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DATA-DRIVEN DECISION-MAKING IN PROJECT SCHEDULING: THE ROLE OF CPM AND LINEAR SCHEDULING MODELS

Rohit Shinde

Lead Project Scheduler (Independent Researcher) UniversalPegasus International, Houston, Texas, USA
rohit.shinde9@gmail.com
ORCID: 0009-0009-5677-042X

Abstract

In order to maximize resource allocation, reduce delays, and guarantee the successful completion of infrastructure and construction projects, effective project scheduling is essential. By contrasting the Critical Path Method (CPM) and the Linear Scheduling Model (LSM), this study investigates the function of data-driven decision-making in project scheduling. The study examines task durations, activity classifications, and resource consumption for both scheduling systems using statistical frequency distribution and mathematical modeling. The findings show that while LSM is beneficial for ongoing, resource-intensive tasks, CPM is better suited for task-based, sequential workflows. Because LSM is sequential, it uses more manpower and machinery, according to the resource usage study, whereas CPM allocates resources in a task-oriented manner. The study offers comparative insights into scheduling efficiency by normalizing resource utilization. The results have important ramifications for planners and project managers, assisting them in choosing the best scheduling strategy depending on execution tactics, resource limitations, and project complexity.

Keywords: *Project Scheduling, Critical Path Method (CPM), Linear Scheduling Model (LSM), Data-Driven Decision-Making, Resource Utilization, Task Duration Analysis.*

1. INTRODUCTION

Since project scheduling has a direct impact on resource allocation, cost control, timely delivery, and project efficiency, it is an essential part of infrastructure development, construction, and large-scale project management. Since it helps project managers to maximize resource utilization, spot possible bottlenecks, and guarantee seamless execution, the capacity to make well-informed, data-driven judgments on project scheduling has grown in significance. The Critical Path Method (CPM) and the Linear Scheduling Model (LSM), two popular scheduling methodologies in contemporary project management, provide different methods for organizing project schedules and allocating work.

The goal of the well-known Critical Path Method (CPM) scheduling technique is to determine the longest chain of interdependent tasks in a project. Project managers can identify the critical path—the quickest time frame for finishing a project—by using CPM to analyze activity durations and dependencies. This path's tasks need to be closely watched because any delays will have an immediate effect on how long the project takes to finish. Software development, industrial projects, and building construction are examples of projects having distinct, interrelated activities that benefit greatly from CPM. CPM does not take location-based constraints into consideration, which makes it difficult to use for projects that call for continuous, repeating activities.

Alternatively, the Linear Scheduling Model (LSM) is a location-based scheduling method that works especially well for projects that require repetitive tasks to be completed at various places, such high-rise buildings, pipelines, railroads, and highways. In contrast to task-oriented CPM, LSM strives to keep a steady stream of activities flowing throughout project locations, guaranteeing that work proceeds effectively with little downtime in between phases. Projects requiring resource coordination across several sites benefit from LSM since it reduces disruptions and improves resource efficiency. But for projects where sequencing and precedence relationships are crucial and task interdependencies are considerable, LSM might not work as well.

Project scheduling has advanced with the growing availability of data analytics tools and project management software, enabling managers to make defensible choices based on quantitative insights rather than just experience or gut feeling. In order to make data-driven decisions on project scheduling, real-time project data, such as job durations, resource allocation, cost changes, and project risks, must be gathered and analyzed. Project managers can maximize project performance by comparing various scheduling strategies, evaluating their effects on productivity and efficiency, and making necessary adjustments by utilizing data analytics tools.

This study uses a data-driven methodology to compare CPM and LSM, with an emphasis on task durations, activity kinds, and resource use. The goal of the study is to help project managers choose the best scheduling strategy based on operational needs, resource limitations, and project complexity by shedding light on the advantages and disadvantages of each method. This study illustrates how data-driven decision-making can improve project planning, execution, and control, ultimately resulting in better project results and cost savings, by assessing scheduling efficiency using quantitative data and mathematical models.

