., El Kherbawy, A., & Khalifa, M. (2013). Factors influencing sub-contractors selection in construction projects. Housing and Building National Research Center, 9(2), 150–158.

177. Maués, L., Santana, W., Santos, P., Neves, R., & Duarte, A. (2017). Construction delays: a case study in the Brazilian Amazon. Associação Nacional de Tecnologia do Ambiente Construído, 17(3), 167-181.

178. Mavasa, A. (2017). The influence of unrealistic initial contract duration on time performance of construction projects in South Africa. Master thesis.

179. McCord, J., McCord, M., Davis, P., Haran, M., & Rodgers, W. (2015). Understanding delays in housing construction: evidence from Northern Ireland. Journal of Financial Management of Property and Construction, 20(3), 286-319.

180. Mehlawat, M., & Gupta, P. (2016). A new fuzzy group multi-criteria decision making method with an application to the critical path selection. The International Journal of Advanced Manufacturing Technology, 83(5-8), 1281-1296.

181. Meiling, J., Backlund, F., & Johnsson, H. (2012). Managing for continuous improvement in off-site construction. Engineering, Construction and Architectural Management, 19(2), 141 - 158.

182. Memon, A. (2014). Contractor Perspective on Time Overrun Factors in Malaysian Construction Projects. International Journal of Science, Environment and Technology, 3(3), 1184 – 1192.

183. Memon, A., Abdul Rahman, I., & Memon, I. (2014). Rule Based DSS in Controlling Construction Waste, 11(6), 417-424. Life Science Journal.

184. Memon, A., Abdul Rahman, I., Akram, M., & Ali, N. (2014). Significant Factors Causing Time Overrun in Construction Projects of Peninsular Malaysia, 8(4), 16-28. Modern Applied Science.

185. Meng, X. (2012). The effect of relationship management on project performance in construction, 30(2), 188-198. International Journal of Project Management, 188–198.

186. Mihic, M., Sertic, J., & Zavrski, I. (2014). Integrated project delivery as integration between solution development and solution implementation. 27th IPMA World Congress (119, pp. 557 – 565). Elsevier Ltd.

187. Minchin Jr., R., Li, X., Issa, R., & Vargas, G. (2013). Comparison of Cost and Time Performance of Design-Build and Design-Bid-Build Delivery Systems in Florida, 139(10), 04013007. Journal of Management in Engineering.

188. Mir, F., & Pinnington, A. (2014). Exploring the value of project management: Linking Project Management Performance and Project Success. International Journal of Project Management, 32(2), 202-217.

189. Mirawati, N., Othman, S., & Risyawati, M. (2015). Supplier-Contractor Partnering Impact on Construction Performance: A Study on Malaysian Construction Industry, 3(1), 29-33. Journal of Economics, Business and Management.

190. Mohamad, A. (2015). Managing the potential of modularization and standardization of MEP systems in industrial buildings -Guidelines for improvement based on lean principles-. PhD thesis.

191. Mohammed, D., & Khodeir, L. (2017). Examining the Role of Lean Management in Leading Architecture Renovation Projects, 1-41. Research Gate.

192. Mohammed, E., Mohammed, S., & Hassan, A. (2017). Factors causing variation orders in building projects in Khartoum - State Sudan, 6(11), 117-129. International Journal of Engineering Sciences & Research Technology.

193. Mohan, V., & Paila, A. (2013). Stakeholder Management in Infrastructure/Construction Projects: The Role Of Stakeholder Mapping And Social Network Analysis (SNA). Weshkar research journal, 15(1), 48-61.

194. Mok, K., Shen, G., & Yang, J. (2015). Stakeholder management studies in mega construction projects: A review and future directions. International Journal of Project Management, 33(2), 446–457.

195. Momanyi, H. (2017). Determinants of completion of road construction projects in Nyamira County Government, Kenya. Master thesis.

196. Montes, S. (2017). Sustainable Building Project Execution: Impact of Construction Project Management on DGNB Sustainability Certification. Master Thesis.

197. Muhwezi, L., Acai, J., & Otim, G. (2014). An Assessment of the Factors Causing Delays on Building Construction Projects in Uganda. International Journal of Construction Engineering and Management, 3(1), 13-23.

198. Mukhtar, M., Amirudin, R., Sofield, T., & Mohamad, I. (2017). Critical success factors for public housing projects in developing countries: a case study of Nigeria. Environment, Development and Sustainability, 19(5), 2039-2067.

199. Murguía, D., Brioso, X., & Pimentel, A. (2016). Applying Lean Techniques to Improve Performance in the Finishing Phase of a Residential Building, pp. section 2, 43-52. The 24th Annual Conference of the International Group for Lean Construction, (pp. 43–52). Boston, USA.

200. Nadzirah, R. (2015). Mitigation measures for controlling time and cost overrun factors. Master thesis.

201. Nahmens, I., & Ikuma, L. (2012). Effects of Lean Construction on Sustainability of Modular Homebuilding. Journal of architectural engineering, 18(2), 155-163.

202. Nahmens, I., Ikuma, L., & Khot, D. (2012). Lean and Job Satisfaction in Industrialized Homebuilding. Lean Construction Journal, 91-104.

203. Namadi, S., Pasquire, C., & Manu, E. (2017). Discrete Costing Versus Collaborative Costing. The 25th Annual Conference of the International Group for Lean Construction, (pp. 3–10). Heraklion, Greece.

204. Nath, T., Attarzadeh, M., Tiong, R., Chidambaram, C., & Yu, Z. (2015). Productivity improvement of precast shop drawings generation through BIM-based process re-engineering. Automation in Construction, 54, 54–68.

205. Nieto-Morote, A., & Ruz-Vila, F. (2012). Last Planner Control System Applied to a Chemical Plant Construction. Construction Engineering and Management, 138(2), 287-293.

206. Ogunbiyi, O. (2014). Implementation of the Lean Approach in Sustainable Construction: A Conceptual Framework. PhD thesis.

207. Okere, G. (2017). Barriers and Enablers of Effective Knowledge Management: A Case in the Construction Sector. The Electronic Journal of Knowledge Management, 15(2), 85-97.

208. Oliva, C., & Granja, A. (2013). An investigation into collaborative practices in social housing projects as a precondition for target value design adoption, 429-437. International group for lean construction. Fortaleza, Brazil.

209. Olivieri, H., Seppänen, O., & Granja, A. (2016). Integrating LBMS, LPS and CPM: A Practical Process. The 24th Ann. Conf. of the Int'l. Group for Lean Construction, (pp. section 6, 3-12). Boston, MA, USA.

210. OMOTAYO, T. (2017). Strategic realignment of the post-contract cost control process in the Nigerian construction industry using kaizen. PhD thesis.

211. Onyango, A. (2016). Interaction between Lean Construction and BIM. Master thesis. Stockholm, Sweden.

212. Orihuela, P., Orihuela, J., & Pacheco, S. (2015). Implementation of Target Value Design (TVD) in building projects, 279-284. Creative Construction Conference. Krakow, Poland.

213. Othman, A., Ghaly, M., & Abidin, N. (2014). Lean Principles: An Innovative Approach for Achieving Sustainability in the Egyptian Construction Industry. Organization, technology and management in construction, 6(1), 917 - 932.

214. Ozorhon, B., Abbott, C., & Aouad, G. (2014). Integration and Leadership as Enablers of Innovation in Construction: Case Study. Management in Engineering, 30(2), 256-263.

215. Pasquire, C., & Court, P. (2013). An Exploration of Knowledge and Understanding – The Eighth Flow. The Annual Conference of the International Group for Lean Construction. Forteleza, Brazil.

216. Pasquire, C., & Ebbs, P. (2017). Shared Understanding: the Machine Code of the Social in a Socio-Technical System. The 25th Annual Conference of the International Group for Lean Construction (2, pp. 365-372). Heraklion, Greece: ResearchGate.

217. Pasquire, C., Daniel, E., & Dickens, G. (2015). Scoping study to define a major research project investigating the implementation of Last Planner System, collaborative planning and collaborative working in the uk road transport sector including identifying funding sources. Nottingham : Nottingham trent university.

218. Pellicer, E., & Ponz-Tienda, J. (2014). Teaching and Learning Lean Construction in Spain: A pioneer Experience, 3, 1245-1256. International Group for Lean Construction . Oslo, Norway.

219. Pellicer, E., Cerveró, F., Lozano, A., & Ponz-Tienda, J. (2015). The Last Planner System of construction planning and control as a teaching and learning tool. International Technology, 4877-4884, Education and Development Conference. Madrid, Spain: Research Gate.

220. Perrenoud, A., Lines, B., & Sullivan, K. (2014). Measuring risk management performance within a capital program, 12(2), 158-171. Journal of Facilities Management.

221. Pestana, A. (2016). Multi-Criteria Risk Mapping Using Lean Tools for the Architecture, Engineering, and Construction Industry. PhD thesis.

222. Pestana, A., Alves, T., & Barbosa, A. (2014). Application of Lean Construction Concepts to Manage the Submittal Process in AEC Projects, 30(4), 05014006.. Management in Engineering.

223. Pettersen, M. (2017). Lean Construction in Norwegian Transport Infrastructure. Master thesis. Norway: Norwegian university of science and technology department of civil and transport engineering.

224. Pishdad-Bozorgi, P., Moghaddam, E., & Karasulu, Y. (2013). Advancing Target Price and Target Value Design Process in IPD Using BIM and Risk-Sharing Approaches. The 49th Associated Schools of Construction Annual International Conference Proceedings.

225. Prihartanto, E., & Bakri, M. (2017). Identification the Highest Risk of Performance Based Contract in Bojonegoro-Padangan Road Projects, 3(6), 128-132. The Third International Conference on Civil Engineering Research. Surabaya, Indonesia.

226. Radhika, R., & Sukumar, S. (2017). An overview of the concept of Lean Construction and the barriers in its implementation. International Journal of Engineering Technologies and Management Research, 4(3), 13-26.

227. Rajkumar, G., Saravanakumar, S., & Gowtham, R. (2017). Applying Value Stream Mapping For Improving Productivity in Construction Productivity in Construction, 5(3), 149-154. International Journal of Engineering Technology, Management and Applied Sciences.

