Development of a Production Planning Decision-Support Tool for Aerospace Engine Manufacturing

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Master in Engineering Management
Graduate Project EXPO, May 2026

Abstract

This study developed a conceptual production planning decision-support tool for aerospace engine manufacturing environments by integrating supply chain performance, manufacturing capacity, workforce availability, and testing constraints into a unified model. The objective was to improve production forecasting accuracy by representing the system as a set of interdependent operational constraints rather than isolated functional capacities. A constraint-based modeling approach was applied to estimate maximum monthly engine production under varying operational scenarios using representative datasets. The results showed that supplier delivery reliability is the most significant factor influencing production output, producing a 38% reduction in total engine production when constrained, followed by manufacturing capacity, labor availability, and testing constraints. The proposed framework enhances decision-making by enabling scenario-based analysis and improving visibility of production bottlenecks within complex aerospace manufacturing systems.

Introduction

The aerospace industry operates within complex supply chains where production commitments must align with manufacturing capacity. Recent geopolitical instability and increased military demand have intensified the need for reliable aircraft engine production forecasts to support operational planning and fleet readiness. Aircraft engine manufacturing depends on globally sourced precision components, supplier performance, workforce availability, testing resources, and assembly capacity. In many organizations, production planning relies on fragmented data and manual processes, limiting forecast accuracy and increasing operational risk. This project developed a conceptual decision-support tool that integrates supply chain commitments, manufacturing capacity, and operational constraints to estimate monthly engine production and support scenario-based planning.

Literature Review

The aerospace industry relies on complex global supply chains where supplier dependencies, regulatory requirements, and operational risks strongly affect production performance. Research shows that distributed supplier networks increase uncertainty in material availability and delivery schedules, making production planning more difficult [1]. This challenge is intensified by the growing need for digital integration and real-time data exchange across supply chain stakeholders [2].Studies also emphasize that production capacity and inventory decisions must be evaluated together because they directly affect operational efficiency and forecasting accuracy [3]. Effective capacity planning must address uncertainty related to demand, supplier performance, and resource availability through flexible and adaptive planning methods [4]. In response, modern supply chain management approaches promote dynamic, data-driven models that support real-time decision-making and scenario-based analysis under changing operational conditions [5].Overall, the literature supports the development of integrated production planning models that combine supply chain data, manufacturing capacity, and uncertainty considerations to improve forecasting and decision-making in aerospace manufacturing environments.

Methodology

This project applied the DMAIC (Define, Measure, Analyze, Improve, Control) engineering management framework to guide the development of a production planning decision-support tool for aerospace engine manufacturing.

During the Define phase, the production planning problem and key operational variables affecting engine output were identified, including supplier component availability capacity, manufacturing throughput capacity, labor resource capacity and testing and inspection capacity. The Measure phase established representative datasets simulating aerospace manufacturing conditions, including supplier lead times, production rates, labor capacity, and component delivery schedules.

In the Analyze phase, constraint analysis, capacity modeling, bottleneck identification, and sensitivity analysis were used to evaluate how operational variables affected monthly production capacity. The Improve phase focused on developing a spreadsheet-based analytical model capable of forecasting engine production under multiple operational scenarios by integrating supply chain and manufacturing constraints.