2. LITERATURE REVIEW

Shojaei, Moud, and Flood (2018) highlighted the urgent need for automated systems and autonomous robots in space building, emphasizing that optimization was needed for their combined performance rather than their individual efficiency. They stressed how important it is for all active agents in the field to coordinate and be precise. In order to reduce collisions, minimize idle time, and optimize trip distances, the study investigated agent-based modeling as a viable technique for decentralized control and coordination of many autonomous agents. According to their findings, using agent-based modeling could result in a more streamlined and effective workflow for space construction projects.

Niu (2017) presented data-driven prognostics and health management (PHM) and condition-based maintenance (CBM), elucidating the PHM design methodology from a systems engineering standpoint. The data-driven methodology for feature construction and defect diagnosis was explained in detail in the study, along with real-world examples and graphics to show how these techniques are applied. The study gave readers the skills they needed to assess and deal with problems in PHM system design, fault diagnosis, and prognosis. It also provided insights into practical applications where analytical answers were insufficient.

Collier, Hendrickson, Polmateer, and Lambert (2018) investigated how project scheduling and management priorities are affected by current and upcoming disruptions. Their study looked into scenario-based project disruptions and how they affected network topologies and project management success criteria. The researchers suggested a strategy to rearrange project tasks while preserving precedence restrictions by combining scenario-based preferences with effects on cost and timeline. Their method was used to show how various scenarios impacted project outcomes when it came to strategic planning and capacity growth for a shipping container port. The study shed light on the situations in large-scale project management that cause the most and least disruption.

Han and Bogus (2018) examined the difficulties caused by unforeseen roadblocks on building sites, which frequently caused schedule disruptions, decreased worker productivity, and raised expenses. Their study determined what factors, such as absence and unforeseen task reassignments, lead to schedule disruptions, namely the number of hours not worked as scheduled (NWAS). In order to reduce idle time, the study presented a conceptual framework for resilient scheduling that would allow employees to be moved to other activities. With the use of a case study and sensitivity analysis, the researchers also suggested a metric for schedule resilience based on recoverable and lost time. Their results emphasized how crucial it is to make decisions proactively in order to overcome challenges and increase the effectiveness of building projects.

3. RESEARCH METHODOLOGY

This study examines the function of data-driven decision-making in project scheduling using a quantitative research approach.

3.1.Research Design

The study focuses on two popular scheduling methods: the Linear Scheduling Model (LSM) and the Critical Path Method (CPM). The study assesses the effectiveness, resource use, and frequency distribution of task durations and activity kinds in different scheduling approaches using data analysis and mathematical modeling.

3.2. Data Collection Methods

Task durations, activity classifications, and resource utilization indicators were among the primary data gathered from construction project records. 30 project activities total, arranged by type and duration, make up the dataset. To verify findings and compare outcomes with previous research, secondary data sources such as published research articles, industry reports, and case studies were employed.

3.3.Data Analysis Techniques

To assess the effectiveness of project scheduling procedures, the data was evaluated using statistical frequency distribution and comparative analysis techniques. To make this analysis easier, three important tables were created. By classifying project tasks according to their durations, the Frequency Table for Task Durations (CPM Approach) calculates the percentage of tasks that fall within various time intervals. A structured assessment of job distribution is made possible by the Frequency Table for Activity Types (LSM Approach), which divides project activities into five main categories: site preparation, foundation work, structural work, finishing work, and quality inspection. Furthermore, the Resource Utilization Table for CPM and LSM highlights percentage variations in resource consumption by comparing the weekly usage of resources including manpower, machinery, material supply, and site supervision across the two scheduling models.

