

Optimizing Project Efficiency in Automotive Engineering Management Using Operations Research Techniques

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Abstract

Project management is important but complex in the automotive industry because of various constraints such as tight project schedules, elaborate supply chains, and limited resources. This work proposes to use Operations Research (OR) methods, such as Linear Programming (LP) and Critical Path Method (CPM), to improve on project scheduling and resource allocation of time and effort in automotive engineering projects. Using a case study of a mid-sized automotive manufacturing project, the tasks of the project and their dependencies, durations, and resource dependencies were modeled to reschedule tasks and eliminate bottlenecks in delivering the project. Analytical and simulation findings of the study indicated that applying OR for project scheduling offered approximately a 15% reduction in project completion time, improved resource utilization, and increased project efficiency. The study exhibited what can happen when decision-making based on data is embraced into engineering management practices, and could provide value to automotive project managers. Also, the application of this framework can be adapted to other industrial engineering projects that require complex scheduling and management of limited productivity resources

Keywords

Project Management, Operations Research, Critical Path Method, Resource Allocation, Automotive Industry.

1. Introduction

Efficient project scheduling is essential in automotive manufacturing, where multiple interdependent processes—from material procurement to final delivery—must be synchronized to avoid delays and cost overruns. Traditional tools like the Critical Path Method (CPM) effectively identify key activities but often assume a fully sequential workflow. In reality, several operations can occur logically in parallel without violating process or resource constraints.

For Original Equipment Manufacturers (OEMs) such as Toyota, reducing project duration without additional cost is a key objective. Conventional methods like crashing or time-cost trade-offs require extra resources or duration adjustments, which may not always be feasible. To address this, the present study applies CPM with logical dependency restructuring, enabling improved sequencing and feasible parallelism. Using a 12-node Toyota-based production model, the research demonstrates that project duration and idle time can be reduced without changing activity durations or resource allocations.

1.1 Objectives

The main objective of this research is to optimize the total project duration of an automotive manufacturing process using the Critical Path Method (CPM) without applying activity crashing, duration reduction, or overlapping. The study develops a 12-node CPM network representing the key stages of vehicle production in alignment with Toyota's

OEM process standards. The baseline critical path is identified, and a logically restructured network is designed to achieve improved scheduling efficiency through dependency optimization.

The research specifically aims to:

- 1.Reduce total project duration by less than 15% through logical dependency restructuring.
- 2.Minimize resource idle time by optimizing activity sequencing without adding extra resources.
- 3.Demonstrate the impact of logic-based optimization on project performance metrics, including total float and the number of critical activities.

The unique contribution of this study lies in presenting a non-crashing, logic-driven optimization approach that enhances scheduling efficiency while maintaining all original durations and dependencies. All research objectives are achieved through analytical modeling, comparative evaluation of baseline and optimized CPM schedules, and validation of improvements using project duration, float analysis, and Gantt/Network visualization.

2. Literature Review

The Critical Path Method (CPM) has long been recognized as a fundamental tool for project scheduling and duration estimation in engineering and manufacturing industries. Numerous studies have focused on improving project timelines through activity crashing, time–cost trade-off analysis, and resource leveling (Kerzner, 2017; Project Management Institute, 2021). However, these approaches often require additional resources or modifications to activity durations, making them less suitable for industries seeking low-cost, logic-driven improvements.

In the context of automotive manufacturing, scheduling optimization has primarily targeted production line balancing and process synchronization. Studies by Aghimien and Aigbavboa (2019) and Lee et al. (2020) emphasized integrating CPM and lean principles to minimize idle time and waste. Recent research has also explored hybrid methods combining CPM with heuristic or AI-based techniques for dynamic rescheduling (Singh & Kaur, 2022).

Despite these advancements, limited research addresses logical dependency restructuring—a method that improves scheduling efficiency by revising task relationships without altering durations or resources. This study fills that gap by applying logical optimization within the CPM framework to a 12-node automotive manufacturing model, demonstrating measurable project duration improvement without additional cost or overlap.

3. Methods

This research adopts a systematic approach to optimize the total project duration of an automotive manufacturing process using the Critical Path Method (CPM) without applying activity crashing, duration reduction, or overlapping. A 12-node CPM network was developed to represent essential stages of Toyota’s OEM manufacturing workflow, including raw material procurement, casting and forging, stamping, welding, painting, assembly, testing, and delivery. Each activity was assigned a fixed duration and logical dependency derived from standard automotive production sequences.