228. Ram, J., & Corkindale, D. (2014). How "critical" are the critical success factors (CSFs)? Examining the role of CSFs for ERP. Business Process Management Journal, 20(1), 151-174.

229. Ram, J., Corkindale, D., & Wu, M.-L. (2013). Implementation critical success factors (CSFs) for ERP: Do they contribute to implementation success and post-implementation performance? International Journal of Production Economics, 144, 157–174.

230. Rodewohl, C. (2014). The presence of Lean Construction principles in Norways transport infrastructure projects. Master Thesis. Norway.

231. Rodrigues, J., Costa, A., & Gestoso, C. (2014). Project planning and control: Does national culture influence project success? International Conference on Project Management, (16, pp. 1047 – 1056).

232. Roebuck, T., Sewalk, S., Taylor, J., & Chinowsky, P. (2016). Integrating Mechanical Contractors into IPD: Does IPD Work for them? Engineering Project Organization Journal.

233. Rose, K. (2013). A Guide to the Project Management Body of Knowledge (PMBOK® Guide)—Fifth Edition, 44(3), e1-e1. Project management journal .

234. Rouhana, C., & Hamzeh, F. (2016). An ABC Approach to Modeling the Emergence of 'New Tasks' in Weekly Construction Planning. Lean Construction Journal, 35-56.

235. Roy, D., Malsane, S., & Samanta, P. (2017). Procedural challenges in interorganizational collaboration for IPD adoption, C299-C307. Indian Lean Construction Conference.

236. Rybkowski, Z., Shepley, M., & Ballard, H. (2012). Target Value Design: applications to newborn intensive care units, 5(4), 5-23. Health environments research & design journal.

237. Saadé, R. G., Dong, H., & Wan, J. (2015). Factors of Project Manager Success. Interdisciplinary Journal of Information, Knowledge, and Management, 10, 63-80.

238. Salifu-Asubay, E., & Mensah, C. (2015). Improving Delivery of Construction Projects in Ghana's Cities: A Lean Construction Approach, 6(1), 1-15. International Journal of Sustainable Construction Engineering & Technology.

239. Samarah, A., & Bekr, G. (2016). Causes and Effects of Delay in Public Construction Projects in Jordan, 5(5), 87-94. American Journal of Engineering Research.

240. Sarhan, J., Xia, B., Fawzia, S., & Karim, A. (2017). Lean Construction Implementation in the Saudi Arabian Construction Industry. Construction Economics and Building, 17(1), 46-69.

241. Sarhan, S., & Fox, A. (2012). Trends and Challenges to the Development of a Lean Culture Among UK Construction Organisations. 20th Annual Conference of the International Group for Lean Construction.

242. Sarhan, S., & Fox, A. (2013a). Performance measurement in the UK construction industry and its role in supporting the application of lean construction concepts. Australasian Journal of Construction Economics and Building, 13(1), 23-35.

243. Sarhan, S., & Fox, A. (2013b). Barriers to implementing lean construction in the UK construction industry, 6, 1-17. The Built & Human Environment Review.

244. Schöttle, A. (2015, September). What is the Lean Project Delivery System? Retrieved from lean Construction Blog: https://leanconstructionblog.com/What-is-the-lean-project-delivery-system.html

245. Scoggin, J. (2017). The Interdependency of Lean Implementation and Organization Development. PhD thesis.

246. Sebestyen, Z. (2017). Further Considerations in Project Success. Creative Construction Conference, (196, pp. 571 – 577).

247. Seman, M., Hanafi, M., & Abdullah, S. (2013). Main Factors Lack of Workspace Planning That Causes Workspace Conflict on Project Environment: Industrialised Building System In Malaysia, 7(6), 408-419. Australian Journal of Basic and Applied Sciences.

248. Sertyesilisik, B. (2016). Embending Sustainability Dynamics in the Lean Construction Supply Chain Management, 4(1), 60-78. Journal of built environment.

249. Shabehpour, N. (2016). An investigation of the implementation of lean philosophy within a specialty trade. Master of applied science. Canada: The University of British Columbia.

250. Shah, J., & Deshpande, V. (2015). Lean Six Sigma: An integrative approach of Lean and Six Sigma methodology, 5(6), 3528-3534. International Journal of Current Engineering and Technology.

251. Shang, G., & Pheng, L. (2014). The Last Planner System in China's construction industry — A SWOT analysis on implementation. International Journal of Project Management, 32, 1260–1272.

252. Sharma, S., & Goyal, P. (2014). Cost Overrun Factors and Project Cost Risk Assessment in Construction Industry - A State of the Art Review, 3(3), 139-154. International Journal of Civil Engineering.

253. Shen, Y., Zygmunt, K., & Wandahl, S. (2017). Reducing variability of workforce as a tool to improve plan reliability. Modern Building Materials, Structures and Techniques (172, pp. 969 – 976). Science Direct.

254. Siddique, L., & Hussein, B. (2016). A qualitative study of success criteria in Norwegian agile software projects from suppliers' perspective. International Journal of Information Systems and Project Management, 4(2), 65-79.

255. Sinesilassie, E., Tabish, S., & Jha, K. (2017). Critical factors affecting schedule performance: A case of Ethiopian public construction projects–engineers' perspective. Engineering, Construction and Architectural Management, 24(5), 757-773.

256. Singh, R., Gohil, A., Shah, D., & Desai, S. (2013). 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, (51, pp. 592 – 599).

257. Small, E., Al Hamouri, K., & Al Hamouri, H. (2017). Examination of Opportunities for Integration of Lean Principles in Construction in Dubai. Creative Construction Conference 2017, CCC 2017 (196, pp. 616 – 621). Primosten, Croatia: Elsevier Ltd.

258. Soliman, E. (2017). Recommendations to Mitigate Delay Causes in Kuwait Construction Projects. American Journal of Civil Engineering and Architecture, 5(6), 253-262.

259. Somani, A., & Minde, P. (2017). Lean Waste Assessment And Blue Print For Elimination Of Waste Through Lean Digital Method. International Research Journal of Engineering and Technology (IRJET), 4(7), 116-120.

260. Son, H., Kim, C., & Cho, Y. (2017). Automated Schedule Updates Using As-Built Data and a 4D Building Information Model. Journal of Management in Engineering, 33(4).

261. Soto, B., Rosarius, A., Rieger, J., Chen, Q., & Adey, B. (2017). Using a Tabu-search Algorithm and 4D Models to Improve Construction Project Schedules. Creative Construction Conference, (196, pp. 698 – 705). Primosten, Croatia.

262. Stevens, M. (2014). Increasing Adoption of Lean Construction by Contractors, 377-388. 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway.

263. Subramanyan, H., Sawant, P., & Bhatt, V. (2012). Construction Project Risk Assessment: Development of Model Based on Investigation of Opinion of Construction Project Experts from India. Journal of Construction Engineering and Management, 138(3), 409–421.

264. Suleiman, I., & Luvara, V. (2016). Factors Influencing Change of Design of Building Projects during Construction Stage in Dar-es- Salaam Tanzania. International Journal of Construction Engineering and Management, 5(4), 93-101.

265. Swefie, M. (2013). Improving Project Performance Using Lean Construction in Egypt: A Proposed Framework. Master of Science thesis. Egypt: The American Univerisity in Cairo .

266. Sweis, G. (2013). Factors Affecting Time Overruns in Public Construction Projects: The Case of Jordan. International Journal of Business and Management, 8(23), 120-129.

267. Szymanski, P. (2017). Risk management in construction projects. Second International Joint Conference on Innovative Solutions in Construction Engineering and Management, 208(2017), 174–182.

268. Tabatabaee, S., Mahdiyar, A., Yahya, K., Marsono, A., & Sadeghifam, A. (2017). Level Of Awareness On Lean Thinking Concept In Construction Among Higher Learning Students. Malaysian Journal of Civil Engineering, 29(1), 94-107.

269. Tamošaitienė, J., Zavadskas, E., & Turskis, Z. (2013). Multi-criteria risk assessment of a construction project. Procedia Computer Science, 17, 129 – 133.

270. Tanko, B., Abdullah, F., & Ramly, Z. (2017). Stakeholders Assessment of Constraints to Project Delivery in the Nigerian Construction Industry. International journal of Built Environment and Sustainability, 4(4), 56-62.

271. Taroun, A. (2014). Towards a better modelling and assessment of construction risk: Insights from a literature review. International Journal of Project Management, 32(1), 101–115.

272. Tawfik, A., & Othman, A. (2013). Towards lean construction: Using quality management as a tool to minimise waste in the Egyptian construction Industry. 6th Annual SACQSP Research Conference on “Green Vision 20/20”, (pp. 129-144). Cape Town, South Africa.

273. Taylan, O., Bafail, A., Abdulaal, R., & Kabli, M. (2014). Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. Applied Soft Computing, 17, 105–116.

274. Tezel, A., & Nielsen, Y. (2013). Lean Construction Conformance among Construction Contractors in Turkey. Journal Of Management in Engineering, 29(3), 236-250.

275. Tezel, A., Koskela, L., & Aziz, Z. (2017). Lean Construction in Small-Medium Sized Enterprises (SMEs): an exploration of the highways supply chain. The 25th Annual Conference of the International Group for Lean Construction (IGLC), 2, (pp. 853 – 859). Heraklion, Greece.

276. Thorat, S., Khandare, M., & Kanase, A. (2017). Identifying the Causes and Effects of Delay in Residential Projects. International Research Journal of Engineering and Technology (IRJET), 4(4), 2993-2996.

277. Thuranira, M. (2016). The effect of lean supply chain management components on operational performance among tea factories in kenya. Master thesis.

278. Tran, V. (2017). Evaluating the economics of construction and demolition waste minimisation and zero waste in the New Zealand construction industry. PhD thesis.

279. Tsiga, Z., Emes, M., & Smith, A. (2017). Critical success factors for projects in the petroleum industry. International Conference on Project Management, (121, pp. 224–231).

280. Uusitalo, P., Olivieri , H., Sepp–nen, O., Pikas , E., & Peltokorpi , A. (2017). Review Of Lean Design Management: Processes, Methods And Technologies. 25th Annual Conference of the International Group for Lean Construction (IGLC), (pp. 571-578). Heraklion, Greece.