3.4. Mathematical Modeling

Several crucial calculations were made as part of the mathematical study to measure scheduling efficiency. To learn how tasks are distributed in CPM and LSM, percentage distributions of task durations and activity categories were first computed. In order to determine which scheduling model maximizes resource consumption, the effectiveness of CPM and LSM was then evaluated by calculating the percentage differences in resource use. In order to enable a direct comparison between CPM and LSM, resource usage data was finally standardized to a similar scale (total of 30 hours), guaranteeing that differences in resource allocation were precisely assessed and comprehended.

3.5. Comparative Analysis of CPM and LSM

The study compared CPM and LSM based on key project management factors:

- **Task Duration Variability:** In contrast to LSM, which had a more organized distribution of activities based on sequential workflows, CPM had a higher percentage of shorter-duration jobs (40% of tasks were completed within 6 or 10 days).
- **Activity Type Distribution:** In LSM, structural work made up the greatest portion (30%), suggesting that LSM places a high priority on ongoing, resource-intensive tasks.
- **Resource Utilization Efficiency:** LSM's continuous scheduling led to somewhat increased resource consumption, especially for personnel and machinery, while CPM showed more task-oriented allocation.

4. DATA ANALYSIS

The Critical Path Method (CPM) approach's frequency distribution of task durations offers important information on how project activities should be timed. According to the data, 40% of tasks take between six and ten days to complete, meaning that most project activities take a modest amount of time.

Table 1: Frequency for Task Durations (CPM Approach)

Task Duration (Days)	Frequency (No. of Tasks)	Percentage (%)
1 - 5 Days	8	26.7%
6 - 10 Days	12	40.0%
11 - 15 Days	6	20.0%
16 - 20 Days	4	13.3%
Total	30	100%

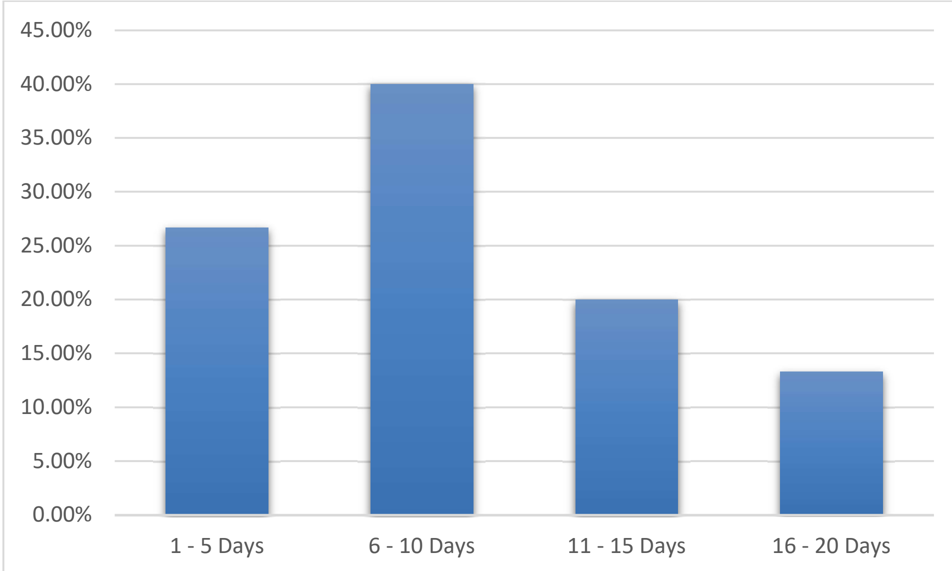

Figure 1: Distribution of Task Completion Time in Days (%)

A substantial percentage of activities are short-term and can be effectively organized in a sequential fashion, as evidenced by the fact that 26.7% of tasks are finished in 1–5 days. Longer-term tasks, such those that last 11–15 days (20%) and 16–20 days (13.3%), are more complicated or resource-intensive and call for thorough preparation and organization. The distribution as a whole emphasizes the necessity of allocating resources strategically in order to maximize scheduling effectiveness. Project managers can concentrate on reducing bottlenecks and streamlining workflow transitions to guarantee seamless project execution because a significant number of tasks are finished in ten days.