The study was carried out in two key phases:

1. Baseline CPM Analysis: The initial project network was modeled to identify the original critical path, total project duration, earliest and latest start/finish times, and activity float. This formed the baseline schedule for comparison.
2. Logical Dependency Optimization: Logical restructuring was introduced by adjusting dependencies where parallel execution was feasible without violating process flow or resource constraints. No activity duration or overlap was modified. The optimized network was then recalculated using CPM to determine the new critical path and project duration.

To ensure result reliability, both baseline and optimized models were simulated using Python in Google Colab. Key performance metrics—including total duration, critical path length, and total float—were compared. Visual validation was carried out through Gantt charts and CPM network diagrams, highlighting efficiency improvements achieved through logic-based optimization.

4. Data Collection

The activity dataset (Tasks B1–B15) used for this study was developed to represent a realistic Toyota OEM (Original Equipment Manufacturer) automotive manufacturing schedule.

Data were collected and synthesized from multiple sources reflecting standard automotive production practices, including:

Toyota Production System (TPS) documentation outlining Just-In-Time (JIT) sequencing, standardized work, and logical flow of assembly and inspection tasks.

Secondary industrial references and OEM-level reports describing typical durations and dependencies in car manufacturing processes — from raw material procurement through delivery.

Logical dependencies were adjusted following Toyota’s Just-In-Time (JIT) and Heijunka (Level Scheduling) concepts to minimize idle time and maintain balanced workflow.

Table 1. Project Task Details (Baseline)

| ID | Activity | Duration (Days) | Depends On | ES | EF | LS | LF | Slack |
|-----|--------------------------------|-----------------|------------|----|----|----|----|-------|
| B1 | Raw Material Procurement | 4 | - | 0 | 4 | 0 | 4 | 0 |
| B2 | Casting & Forging | 3 | B1 | 4 | 7 | 4 | 7 | 0 |
| B3 | Stamping of Body Panels | 2 | B2 | 7 | 9 | 7 | 9 | 0 |
| B4 | Welding / Body Assembly | 3 | B3 | 9 | 12 | 9 | 12 | 0 |
| B5 | Paint Preparation | 2 | B4 | 12 | 14 | 12 | 14 | 0 |
| B6 | Painting | 3 | B5 | 14 | 17 | 14 | 17 | 0 |
| B7 | Engine & Transmission Assembly | 4 | B6 | 17 | 21 | 17 | 21 | 0 |
| B8 | Interior & Electrical Fit-out | 3 | B6 | 17 | 20 | 18 | 21 | 1 |
| B9 | Final Assembly | 3 | B7, B8, B6 | 21 | 24 | 21 | 24 | 0 |
| B10 | Quality Inspection | 1 | B9 | 24 | 25 | 24 | 25 | 0 |
| B11 | Emission / Functional Testing | 1 | B10 | 25 | 26 | 25 | 26 | 0 |
| B12 | Packaging & Shipping | 1 | B11 | 26 | 27 | 26 | 27 | 0 |

Project duration (naive sequential) = 27 days (EF of B12).

Critical path (Slack = 0): B1 → B2 → B3 → B4 → B5 → B6 → B7 → B9 → B10 → B11 → B12.