281. Vaidyanathan, K., Mohanbabu, S., Sriram, P., Rahman, S., & Arunkumar, S. (2016). Application of Lean Principles to Managing Construction of an IT Commercial Facility – An Indian Experience. The 24th Ann. Conf. of the Int'l. Group for Lean Construction, (pp. section 6, 183-192). Boston, MA, USA.

282. Viana, T., Salles, P., Carvalho, C., Teixeira, B., Moraes, M., & Santos, W. (2017). Impacts of the Application of Lean Construction to Reduce the Generation of Waste and Improve Processes in Construction. International Journal of Science and Engineering Investigations, 6(64), 52-58.

283. Vilventhan, A., & Kalidindi, S. (2016). Interrelationships of factors causing delays in the relocation of utilities: a cognitive mapping approach. Engineering, Construction and Architectural Management, 23(3), 349-368.

284. Walia, B., & Suri, N. (2017). Implementation Of Last Planner System And Challenges Encountered In An Indian Residential Construction Project. International Research Journal of Engineering and Technology (IRJET), 4(6), 2881-2888.

285. Wang , W.-C., Lin, C.-L., Wang, S.-H., Liu, J.-J., & Lee, M.-T. (2014). Application of importance-satisfaction analysis and influence-relations map to evaluate design delay factors. Journal of Civil Engineering and Management, 20(4), 497–510.

286. Warcup, R., & Reeve, E. (2014). Using the Villego® Simulation to Teach the Last Planner® System. Lean Construction Journal, 1-15.

287. Xiang, P., Zhou, J., Zhou, X., & Ye, K. (2012). Construction Project Risk Management Based on the View of Asymmetric Information. Journal of Construction Engineering and Management, 138(11), 1303-1311.

288. Xiong, B., Skitmore, M., Xia, B., Masrom, M., Ye, K., & Bridge, A. (2014). Examining the influence of participant performance factors on contractor satisfaction: A structural equation model. International Journal of Project Management, 32(3), 482–491.

289. Yan, L. (2017). Transformation Pathway of Chinese Construction Enterprises. Boletín Técnico, 55(9), 350-356.

290. Yap, J., Abdul-Rahman, H., & Chen, W. (2017). Collaborative model: Managing design changes with reusable project experiences through project learning and effective communication. International Journal of Project Management, 35(7), 1253–1271.

291. Yap, J., Abdul-Rahman, H., & Wang, C. (2016). A Conceptual Framework for Managing Design Changes in Building Construction. MATEC Web of Conferences, 66 (2016).

292. Yap, J., Low, P., & Wang, C. (2017). Rework in Malaysian building construction: impacts, causes and potential solutions. Journal of Engineering, Design and Technology, 15(5), 591-618.

293. Yu, H., Al-Hussein, M., Al-Jibouri, S., & Telyas, A. (2013). Lean Transformation in a Modular Building Company: A Case for Implementation. Journal Of Management In Engineering, 29(1), 103-111.

294. Yunus, R., Noor, S., Abdullah, A., Nagapan, S., Abdul Hamid, A., Tajudin, S., & Jusof, S. (2017). Critical Success Factors for Lean Thinking in the Application of Industrialised Building System (IBS), 226, 012045. International Research and Innovation Summit.

295. Zakari Danlami, T., Emes, M., & Smith, A. (2016). Critical success factors for projects in the space sector. Journal of Modern Project Management, 3(3), 56-63.

296. Zhang, L., & Chen, X. (2016). Role of lean tools in supporting knowledge creation and performance in lean construction. International Conference on Sustainable Design, Engineering and Construction, (145, pp. 1267 – 1274).

297. Zhang, X., Azhar, S., & Nadeem, A. (2015). Using Building Information Modeling to Achieve Lean Principles by Improving Efficiency of Work Teams, 18(4), 293-300.. Eighth International Conference on Construction in the 21st Century. Thessaloniki, Greece.

298. Zhang, Y. (2017). A Framework to Improve Modular Construction Manufacturing Production Line Performance. Master thesis.

299. Zhao, X., Hwang, B.-G., & Phng, W. (2014). Construction Project Risk Management in Singapore: Resources, Effectiveness, Impact, and Understanding. Journal of Civil Engineering, 18(1), 27-36.

300. Zhou, T., Zhou, Y., & Liu, G. (2017). Comparison of critical success paths for historic district renovation and redevelopment projects in China. Habitat International, 67, 54-68.

301. Zou, P., & Sunindijo, R. (2013). Skills for managing safety risk, implementing safety task, and developing positive safety climate in construction project. Automation in Construction, 34, 92-100.

APPENDIX A-1

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	UnloadingSBEWL1	10	SubBaseEW	Input@Section12	AggregateTruckSBEW	TTUSBEWL1	NumAggTrSBL1	0	Produce	AggregateEWSB	Always
Section1	UnloadingSBEWL1	10	SubBaseEW	Input@Section13	AggregateTruckSBEW	0	0	QuantityEWSB	Produce	AggregateEWSB	Always
Section1	W4EWSB	20	SubBaseEW	Input@Section12	null	W4EWSBL1	0	0	null	null	Independent Probabilistic
Section1	W4EWSB	20	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBEWL1	30	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL1	NumGrSBL1	0	Consume	AggregateEWSB	Always
Section1	LevellingSBEWL1	30	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	40	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	40	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	50	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	50	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	60	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	60	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBEWL1	70	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL1	NumWSprSBL1	0	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL1	70	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	80	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	80	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	90	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	90	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	100	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	100	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBEWL1	110	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL1	NumSDRSBL1	0	Consume	AggregateEWSB	Always
Section1	CompactSBEWL1	110	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	120	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	120	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	130	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	130	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	140	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	140	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBEWL2	150	SubBaseEW	Input@Section12	AggregateTruckSBEW	TTUSBEWL2	NumAggTrSBL2	0	Produce	AggregateEWSB	Always

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	UnloadingSBEWL2	150	SubBaseEW	Input@Section13	AggregateTruckSBEW	0	0	QuantityEWSB	Produce	AggregateEWSB	Always
Section1	W4EWSB	160	SubBaseEW	Input@Section12	null	W4EWSBL2	0	0	null	null	Independent Probabilistic
Section1	W4EWSB	160	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBEWL2	170	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL2	NumGrSBL2	0	Consume	AggregateEWSB	Always
Section1	LevellingSBEWL2	170	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	180	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	180	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	190	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	190	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	200	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	200	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBEWL2	210	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL2	NumWSprSBL2	0	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL2	210	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	220	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	220	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	230	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	230	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	240	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	240	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBEWL2	250	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL2	NumSDRSBL2	0	Consume	AggregateEWSB	Always
Section1	CompactSBEWL2	250	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	260	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	260	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	270	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	270	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	280	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	280	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBEWL3	290	SubBaseEW	Input@Section12	AggregateTruckSBEW	TTUSBEWL3	NumAggTrSBL3	0	Produce	AggregateEWSB	Always
Section1	UnloadingSBEWL3	290	SubBaseEW	Input@Section13	AggregateTruckSBEW	0	0	QuantityEWSB	Produce	AggregateEWSB	Always
Section1	W4EWSB	300	SubBaseEW	Input@Section12	null	W4EWSBL3	0	0	null	null	Independent Probabilistic

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W4EWSB	300	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBEWL3	310	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL3	NumGrSBL3	0	Consume	AggregateEWSB	Always
Section1	LevellingSBEWL3	310	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	320	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	320	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	330	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	330	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	340	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	340	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBEWL3	350	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL3	NumWSprSBL3	0	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL3	350	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	360	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	360	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	370	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	370	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	380	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	380	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBEWL3	390	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL3	NumSDRSBL3	0	Consume	AggregateEWSB	Always
Section1	CompactSBEWL3	390	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	400	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	400	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	410	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	410	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	420	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	420	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBEWL4	430	SubBaseEW	Input@Section12	AggregateTruckSBEW	TTUSBEWL4	NumAggTrSBL4	0	Produce	AggregateEWSB	Always
Section1	UnloadingSBEWL4	430	SubBaseEW	Input@Section13	AggregateTruckSBEW	0	0	QuantityEWSB	Produce	AggregateEWSB	Always
Section1	W4EWSB	440	SubBaseEW	Input@Section12	null	W4EWSBL4	0	0	null	null	Independent Probabilistic
Section1	W4EWSB	440	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBEWL4	450	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL4	NumGrSBL4	0	Consume	AggregateEWSB	Always

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	LevellingSBEWL4	450	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	460	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	460	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	470	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	470	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	480	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	480	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBEWL4	490	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL4	NumWSprSBL4	0	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL4	490	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	500	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	500	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	510	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	510	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	520	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	520	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBEWL4	530	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL4	NumSDRSBL4	0	Consume	AggregateEWSB	Always
Section1	CompactSBEWL4	530	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	540	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	540	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	550	SubBaseEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	550	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	560	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	560	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBNEWL1	570	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL1	NumAggTrSBL1	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL1	570	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	W4NEWSB	580	SubBaseNEW	Input@Section12	null	W4NEWSBL1	0	0	null	null	Independent Probabilistic
Section1	W4NEWSB	580	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBNEWL1	590	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL1	NumGrSBL1	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL1	590	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	600	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W5	600	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	610	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	610	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	620	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	620	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBNEWL1	630	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL1	NumWSprSBL1	0	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL1	630	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	640	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	640	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	650	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	650	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	660	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	660	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBNEWL1	670	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL1	NumSDRSBL1	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL1	670	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	680	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	680	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	690	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	690	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	700	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	700	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBNEWL2	710	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL2	NumAggTrSBL2	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL2	710	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	W4NEWSB	720	SubBaseNEW	Input@Section12	null	W4NEWSBL2	0	0	null	null	Independent Probabilistic
Section1	W4NEWSB	720	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBNEWL2	730	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL2	NumGrSBL2	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL2	730	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	740	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	740	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	750	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W3	750	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	760	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	760	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBNEWL2	770	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL2	NumWSprSBL2	0	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL2	770	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	780	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	780	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	790	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	790	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	800	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	800	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBNEWL2	810	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL2	NumSDRSBL2	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL2	810	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	820	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	820	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	830	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	830	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	840	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	840	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBNEWL3	850	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL3	NumAggTrSBL3	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL3	850	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	W4NEWSB	860	SubBaseNEW	Input@Section12	null	W4NEWSBL3	0	0	null	null	Independent Probabilistic
Section1	W4NEWSB	860	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBNEWL3	870	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL3	NumGrSBL3	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL3	870	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	880	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	880	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	890	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	890	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	900	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W1	900	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBNEWL3	910	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL3	NumWSprSBL3	0	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL3	910	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	920	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	920	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	930	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	930	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	940	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	940	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBNEWL3	950	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL3	NumSDRSBL3	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL3	950	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	960	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	960	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	970	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	970	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	980	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	980	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBNEWL4	990	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL4	NumAggTrSBL4	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL4	990	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	W4NEWSB	1000	SubBaseNEW	Input@Section12	null	W4NEWSBL4	0	0	null	null	Independent Probabilistic
Section1	W4NEWSB	1000	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBNEWL4	1010	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL4	NumGrSBL4	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL4	1010	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	1020	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1020	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1030	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1030	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1040	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1040	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBNEWL4	1050	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL4	NumWSprSBL4	0	Consume	AggregateNEWSB	Always