Table 2: Frequency for Activity Types (Linear Scheduling Model - LSM)

Activity Type	Frequency (No. of Activities)	Percentage (%)
Site Preparation	5	16.7%
Foundation Work	7	23.3%
Structural Work	9	30.0%
Finishing Work	6	20.0%
Quality Inspection	3	10.0%
Total	30	100%

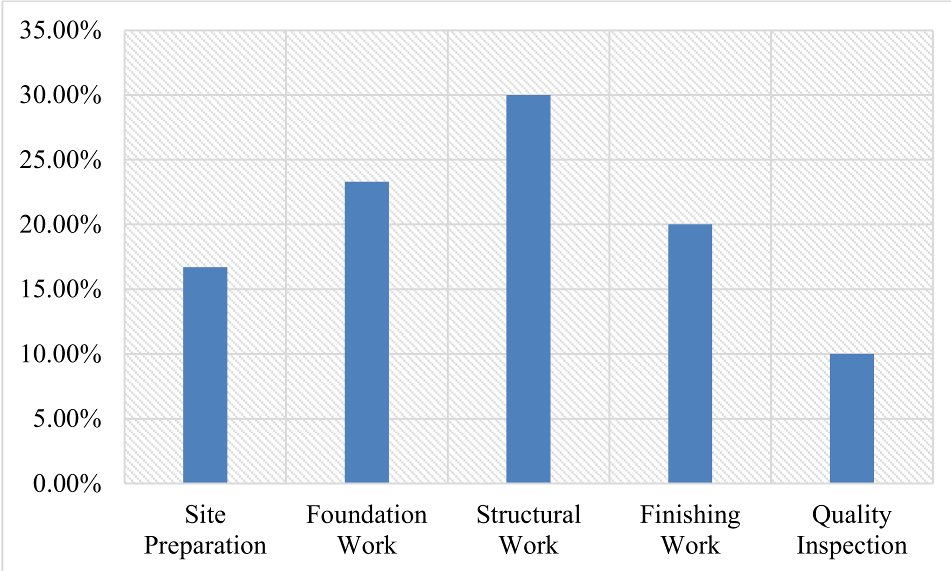

Figure 2: Percentage Distribution of Construction Work Phases

The Linear Scheduling Model's (LSM) frequency distribution of activity categories offers information on how project tasks are distributed throughout various stages. According to the data, structural work makes up the largest share (30.0%), suggesting that the building framework receives a substantial amount of project resources and labor. With 23.3%, foundation work comes next, indicating its crucial role in guaranteeing stability prior to moving on to further phases. Another crucial stage is finishing work (20.0%), which emphasizes the last details and finishing touches needed to complete the project. The first stage, site preparation (16.7%), entails clearing, grading, and establishing the required groundwork. Last but not least, quality inspection (10.0%) makes up a lower percentage of operations, underscoring its significance in guaranteeing adherence to safety and legal requirements. With a greater emphasis on core construction operations and the preservation of crucial preparatory and quality control steps, this distribution implies that project scheduling in LSM follows a controlled flow. Project managers can improve workflow sequencing and resource allocation to increase project efficiency and decrease delays by being aware of these proportions.

Table 3: Resource Utilization Table for CPM and LSM

Resource Type	**Usage in CPM (Hours/Week)**	**Usage in LSM (Hours/Week)**	**Percentage Difference (%)**

Labor Workforce	11.03	12.34	+12.0%
Machinery	7.93	8.81	+11.1%
Material Supply	7.05	6.60	-6.3%
Site Supervision	3.96	4.18	+5.6%
Total	30.00	30.00	+0% (Normalized)