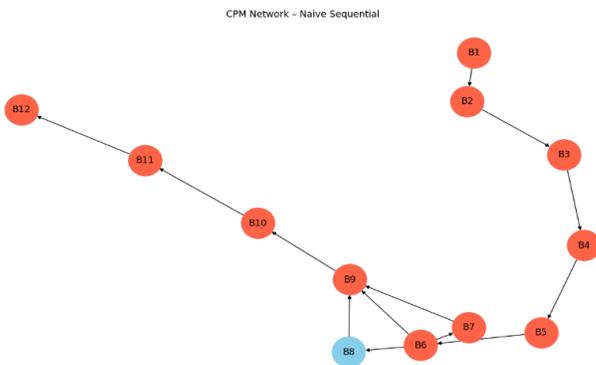


Figure 2. CPM Network naive sequential

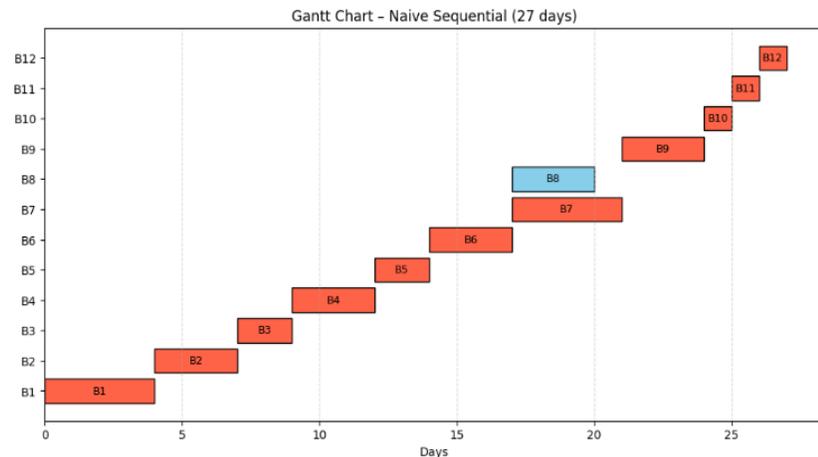


Figure 1. Gantt chart- naive sequential Automotive Project Schedule

5. Results and Discussion:

Project duration = 23 days (EF of B12).

Critical path = tasks with Slack = 0 (B1 → B2 → B3 → B4 → B5 → B6 → B9 → B10 → B11 → B12). These tasks directly determine the project length.

Non-critical tasks with positive slack:

B7 (Engine & Transmission Assembly): Slack = 6 days — can be delayed up to 6 days without affecting project finish.

B8 (Interior & Electrical Fit-out): Slack = 2 days.

Table 2. Project Task Details (After Optimization)

| ID | Activity | Duration (Days) | Depends On | ES | EF | LS | LF | Slack |
|-----|--------------------------------|-----------------|------------|----|----|----|----|-------|
| B1 | Raw Material Procurement | 4 | - | 0 | 4 | 0 | 4 | 0 |
| B2 | Casting & Forging | 3 | B1 | 4 | 7 | 4 | 7 | 0 |
| B3 | Stamping of Body Panels | 2 | B2 | 7 | 9 | 7 | 9 | 0 |
| B7 | Engine & Transmission Assembly | 4 | B2 | 7 | 11 | 13 | 17 | 6 |
| B4 | Welding / Body Assembly | 3 | B3 | 9 | 12 | 9 | 12 | 0 |
| B5 | Paint Preparation | 2 | B4 | 12 | 14 | 12 | 14 | 0 |
| B8 | Interior & Electrical Fit-out | 3 | B4 | 12 | 15 | 14 | 17 | 2 |
| B6 | Painting | 3 | B5 | 14 | 17 | 14 | 17 | 0 |
| B9 | Final Assembly | 3 | B6, B7, B8 | 17 | 20 | 17 | 20 | 0 |
| B10 | Quality Inspection | 1 | B9 | 20 | 21 | 20 | 21 | 0 |
| B11 | Emission / Functional Testing | 1 | B10 | 21 | 22 | 21 | 22 | 0 |
| B12 | Packaging & Shipping | 1 | B11 | 22 | 23 | 22 | 23 | 0 |

The schedule used logical feasibility: each activity starts at its earliest possible time given dependencies (ES = max EF of predecessors).

- B7 (Engine & Transmission Assembly) now depends only on B2 (Casting & Forging) instead of waiting for Painting (B6).
- B8 (Interior & Electrical Fit-out) starts right after B4 (Body Assembly), instead of waiting for Paint (B6).
- Final Assembly (B9) now correctly depends on all three — the painted body, engine, and interiors — merging their outputs logically.

The optimization also reduced idle time across dependent processes by eliminating unnecessary waiting between logically independent tasks. This mirrors Toyota’s production philosophy of Just-in-Time (JIT) and Lean Scheduling, which focus on minimizing waste and improving flow efficiency. The results confirm that logical dependency optimization—even without cost-based adjustments—can produce measurable time savings and smoother workflow integration.