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	WaterSprinkleSBNEWL4	1050	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	1060	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1060	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1070	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1070	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1080	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1080	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBNEWL4	1090	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL4	NumSDRSBL4	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL4	1090	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	1100	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1100	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1110	SubBaseNEW	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1110	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1120	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1120	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingFAL1	1130	1stAggregate	Input@Section12	AggregateTruckFA	TTUFAL1	NumAggTrFAL2	0	Produce	AggregateFA	Always
Section1	UnloadingFAL1	1130	1stAggregate	Input@Section13	AggregateTruckFA	0	0	QuantityFA	Produce	AggregateFA	Always
Section1	W4FA	1140	1stAggregate	Input@Section12	null	W4FAL1	0	0	null	null	Independent Probabilistic
Section1	W4FA	1140	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingFAL1	1150	1stAggregate	Input@Section12	GraderFA	TTLFAL1	NumAggTrFAL1	0	Consume	AggregateFA	Always
Section1	LevellingFAL1	1150	1stAggregate	Input@Section13	GraderFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	W5	1160	1stAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1160	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1170	1stAggregate	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1170	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1180	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1180	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleFAL1	1190	1stAggregate	Input@Section12	WaterSprinkleFA	TTWSFAL1	NumGrFAL1	0	Consume	AggregateFA	Always
Section1	WaterSprinkleFAL1	1190	1stAggregate	Input@Section13	WaterSprinkleFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	W5	1200	1stAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section1	W5	1200	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1210	1stAggregate	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1210	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1220	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1220	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactFAL1	1230	1stAggregate	Input@Section12	SingleDrumRollersFA	TTCFAL1	NumSDRFAL1	0	Consume	AggregateFA	Always
Section1	CompactFAL1	1230	1stAggregate	Input@Section13	SingleDrumRollersFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	W5	1240	1stAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1240	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1250	1stAggregate	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1250	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1260	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1260	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingFAL2	1270	1stAggregate	Input@Section12	AggregateTruckFA	TTUFAL2	NumAggTrFAL2	0	Produce	AggregateFA	Always
Section1	UnloadingFAL2	1270	1stAggregate	Input@Section13	AggregateTruckFA	0	0	QuantityFA	Produce	AggregateFA	Always
Section1	W4FA	1280	1stAggregate	Input@Section12	null	W4FAL2	0	0	null	null	Independent Probabilistic
Section1	W4FA	1280	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingFAL2	1290	1stAggregate	Input@Section12	GraderFA	TTLFAL2	NumGrFAL2	0	Consume	AggregateFA	Always
Section1	LevellingFAL2	1290	1stAggregate	Input@Section13	GraderFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	W5	1300	1stAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1300	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1310	1stAggregate	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1310	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1320	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1320	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleFAL2	1330	1stAggregate	Input@Section12	WaterSprinkleFA	TTWSFAL2	NumWSprFAL2	0	Consume	AggregateFA	Always
Section1	WaterSprinkleFAL2	1330	1stAggregate	Input@Section13	WaterSprinkleFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	W5	1340	1stAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1340	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1350	1stAggregate	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W3	1350	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1360	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1360	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactFAL2	1370	1stAggregate	Input@Section12	SingleDrumRollersFA	TTCFAL2	NumSDRFAL2	0	Consume	AggregateFA	Always
Section1	CompactFAL2	1370	1stAggregate	Input@Section13	SingleDrumRollersFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	W5	1380	1stAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1380	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1390	1stAggregate	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1390	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1400	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1400	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSA	1410	2ndAggregate	Input@Section12	AggregateTruckSA	TTUSA	NumAggTrSA	0	Produce	AggregatesSA	Always
Section1	UnloadingSA	1410	2ndAggregate	Input@Section13	AggregateTruckSA	0	0	QuantitySA	Produce	AggregatesSA	Always
Section1	W4SA	1420	2ndAggregate	Input@Section12	null	W4SA	0	0	null	null	Independent Probabilistic
Section1	W4SA	1420	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSA	1430	2ndAggregate	Input@Section12	GraderSA	TTLSA	NumGrSA	0	Consume	AggregatesSA	Always
Section1	LevellingSA	1430	2ndAggregate	Input@Section13	GraderSA	0	0	QuantitySA	Consume	AggregatesSA	Always
Section1	W5	1440	2ndAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1440	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1450	2ndAggregate	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1450	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1460	2ndAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1460	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSA	1470	2ndAggregate	Input@Section12	WaterSprinkleSA	TTWSSA	NumWSprSA	0	Consume	AggregatesSA	Always
Section1	WaterSprinkleSA	1470	2ndAggregate	Input@Section13	WaterSprinkleSA	0	0	QuantitySA	Consume	AggregatesSA	Always
Section1	W5	1480	2ndAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1480	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1490	2ndAggregate	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1490	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1500	2ndAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W1	1500	2ndAggregate	Input@Section13	null		0	0	0 null	null	Independent Probabilistic
Section1	CompactSA	1510	2ndAggregate	Input@Section12	SingleDrumRollersSA	TTCSA	NumSDRSA	0	Consume	AggregateSA	Always
Section1	CompactSA	1510	2ndAggregate	Input@Section13	SingleDrumRollersSA	0	0	QuantitySA	Consume	AggregateSA	Always
Section1	W5	1520	2ndAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1520	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1530	2ndAggregate	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1530	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1540	2ndAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1540	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	MCSprinkle	1550	MCS	Input@Section12	MCSprinkle	TTMCS	NumMCSpr	0	Produce	MC	Always
Section1	MCSprinkle	1550	MCS	Input@Section13	MCSprinkle	0	0	QuantityMC	Produce	MC	Always
Section1	W5	1560	MCS	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1560	MCS	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1570	MCS	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1570	MCS	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1580	MCS	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1580	MCS	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	PavingFTA	1590	1stAsphalt	Input@Section12	PavingFinisherFTA	TTPFFTA	NumPFTA	0	Produce	AsphaltFTA	Always
Section1	PavingFTA	1590	1stAsphalt	Input@Section13	PavingFinisherFTA	0	0	QuantityFTA	Produce	AsphaltFTA	Always
Section1	W1	1600	1stAsphalt	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1600	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W2	1610	1stAsphalt	Input@Section12	null	W2	0	0	null	null	Independent Probabilistic
Section1	W2	1610	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1620	1stAsphalt	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1620	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W5	1630	1stAsphalt	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1630	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W7	1640	1stAsphalt	Input@Section12	null	W7	0	0	null	null	Independent Probabilistic
Section1	W7	1640	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W8	1650	1stAsphalt	Input@Section12	null	W8FTA	0	0	null	null	Independent Probabilistic

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W8	1650	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactFTA	1660	1stAsphalt	Input@Section12	DoubleDrumRollersFTA	TTCFTA	NumDDRFTA	0	Consume	AsphaltFTA	Always
Section1	CompactFTA	1660	1stAsphalt	Input@Section13	DoubleDrumRollersFTA	0	0	QuantityFTA	Consume	AsphaltFTA	Always
Section1	W1	1670	1stAsphalt	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1670	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W2	1680	1stAsphalt	Input@Section12	null	W2	0	0	null	null	Independent Probabilistic
Section1	W2	1680	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1690	1stAsphalt	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1690	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W5	1700	1stAsphalt	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1700	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W6	1710	1stAsphalt	Input@Section12	null	W6	0	0	null	null	Independent Probabilistic
Section1	W6	1710	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	RCSprinkle	1720	RCS	Input@Section12	RCSprinkle	TTRCS	NumRCSpr	0	Produce	RC	Always
Section1	RCSprinkle	1720	RCS	Input@Section13	RCSprinkle	0	0	QuantityRC	Produce	RC	Always
Section1	W5	1730	RCS	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1730	RCS	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1740	RCS	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1740	RCS	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	1750	RCS	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1750	RCS	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	PavingSDA	1760	2ndAsphalt	Input@Section12	PavingFinisherSDA	TTPFSDA	NumPSDA	0	Produce	AsphaltSDA	Always
Section1	PavingSDA	1760	2ndAsphalt	Input@Section13	PavingFinisherSDA	0	0	QuantitySDA	Produce	AsphaltSDA	Always
Section1	W1	1770	2ndAsphalt	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1770	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W2	1780	2ndAsphalt	Input@Section12	null	W2	0	0	null	null	Independent Probabilistic
Section1	W2	1780	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1790	2ndAsphalt	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1790	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W5	1800	2ndAsphalt	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic