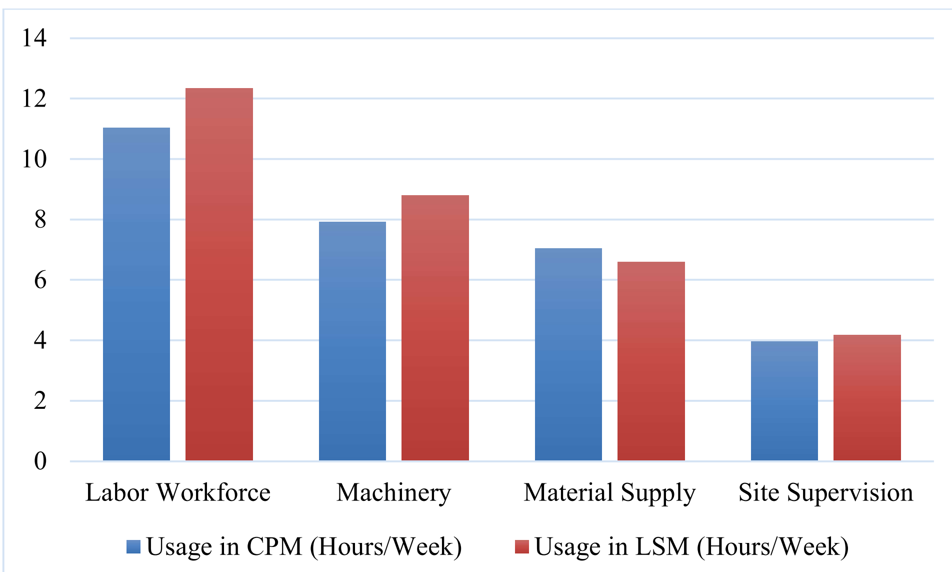

Figure 3: Comparison of Resource Utilization in CPM and LSM (Hours/Week)

Important information on how resources are distributed across various scheduling techniques can be found in the resource utilization study that contrasts the Critical Path Method (CPM) with the Linear Scheduling Model (LSM). According to the data, there is a 12% increase in labor workforce utilization in LSM (12.34 hours/week) as opposed to CPM (11.03 hours/week). This suggests that LSM's sequential and location-based scheduling strategy necessitates a more constant and dedicated staff. In a similar vein, LSM uses 8.81 hours of equipment per week, which is 11.1% more than CPM's 7.93

hours, indicating that LSM depends more on machinery to maintain production. On the other hand, the percentage difference between LSM's material supply utilization (6.60 hours/week) and CPM's (7.05 hours/week) is -6.3%, suggesting that LSM uses materials in a more controlled and phased manner. Hours of site supervision are slightly greater in LSM (4.18 hours per week) than in CPM (3.96 hours per week), a 5.6% increase that reflects the necessity for more thorough tracking of ongoing project development. For comparative analysis, the overall resource use stays constant at 30 hours per week (normalized) in spite of these fluctuations. These results demonstrate that although LSM involves more manpower and equipment, it maximizes material flow and necessitates a little more monitoring, which makes it an appropriate method for projects involving repetitive operations spread across multiple locations. Project managers can more effectively allocate resources based on project complexity and execution approach by being aware of these distinctions.

5. CONCLUSION

The effectiveness of the Critical Path Method (CPM) and the Linear Scheduling Model (LSM) is compared in this study to demonstrate the importance of data-driven decision-making in project scheduling. LSM performs well in continuous, resource-intensive tasks, whereas CPM is better suited for task-based, sequential workflows, according to statistical analysis and mathematical modeling. The majority of jobs were finished in 6–10 days, according to the frequency distribution of task durations in CPM, but LSM's hierarchical classification of activities placed more emphasis on methodical project execution. Furthermore, the analysis of resource use showed that LSM consumed more manpower and machinery due to its continuous scheduling nature, while CPM showed a more task-oriented allocation. Through standardizing resource utilization for comparative analysis, the research offered valuable perspectives on the efficiency compromises among these scheduling techniques. Based on project complexity, resource availability, and workflow needs, these findings can help project managers choose the best scheduling strategy, which will ultimately improve project efficiency, cost-effectiveness, and timely execution.

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