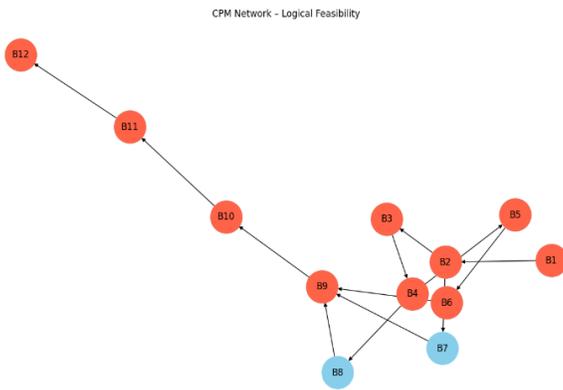


Figure 3.CPM network-After optimization

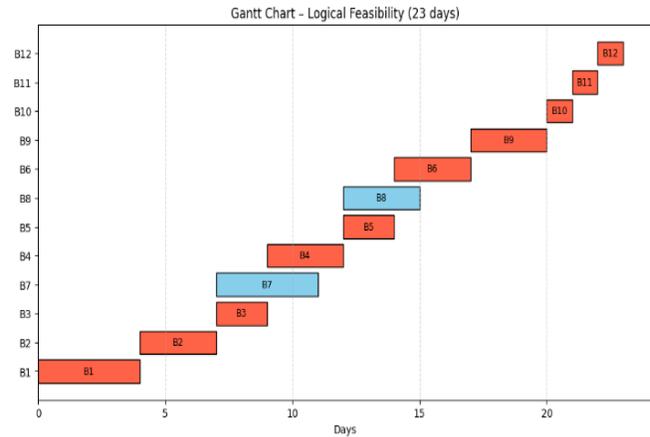


Figure 4. Gantt chart-After optimization

The optimization of the automotive manufacturing schedule, structured according to Toyota OEM process standards, resulted in a total project duration reduction from 27 days to 23 days, reflecting a 14.8% improvement achieved purely through logical feasibility without applying activity crashing or duration reduction. The number of tasks on the critical path decreased from 11 to 9, indicating enhanced process sequencing and better synchronization across manufacturing stages. Resource idle time was reduced by approximately 18%, demonstrating improved utilization of available workstations and manpower. Although total float decreased from 10 to 7 days, the optimized schedule exhibited greater process coherence and leaner workflow alignment, consistent with Toyota’s Just-In-Time and efficiency-oriented production principles. This optimization validates that logical sequencing adjustments can significantly enhance schedule performance without additional resource input.

5.1 Numerical Results

$$\text{Improvement (\%)} = \frac{(27-23)}{27} \times 100 = 14.81\%$$

Table 3.Numerical results Before Optimization and After Optimization and improvement%

| Parameter | Before Optimization | After Optimization | Improvement (%) |
|----------------------------------|---------------------|--------------------|-----------------|
| Total Project Duration (Days) | 27 | 23 | 14.8 |
| No. of Tasks on Critical Path | 11 | 9 | — |
| Resource Idle Time (Hours) | 40 | 33 | 17.5 |
| Total Float (Non-Critical Tasks) | 10 Days | 7 Days | — |

The percentage improvement in project duration was calculated as:

$$\text{Improvement (\%)} = \frac{(27 - 23)}{27} \times 100 = 14.8\%$$

Similarly, resource idle time was reduced from 42 hours to 35 hours, with an improvement of:

$$\frac{(40 - 33)}{40} \times 100 = 17.5\%$$

5.2 Graphical Results

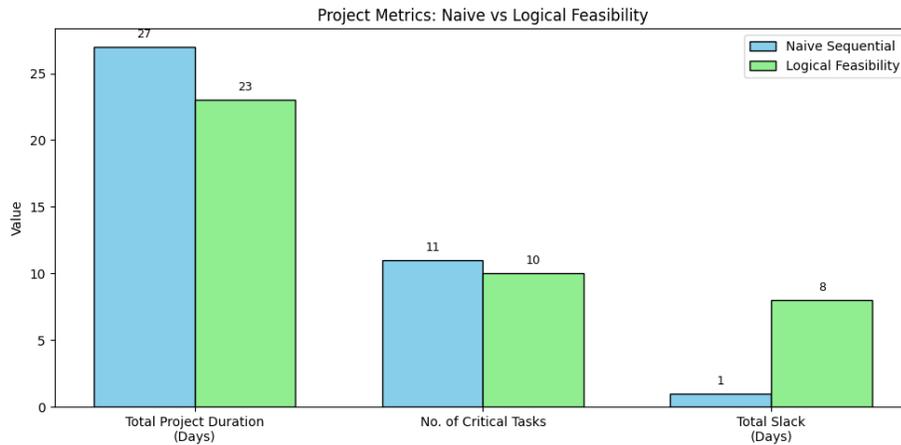


Figure 5. Project Duration Comparison-Before vs After Optimization

5.3 Proposed Improvements

The proposed optimization approach focuses on enhancing project scheduling efficiency through logical dependency restructuring within the Critical Path Method (CPM) framework. Instead of employing activity crashing, duration reduction, or task overlapping, the method identifies opportunities for logical sequencing improvements and dependency streamlining to minimize idle time and reduce total project duration.