Simulation PM-EW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W5	1800	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W7	1810	2ndAsphalt	Input@Section12	null	W7	0	0	null	null	Independent Probabilistic
Section1	W7	1810	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W8	1820	2ndAsphalt	Input@Section12	null	W8SDA	0	0	null	null	Independent Probabilistic
Section1	W8	1820	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSDA	1830	2ndAsphalt	Input@Section12	DoubleDrumRollersSDA	TTCSDA	NumDDRSDA	0	Consume	AsphaltSDA	Always
Section1	CompactSDA	1830	2ndAsphalt	Input@Section13	DoubleDrumRollersSDA	0	0	QuantitySDA	Consume	AsphaltSDA	Always
Section1	W1	1840	2ndAsphalt	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1840	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W2	1850	2ndAsphalt	Input@Section12	null	W2	0	0	null	null	Independent Probabilistic
Section1	W2	1850	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1860	2ndAsphalt	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1860	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W5	1870	2ndAsphalt	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	1870	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W6	1880	2ndAsphalt	Input@Section12	null	W6	0	0	null	null	Independent Probabilistic
Section1	W6	1880	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic

APPENDIX A-2

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	UnloadingSBEWL1	10	SubBaseEW	Input@Section12	AggregateTruckSBEW	TTUSBEWL1	NumAggTrSBL1	0	Produce	AggregateEWSB	Always
Section1	UnloadingSBEWL1	10	SubBaseEW	Input@Section13	AggregateTruckSBEW	0	0	QuantityEWSB	Produce	AggregateEWSB	Always
Section1	W4EWSB	20	SubBaseEW	Input@Section12	null	W4EWSBL1	0	0	null	null	Independent Probabilistic
Section1	W4EWSB	20	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBEWL1	30	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL1	NumGrSBL1	0	Consume	AggregateEWSB	Always
Section1	LevellingSBEWL1	30	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	40	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	40	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	50	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	50	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBEWL1	60	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL1	NumWSprSBL1	0	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL1	60	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W1	70	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	70	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBEWL1	80	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL1	NumSDRSBL1	0	Consume	AggregateEWSB	Always
Section1	CompactSBEWL1	80	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W1	90	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	90	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBEWL2	100	SubBaseEW	Input@Section12	AggregateTruckSBEW	TTUSBEWL2	NumAggTrSBL2	0	Produce	AggregateEWSB	Always

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	UnloadingSBEWL2	100	SubBaseEW	Input@Section13	AggregateTruckSBEW	0	0	QuantityEWSB	Produce	AggregateEWSB	Always
Section1	W4EWSB	110	SubBaseEW	Input@Section12	null	W4EWSBL2	0	0	null	null	Independent Probabilistic
Section1	W4EWSB	110	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBEWL2	120	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL2	NumGrSBL2	0	Consume	AggregateEWSB	Always
Section1	LevellingSBEWL2	120	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	130	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	130	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	140	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	140	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBEWL2	150	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL2	NumWSprSBL2	0	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL2	150	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W1	160	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	160	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBEWL2	170	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL2	NumSDRSBL2	0	Consume	AggregateEWSB	Always
Section1	CompactSBEWL2	170	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W1	180	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	180	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBEWL3	190	SubBaseEW	Input@Section12	AggregateTruckSBEW	TTUSBEWL3	NumAggTrSBL3	0	Produce	AggregateEWSB	Always
Section1	UnloadingSBEWL3	190	SubBaseEW	Input@Section13	AggregateTruckSBEW	0	0	QuantityEWSB	Produce	AggregateEWSB	Always
Section1	W4EWSB	200	SubBaseEW	Input@Section12	null	W4EWSBL3	0	0	null	null	Independent Probabilistic

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W4EWSB	200	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBEWL3	210	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL3	NumGrSBL3	0	Consume	AggregateEWSB	Always
Section1	LevellingSBEWL3	210	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	220	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	220	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	230	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	230	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBEWL3	240	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL3	NumWSprSBL3	0	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL3	240	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W1	250	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	250	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBEWL3	260	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL3	NumSDRSBL3	0	Consume	AggregateEWSB	Always
Section1	CompactSBEWL3	260	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W1	270	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	270	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBEWL4	280	SubBaseEW	Input@Section12	AggregateTruckSBEW	TTUSBEWL4	NumAggTrSBL4	0	Produce	AggregateEWSB	Always
Section1	UnloadingSBEWL4	280	SubBaseEW	Input@Section13	AggregateTruckSBEW	0	0	QuantityEWSB	Produce	AggregateEWSB	Always
Section1	W4EWSB	290	SubBaseEW	Input@Section12	null	W4EWSBL4	0	0	null	null	Independent Probabilistic
Section1	W4EWSB	290	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBEWL4	300	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL4	NumGrSBL4	0	Consume	AggregateEWSB	Always

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	LevellingSBEWL4	300	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W5	310	SubBaseEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	310	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	320	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	320	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBEWL4	320	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL4	NumWSprSBL4	0	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL4	320	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W1	330	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	330	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBEWL4	340	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL4	NumSDRSBL4	0	Consume	AggregateEWSB	Always
Section1	CompactSBEWL4	340	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	W1	350	SubBaseEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	350	SubBaseEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBNEWL1	360	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL1	NumAggTrSBL1	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL1	360	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	W4NEWSB	370	SubBaseNEW	Input@Section12	null	W4NEWSBL1	0	0	null	null	Independent Probabilistic
Section1	W4NEWSB	370	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBNEWL1	380	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL1	NumGrSBL1	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL1	380	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	390	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W5	390	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	400	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	400	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBNEWL1	410	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL1	NumWSprSBL1	0	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL1	410	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W1	420	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	420	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBNEWL1	430	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL1	NumSDRSBL1	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL1	430	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W1	440	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	440	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBNEWL2	450	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL2	NumAggTrSBL2	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL2	450	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	W4NEWSB	460	SubBaseNEW	Input@Section12	null	W4NEWSBL2	0	0	null	null	Independent Probabilistic
Section1	W4NEWSB	460	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBNEWL2	470	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL2	NumGrSBL2	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL2	470	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	480	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	480	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	490	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W1	490	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBNEWL2	500	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL2	NumWSprSBL2	0	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL2	500	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W1	510	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	510	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBNEWL2	520	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL2	NumSDRSBL2	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL2	520	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W1	530	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	530	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBNEWL3	540	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL3	NumAggTrSBL3	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL3	540	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	W4NEWSB	550	SubBaseNEW	Input@Section12	null	W4NEWSBL3	0	0	null	null	Independent Probabilistic
Section1	W4NEWSB	550	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBNEWL3	560	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL3	NumGrSBL3	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL3	560	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	570	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	570	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	580	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	580	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBNEWL3	590	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL3	NumWSprSBL3	0	Consume	AggregateNEWSB	Always

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	WaterSprinkleSBNEWL3	590	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W1	600	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	600	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBNEWL3	610	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL3	NumSDRSBL3	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL3	610	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W1	620	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	620	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingSBNEWL4	630	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL4	NumAggTrSBL4	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL4	630	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	W4NEWSB	640	SubBaseNEW	Input@Section12	null	W4NEWSBL4	0	0	null	null	Independent Probabilistic
Section1	W4NEWSB	640	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingSBNEWL4	650	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL4	NumGrSBL4	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL4	650	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W5	660	SubBaseNEW	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	660	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	670	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	670	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSBNEWL4	680	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL4	NumWSprSBL4	0	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL4	680	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W1	690	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W1	690	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSBNEWL4	700	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL4	NumSDRSBL4	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL4	700	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	W1	710	SubBaseNEW	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	710	SubBaseNEW	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	UnloadingFAL1	720	1stAggregate	Input@Section12	AggregateTruckFA	TTUFAL1	NumAggTrFAL2	0	Produce	AggregateFA	Always
Section1	UnloadingFAL1	720	1stAggregate	Input@Section13	AggregateTruckFA	0	0	QuantityFA	Produce	AggregateFA	Always
Section1	W4FA	730	1stAggregate	Input@Section12	null	W4FAL1	0	0	null	null	Independent Probabilistic
Section1	W4FA	730	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	LevellingFAL1	740	1stAggregate	Input@Section12	GraderFA	TTLFAL1	NumAggTrFAL1	0	Consume	AggregateFA	Always
Section1	LevellingFAL1	740	1stAggregate	Input@Section13	GraderFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	W5	750	1stAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	750	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	760	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	760	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleFAL1	770	1stAggregate	Input@Section12	WaterSprinkleFA	TTWSFAL1	NumGrFAL1	0	Consume	AggregateFA	Always
Section1	WaterSprinkleFAL1	770	1stAggregate	Input@Section13	WaterSprinkleFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	W1	780	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	780	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactFAL1	790	1stAggregate	Input@Section12	SingleDrumRollersFA	TTCFAL1	NumSDRFAL1	0	Consume	AggregateFA	Always

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	CompactFAL1	790	1stAggregate	Input@Section13	SingleDrumRollersFA	0	0	QuantityFA	Consume	Aggregate FA	Always
Section1	W1	800	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	800	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	Unloading FAL2	810	1stAggregate	Input@Section12	Aggregate TruckFA	TTUFAL2	NumAggTrFAL2	0	Produce	Aggregate FA	Always
Section1	Unloading FAL2	810	1stAggregate	Input@Section13	Aggregate TruckFA	0	0	QuantityFA	Produce	Aggregate FA	Always
Section1	W4FA	820	1stAggregate	Input@Section12	null	W4FAL2	0	0	null	null	Independent Probabilistic
Section1	W4FA	820	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	Levelling FAL2	830	1stAggregate	Input@Section12	GraderFA	TTLFAL2	NumGrFAL2	0	Consume	Aggregate FA	Always
Section1	Levelling FAL2	830	1stAggregate	Input@Section13	GraderFA	0	0	QuantityFA	Consume	Aggregate FA	Always
Section1	W5	840	1stAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	840	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	850	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	850	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleFAL2	860	1stAggregate	Input@Section12	WaterSprinkleFA	TTWSFAL2	NumWSprFAL2	0	Consume	Aggregate FA	Always
Section1	WaterSprinkleFAL2	860	1stAggregate	Input@Section13	WaterSprinkleFA	0	0	QuantityFA	Consume	Aggregate FA	Always
Section1	W1	870	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	870	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactFAL2	880	1stAggregate	Input@Section12	SingleDrumRollersFA	TTCFAL2	NumSDRFAL2	0	Consume	Aggregate FA	Always
Section1	CompactFAL2	880	1stAggregate	Input@Section13	SingleDrumRollersFA	0	0	QuantityFA	Consume	Aggregate FA	Always
Section1	W1	890	1stAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W1	890	1stAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	Unloading SA	900	2ndAggregate	Input@Section12	Aggregate TruckSA	TTUSA	NumAggTrSA	0	Produce	Aggregate SA	Always
Section1	Unloading SA	900	2ndAggregate	Input@Section13	Aggregate TruckSA	0	0	QuantitySA	Produce	Aggregate SA	Always
Section1	W4SA	910	2ndAggregate	Input@Section12	null	W4SA	0	0	null	null	Independent Probabilistic
Section1	W4SA	910	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	Levelling SA	920	2ndAggregate	Input@Section12	GraderSA	TTLSA	NumGrSA	0	Consume	Aggregate SA	Always
Section1	Levelling SA	920	2ndAggregate	Input@Section13	GraderSA	0	0	QuantitySA	Consume	Aggregate SA	Always
Section1	W5	930	2ndAggregate	Input@Section12	null	W5	0	0	null	null	Independent Probabilistic
Section1	W5	930	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W1	940	2ndAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	940	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	WaterSprinkleSA	950	2ndAggregate	Input@Section12	WaterSprinkleSA	TTWSSA	NumWSprSA	0	Consume	Aggregate SA	Always
Section1	WaterSprinkleSA	950	2ndAggregate	Input@Section13	WaterSprinkleSA	0	0	QuantitySA	Consume	Aggregate SA	Always
Section1	W1	960	2ndAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	960	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSA	970	2ndAggregate	Input@Section12	SingleDrumRollersSA	TTCSA	NumSDRSA	0	Consume	Aggregate SA	Always
Section1	CompactSA	970	2ndAggregate	Input@Section13	SingleDrumRollersSA	0	0	QuantitySA	Consume	Aggregate SA	Always
Section1	W1	980	2ndAggregate	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	980	2ndAggregate	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	MCSprinkle	990	MCS	Input@Section12	MCSprinkle	TTMCS	NumMCSpr	0	Produce	MC	Always

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	MCSprinkle	990	MCS	Input@Section13	MCSprinkle	0	0	QuantityMC	Produce	MC	Always
Section1	W1	1000	MCS	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1000	MCS	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	PavingFTA	1010	1stAsphalt	Input@Section12	PavingFinisherFTA	TTPFFTA	NumPFTA	0	Produce	AsphaltFTA	Always
Section1	PavingFTA	1010	1stAsphalt	Input@Section13	PavingFinisherFTA	0	0	QuantityFTA	Produce	AsphaltFTA	Always
Section1	W2	1020	1stAsphalt	Input@Section12	null	W2	0	0	null	null	Independent Probabilistic
Section1	W2	1020	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1030	1stAsphalt	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1030	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W7	1040	1stAsphalt	Input@Section12	null	W7	0	0	null	null	Independent Probabilistic
Section1	W7	1040	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W8	1050	1stAsphalt	Input@Section12	null	W8FTA	0	0	null	null	Independent Probabilistic
Section1	W8	1050	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactFTA	1060	1stAsphalt	Input@Section12	DoubleDrumRollersFTA	TTCFTA	NumDDRFTA	0	Consume	AsphaltFTA	Always
Section1	CompactFTA	1060	1stAsphalt	Input@Section13	DoubleDrumRollersFTA	0	0	QuantityFTA	Consume	AsphaltFTA	Always
Section1	W2	1070	1stAsphalt	Input@Section12	null	W2	0	0	null	null	Independent Probabilistic
Section1	W2	1070	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1080	1stAsphalt	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1080	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W6	1090	1stAsphalt	Input@Section12	null	W6	0	0	null	null	Independent Probabilistic

Simulation PM-OW sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	W6	1090	1stAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	RCSprinkle	1100	RCS	Input@Section12	RCSprinkle	TTRCS	NumRCSpr	0	Produce	RC	Always
Section1	RCSprinkle	1100	RCS	Input@Section13	RCSprinkle	0	0	QuantityRC	Produce	RC	Always
Section1	W1	1110	RCS	Input@Section12	null	W1	0	0	null	null	Independent Probabilistic
Section1	W1	1110	RCS	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	PavingSDA	1120	2ndAsphalt	Input@Section12	PavingFinisherSDA	TTPFSDA	NumPSDA	0	Produce	AsphaltSDA	Always
Section1	PavingSDA	1120	2ndAsphalt	Input@Section13	PavingFinisherSDA	0	0	QuantitySDA	Produce	AsphaltSDA	Always
Section1	W2	1130	2ndAsphalt	Input@Section12	null	W2	0	0	null	null	Independent Probabilistic
Section1	W2	1130	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1140	2ndAsphalt	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1140	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W7	1150	2ndAsphalt	Input@Section12	null	W7	0	0	null	null	Independent Probabilistic
Section1	W7	1150	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W8	1160	2ndAsphalt	Input@Section12	null	W8SDA	0	0	null	null	Independent Probabilistic
Section1	W8	1160	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	CompactSDA	1170	2ndAsphalt	Input@Section12	DoubleDrumRollersSDA	TTCSDA	NumDDRSDA	0	Consume	AsphaltSDA	Always
Section1	CompactSDA	1170	2ndAsphalt	Input@Section13	DoubleDrumRollersSDA	0	0	QuantitySDA	Consume	AsphaltSDA	Always
Section1	W2	1180	2ndAsphalt	Input@Section12	null	W2	0	0	null	null	Independent Probabilistic
Section1	W2	1180	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W3	1190	2ndAsphalt	Input@Section12	null	W3	0	0	null	null	Independent Probabilistic
Section1	W3	1190	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic
Section1	W6	1200	2ndAsphalt	Input@Section12	null	W6	0	0	null	null	Independent Probabilistic
Section1	W6	1200	2ndAsphalt	Input@Section13	null	0	0	0	null	null	Independent Probabilistic

APPENDIX A-3

Simulation LC sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	Unloading SBEWL1	10	SubBaseEW	Input@Section12	Aggregate TruckSBEW	TTUSBEWL1	NumAggTrSBL1	0	Produce	Aggregate EWSB	Always
Section1	Unloading SBEWL1	10	SubBaseEW	Input@Section13	Aggregate TruckSBEW	0	0	QuantityEWSB	Produce	Aggregate EWSB	Always
Section1	Levelling SBEWL1	20	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL1	NumGrSBL1	0	Consume	Aggregate EWSB	Always
Section1	Levelling SBEWL1	20	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	Aggregate EWSB	Always
Section1	WaterSprinkleSBEWL1	30	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL1	NumWSprSBL1	0	Consume	Aggregate EWSB	Always
Section1	WaterSprinkleSBEWL1	30	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	Aggregate EWSB	Always
Section1	CompactSBEWL1	40	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL1	NumSDRSBL1	0	Consume	Aggregate EWSB	Always
Section1	CompactSBEWL1	40	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	Aggregate EWSB	Always
Section1	Unloading SBEWL2	50	SubBaseEW	Input@Section12	Aggregate TruckSBEW	TTUSBEWL2	NumAggTrSBL2	0	Produce	Aggregate EWSB	Always
Section1	Unloading SBEWL2	50	SubBaseEW	Input@Section13	Aggregate TruckSBEW	0	0	QuantityEWSB	Produce	Aggregate EWSB	Always
Section1	Levelling SBEWL2	60	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL2	NumGrSBL2	0	Consume	Aggregate EWSB	Always
Section1	Levelling SBEWL2	60	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	Aggregate EWSB	Always
Section1	WaterSprinkleSBEWL2	70	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL2	NumWSprSBL2	0	Consume	Aggregate EWSB	Always
Section1	WaterSprinkleSBEWL2	70	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	Aggregate EWSB	Always
Section1	CompactSBEWL2	80	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL2	NumSDRSBL2	0	Consume	Aggregate EWSB	Always
Section1	CompactSBEWL2	80	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	Aggregate EWSB	Always
Section1	Unloading SBEWL3	90	SubBaseEW	Input@Section12	Aggregate TruckSBEW	TTUSBEWL3	NumAggTrSBL3	0	Produce	Aggregate EWSB	Always
Section1	Unloading SBEWL3	90	SubBaseEW	Input@Section13	Aggregate TruckSBEW	0	0	QuantityEWSB	Produce	Aggregate EWSB	Always
Section1	Levelling SBEWL3	100	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL3	NumGrSBL3	0	Consume	Aggregate EWSB	Always

Simulation LC sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	LevellingSBEWL3	100	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL3	110	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL3	NumWSprSBL3	0	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL3	110	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	CompactSBEWL3	120	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL3	NumSDRSBL3	0	Consume	AggregateEWSB	Always
Section1	CompactSBEWL3	120	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	UnloadingSBEWL4	130	SubBaseEW	Input@Section12	AggregateTruckSBEW	TTUSBEWL4	NumAggTrSBL4	0	Produce	AggregateEWSB	Always
Section1	UnloadingSBEWL4	130	SubBaseEW	Input@Section13	AggregateTruckSBEW	0	0	QuantityEWSB	Produce	AggregateEWSB	Always
Section1	LevellingSBEWL4	140	SubBaseEW	Input@Section12	GraderSBEW	TTLSBEWL4	NumGrSBL4	0	Consume	AggregateEWSB	Always
Section1	LevellingSBEWL4	140	SubBaseEW	Input@Section13	GraderSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL4	150	SubBaseEW	Input@Section12	WaterSprinkleSBEW	TTWSSBEWL4	NumWSprSBL4	0	Consume	AggregateEWSB	Always
Section1	WaterSprinkleSBEWL4	150	SubBaseEW	Input@Section13	WaterSprinkleSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	CompactSBEWL4	160	SubBaseEW	Input@Section12	SingleDrumRollersSBEW	TTCSBEWL4	NumSDRSBL4	0	Consume	AggregateEWSB	Always
Section1	CompactSBEWL4	160	SubBaseEW	Input@Section13	SingleDrumRollersSBEW	0	0	QuantityEWSB	Consume	AggregateEWSB	Always
Section1	UnloadingSBNEWL1	170	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL1	NumAggTrSBL1	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL1	170	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	LevellingSBNEWL1	180	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL1	NumGrSBL1	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL1	180	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL1	190	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL1	NumWSprSBL1	0	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL1	190	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL1	200	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL1	NumSDRSBL1	0	Consume	AggregateNEWSB	Always