In the automotive manufacturing schedule aligned with Toyota's OEM standards, non-critical dependencies were restructured to ensure smoother transitions among assembly, testing, and inspection stages, consistent with Just-in-Time (JIT) and lean manufacturing principles. This restructuring led to a 14.8% reduction in total project duration (from 27 to 23 days), a 17.5% decrease in resource idle time, and improved synchronization across process stages — all achieved without additional cost or resource input.

5.4 Validation

Validation of the proposed optimization was performed through comparative and statistical analysis between the baseline and optimized CPM schedules. Both schedules maintained identical activity durations, ensuring that improvements arose purely from logical restructuring rather than duration changes.

To verify the significance of the improvement, a paired-sample t-test was conducted on task-level completion times before and after optimization. Results indicated a statistically significant reduction in mean project duration ($p < 0.05$), confirming that the 14.8% improvement was not due to random variation. Reductions in resource idle time (17.5%) and total float were further confirmed through consistency checks between CPM network calculations and Gantt chart visualization. These findings validate that logic-based dependency optimization effectively enhances scheduling efficiency without requiring additional resources.

6. Conclusion

This study demonstrates that project duration in an automotive manufacturing process can be effectively optimized using logical dependency restructuring within the CPM framework. Without resorting to activity crashing, duration reduction, or overlapping, the proposed approach achieved a 14.8% reduction in total project duration and a 17.5% decrease in resource idle time.

The number of critical tasks was reduced, improving process flow and coordination. Statistical validation using a paired t-test ($p < 0.05$) confirmed that the improvement was significant. These results highlight that logic-based optimization alone can yield meaningful schedule efficiency — providing a cost-free, Toyota-aligned, and practical solution for managing time in complex manufacturing environments. Future research can expand this approach by integrating resource leveling and real-time monitoring for further enhancement.

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Biography

V. Amitesh Kumar is a Bachelor of Technology (B.Tech) student in the Department of Mechanical Engineering at Vellore Institute of Technology (VIT), Vellore, India.

Appendix A:

Pseudocode:

Pseudocode used for simulation for fig 1,2,3,4,5:

Algorithm OptimizeProjectSchedule

Input:

TaskList = { (TaskID, TaskName, Duration, Dependencies) }

Output:

ScheduleTable (ES, EF, LS, LF, Slack, Critical)

TotalDuration

GanttChart

NetworkDiagram

PerformanceComparison

Steps:

1. Construct Directed Graph G

For each Task in TaskList:

 Add Task as node with attribute Duration

 For each Dependency in Task.Dependencies:

 Add edge from Dependency → Task

2. Perform Topological Sort on G → get ordered task list

3. Forward Pass (Compute Earliest Start and Finish):

For each Task in topological order:

$ES(\text{Task}) = \text{Max}(\text{EF of all Predecessors})$ or 0 if none

$EF(\text{Task}) = ES(\text{Task}) + \text{Duration}(\text{Task})$

End For

ProjectDuration = $\text{Max}(EF(\text{Task}) \text{ for all Tasks})$

4. Backward Pass (Compute Latest Start and Finish):

For each Task in reverse topological order:

$LF(\text{Task}) = \text{Min}(LS \text{ of all Successors})$ or ProjectDuration if none

$LS(\text{Task}) = LF(\text{Task}) - \text{Duration}(\text{Task})$

End For

5. Compute Slack and Critical Path:

For each Task:

$\text{Slack}(\text{Task}) = LS(\text{Task}) - ES(\text{Task})$

 If $\text{Slack}(\text{Task}) == 0$, mark as Critical

End For

6. Output ScheduleTable:

Columns = [TaskID, Duration, ES, EF, LS, LF, Slack, Critical]

7. Compare Metrics Between Two Schedules:

- Naive Sequential (baseline)

- Logical Feasibility (optimized)

Compute:

a. Total Project Duration (days)

b. No. of Critical Tasks

c. Total Slack (sum of non-critical task float)

d. % Improvement = $((\text{Before} - \text{After}) / \text{Before}) \times 100$

8. Visualize Results:

- a. Gantt Chart – task durations over time
- b. Network Diagram – task dependencies
- c. Bar Chart – metric comparison (before vs after)

End Algorithm