Simulation LC sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	CompactSBNEWL1	200	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	UnloadingSBNEWL2	210	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL2	NumAggTrSBL2	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL2	210	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	LevellingSBNEWL2	220	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL2	NumGrSBL2	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL2	220	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL2	230	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL2	NumWSprSBL2	0	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL2	230	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL2	240	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL2	NumSDRSBL2	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL2	240	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	UnloadingSBNEWL3	250	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL3	NumAggTrSBL3	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL3	250	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	LevellingSBNEWL3	260	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL3	NumGrSBL3	0	Consume	AggregateNEWSB	Always
Section1	LevellingSBNEWL3	260	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL3	270	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL3	NumWSprSBL3	0	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL3	270	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL3	280	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL3	NumSDRSBL3	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL3	280	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	UnloadingSBNEWL4	290	SubBaseNEW	Input@Section12	AggregateTruckSBNEW	TTUSBNEWL4	NumAggTrSBL4	0	Produce	AggregateNEWSB	Always
Section1	UnloadingSBNEWL4	290	SubBaseNEW	Input@Section13	AggregateTruckSBNEW	0	0	QuantityNEWSB	Produce	AggregateNEWSB	Always
Section1	LevellingSBNEWL4	300	SubBaseNEW	Input@Section12	GraderSBNEW	TTLSBNEWL4	NumGrSBL4	0	Consume	AggregateNEWSB	Always

Simulation LC sub-activities sequences data for first section (one section of 64 sections)

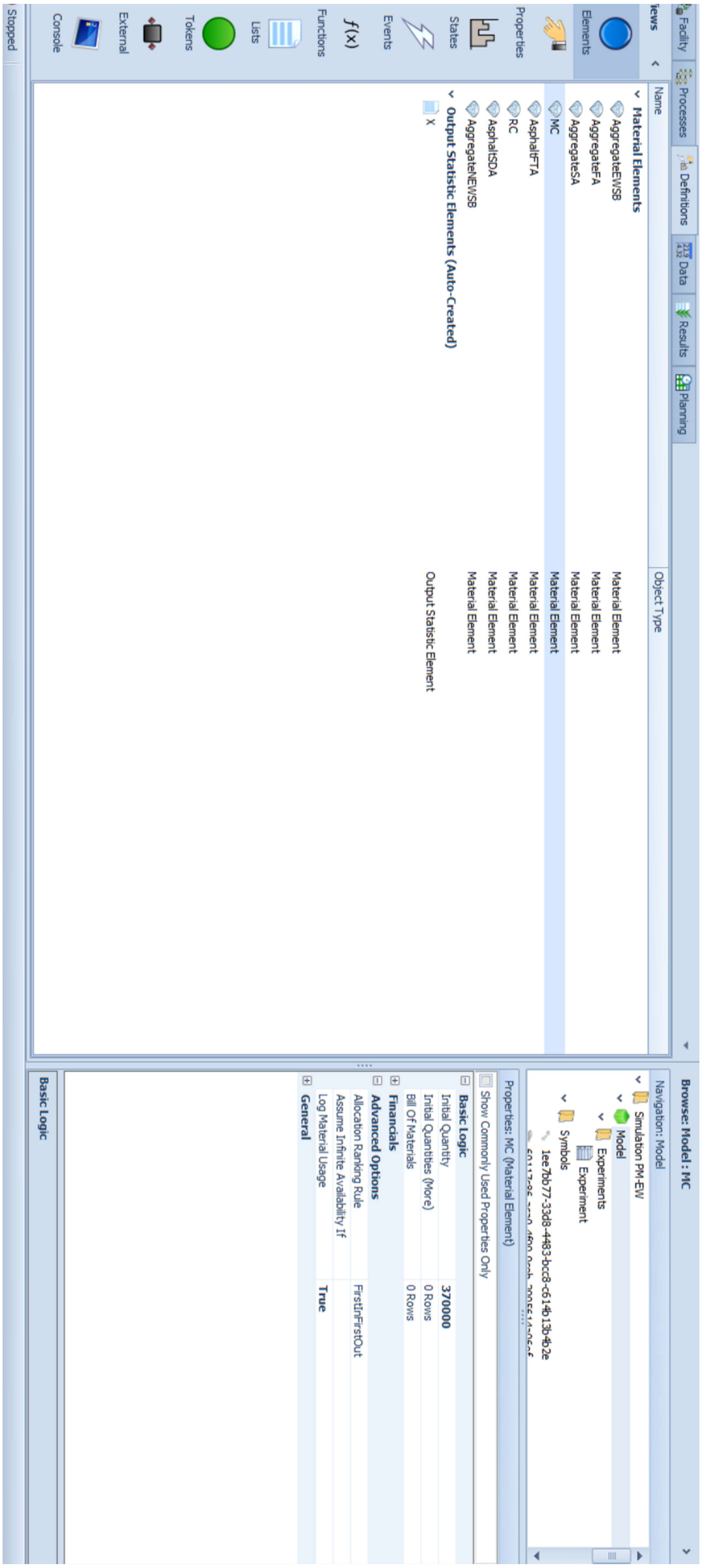
Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	LevellingSBNEWL4	300	SubBaseNEW	Input@Section13	GraderSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL4	310	SubBaseNEW	Input@Section12	WaterSprinkleSBNEW	TTWSSBNEWL4	NumWSprSBL4	0	Consume	AggregateNEWSB	Always
Section1	WaterSprinkleSBNEWL4	310	SubBaseNEW	Input@Section13	WaterSprinkleSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL4	320	SubBaseNEW	Input@Section12	SingleDrumRollersSBNEW	TTCSBNEWL4	NumSDRSBL4	0	Consume	AggregateNEWSB	Always
Section1	CompactSBNEWL4	320	SubBaseNEW	Input@Section13	SingleDrumRollersSBNEW	0	0	QuantityNEWSB	Consume	AggregateNEWSB	Always
Section1	UnloadingFAL1	330	1stAggregate	Input@Section12	AggregateTruckFA	TTUFAL1	NumAggTrFAL2	0	Produce	AggregateFA	Always
Section1	UnloadingFAL1	330	1stAggregate	Input@Section13	AggregateTruckFA	0	0	QuantityFA	Produce	AggregateFA	Always
Section1	LevellingFAL1	340	1stAggregate	Input@Section12	GraderFA	TTLFAL1	NumAggTrFAL1	0	Consume	AggregateFA	Always
Section1	LevellingFAL1	340	1stAggregate	Input@Section13	GraderFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	WaterSprinkleFAL1	350	1stAggregate	Input@Section12	WaterSprinkleFA	TTWSFAL1	NumGrFAL1	0	Consume	AggregateFA	Always
Section1	WaterSprinkleFAL1	350	1stAggregate	Input@Section13	WaterSprinkleFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	CompactFAL1	360	1stAggregate	Input@Section12	SingleDrumRollersFA	TTCFAL1	NumSDRFAL1	0	Consume	AggregateFA	Always
Section1	CompactFAL1	360	1stAggregate	Input@Section13	SingleDrumRollersFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	UnloadingFAL2	370	1stAggregate	Input@Section12	AggregateTruckFA	TTUFAL2	NumAggTrFAL2	0	Produce	AggregateFA	Always
Section1	UnloadingFAL2	370	1stAggregate	Input@Section13	AggregateTruckFA	0	0	QuantityFA	Produce	AggregateFA	Always
Section1	LevellingFAL2	380	1stAggregate	Input@Section12	GraderFA	TTLFAL2	NumGrFAL2	0	Consume	AggregateFA	Always
Section1	LevellingFAL2	380	1stAggregate	Input@Section13	GraderFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	WaterSprinkleFAL2	390	1stAggregate	Input@Section12	WaterSprinkleFA	TTWSFAL2	NumWSprFAL2	0	Consume	AggregateFA	Always
Section1	WaterSprinkleFAL2	390	1stAggregate	Input@Section13	WaterSprinkleFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	CompactFAL2	400	1stAggregate	Input@Section12	SingleDrumRollersFA	TTCFAL2	NumSDRFAL2	0	Consume	AggregateFA	Always

Simulation LC sub-activities sequences data for first section (one section of 64 sections)

Section	Sub-Activity	Sequence Number	Activities Per Section	Destination Node	Object Name	Process Time	Resource Quantity	Total Quantity	Action Type	Material Name	Branch Type
Section1	CompactFAL2	400	1stAggregate	Input@Section13	SingleDrumRollersFA	0	0	QuantityFA	Consume	AggregateFA	Always
Section1	UnloadingSA	410	2ndAggregate	Input@Section12	AggregateTruckSA	TTUSA	NumAggTrSA	0	Produce	AggregateSA	Always
Section1	UnloadingSA	410	2ndAggregate	Input@Section13	AggregateTruckSA	0	0	QuantitySA	Produce	AggregateSA	Always
Section1	LevellingSA	420	2ndAggregate	Input@Section12	GraderSA	TTLSA	NumGrSA	0	Consume	AggregateSA	Always
Section1	LevellingSA	420	2ndAggregate	Input@Section13	GraderSA	0	0	QuantitySA	Consume	AggregateSA	Always
Section1	WaterSprinkleSA	430	2ndAggregate	Input@Section12	WaterSprinkleSA	TTWSSA	NumWSprSA	0	Consume	AggregateSA	Always
Section1	WaterSprinkleSA	430	2ndAggregate	Input@Section13	WaterSprinkleSA	0	0	QuantitySA	Consume	AggregateSA	Always
Section1	CompactSA	440	2ndAggregate	Input@Section12	SingleDrumRollersSA	TTCSA	NumSDRSA	0	Consume	AggregateSA	Always
Section1	CompactSA	440	2ndAggregate	Input@Section13	SingleDrumRollersSA	0	0	QuantitySA	Consume	AggregateSA	Always
Section1	MCSprinkle	450	MCS	Input@Section12	MCSprinkle	TTMCS	NumMCSpr	0	Produce	MC	Always
Section1	MCSprinkle	450	MCS	Input@Section13	MCSprinkle	0	0	QuantityMC	Produce	MC	Always
Section1	PavingFTA	460	1stAsphalt	Input@Section12	PavingFinisherFTA	TTPFFTA	NumPFTA	0	Produce	AsphaltFTA	Always
Section1	PavingFTA	460	1stAsphalt	Input@Section13	PavingFinisherFTA	0	0	QuantityFTA	Produce	AsphaltFTA	Always
Section1	CompactFTA	470	1stAsphalt	Input@Section12	DoubleDrumRollersFTA	TTCFTA	NumDDRFTA	0	Consume	AsphaltFTA	Always
Section1	CompactFTA	470	1stAsphalt	Input@Section13	DoubleDrumRollersFTA	0	0	QuantityFTA	Consume	AsphaltFTA	Always
Section1	RCSprinkle	480	RCS	Input@Section12	RCSprinkle	TTRCS	NumRCSpr	0	Produce	RC	Always
Section1	RCSprinkle	480	RCS	Input@Section13	RCSprinkle	0	0	QuantityRC	Produce	RC	Always
Section1	PavingSDA	490	2ndAsphalt	Input@Section12	PavingFinisherSDA	TTPFSDA	NumPSDA	0	Produce	AsphaltSDA	Always
Section1	PavingSDA	490	2ndAsphalt	Input@Section13	PavingFinisherSDA	0	0	QuantitySDA	Produce	AsphaltSDA	Always
Section1	CompactSDA	500	2ndAsphalt	Input@Section12	DoubleDrumRollersSDA	TTCSDA	NumDDRSDA	0	Consume	AsphaltSDA	Always
Section1	CompactSDA	500	2ndAsphalt	Input@Section13	DoubleDrumRollersSDA	0	0	QuantitySDA	Consume	AsphaltSDA	Always

APPENDIX B-1

Simulations (PM-EW, PM-OW & LC) materials data inputs


Facility
Processes
Definitions
Data
Results
Planning
Browse: Model : MC
Navigation: Model
Simulation PM-EW
Model
Experiments
Experiment
Symbols
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Events
Functions
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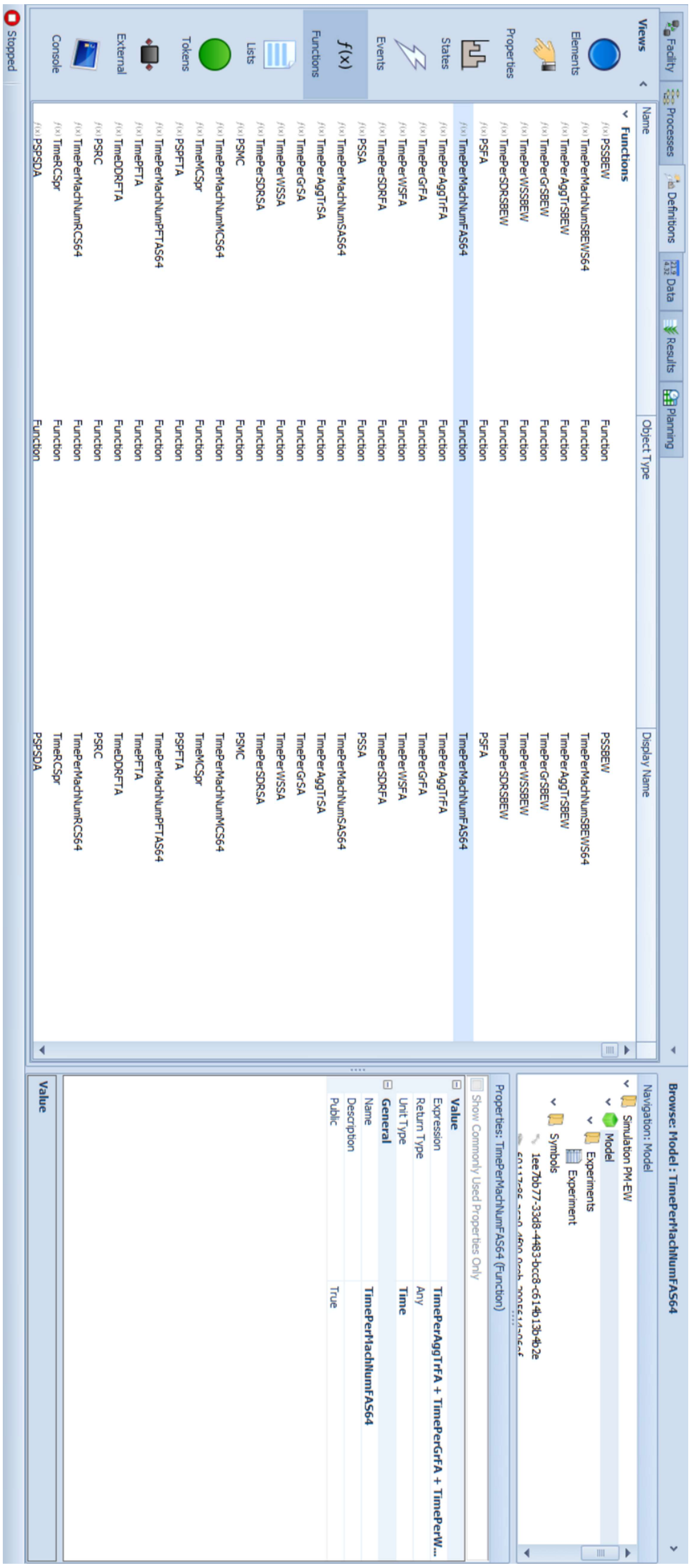
External
Console
Name
Object Type
Material Elements
AggregateEWSB
AggregateFA
AggregateSA
MC
AsphaltFTA
RC
AsphaltSDA
AggregateNEWSB
Material Element
Output Statistic Elements (Auto-Created)
X
Output Statistic Element
Properties: MC (Material Element)
Show Commonly Used Properties Only
Basic Logic
Initial Quantity
370000
Initial Quantities (More)
0 Rows
Bill Of Materials
0 Rows
Financials
Advanced Options
Allocation Ranking Rule
FirstInFirstOut
Assume Infinite Availability If
Log Material Usage
True
General
Basic Logic
Stopped

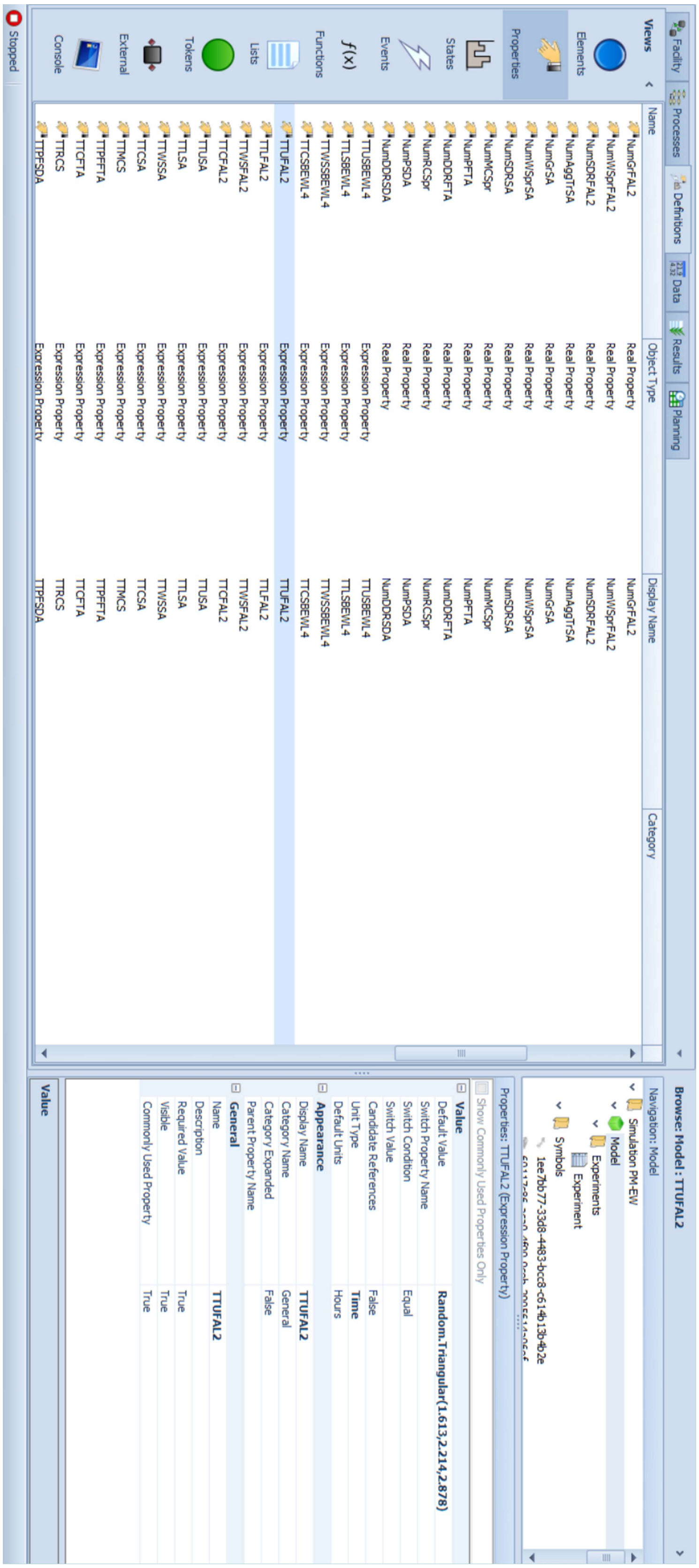
APPENDIX B-2

Simulations (PM-EW, PM-OW & LC) equations inputs



APPENDIX B-3

Simulations (PM-EW, PM-OW & LC) random triangular values and machines quantities inputs


Browse: Model : TTUFAL2
Properties: TTUFAL2 (Expression Property)
Random.Triangular(1.613,2.214,2.878)