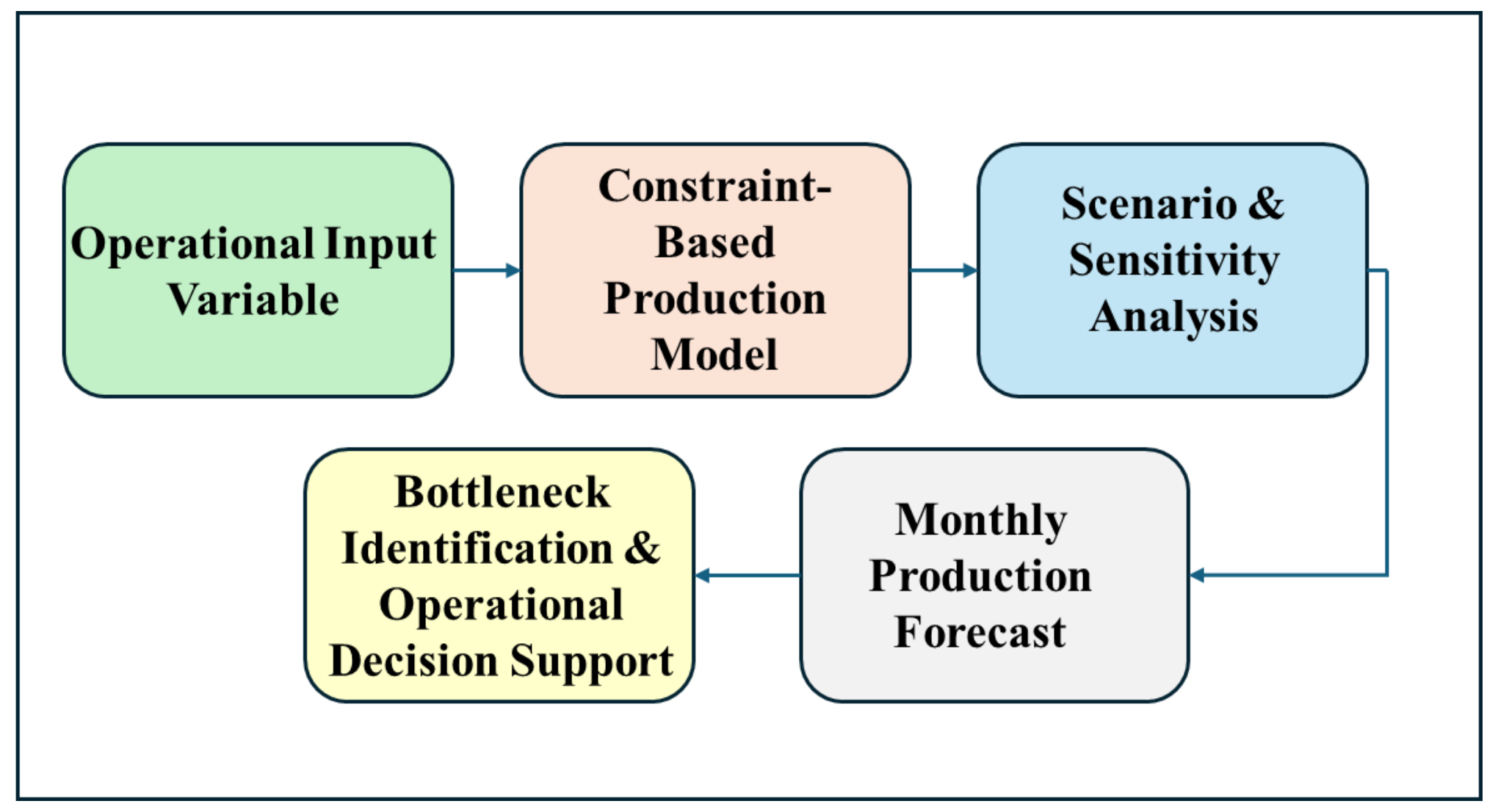
Finally, the Control phase established procedures for updating input data, validating outputs, and maintaining the reliability of the decision-support framework. The final deliverable was an integrated analytical tool designed to support production planning and operational decision-making in aerospace manufacturing environments.

Results and Discussion

The production planning decision-support tool was developed to estimate the maximum achievable monthly aircraft engine production by integrating operational variables associated with supply chain performance, manufacturing throughput, workforce availability, and testing capacity. The model was designed using a constraint-based analytical approach in which overall production output is determined by the operational area with the lowest available capacity.

The production model applies a limiting-factor methodology to represent the interdependent nature of aerospace manufacturing systems. Since aircraft engine production requires all critical resources and components to be available simultaneously, the system output is constrained by the weakest operational element within the production chain.

To provide a consolidated view of the proposed production planning methodology, Figure 1 summarizes the structure of the decision support framework used in this study. The framework integrates operational input variables associated with supplier performance, manufacturing throughput, labor availability, and testing capacity into a constraint-based production model. The model then evaluates multiple operational scenarios to estimate achievable monthly engine production and identify the primary production bottlenecks affecting system performance.



Operational Input Variable

Constraint-Based Production Model

Scenario & Sensitivity Analysis

Monthly Production Forecast

Bottleneck Identification & Operational Decision Support

Figure 1
Decision Support Framework

The maximum monthly production capacity is represented by the following equation:

$$\boldsymbol{P_{max} = \min\left(S_c, M_c, L_c, T_c\right)} \quad (1)$$

where S_c represents supplier component availability capacity, M_c is manufacturing throughput capacity, L_c represents labor resource capacity and T_c is testing and inspection capacity. This equation reflects that total production output is equal to the minimum available capacity among all operational constraints.

The supplier component availability capacity was calculated using supplier delivery data:

$$S_c = R_s \times D_c \quad (2)$$

where R_s is supplier delivery reliability rate, and D_c represents total demanded engine component sets. This relationship was used to estimate the number of complete engine assemblies that could be supported under varying supplier performance conditions.

Labor resource capacity was also incorporated into the model using the following relationship:

$$L_c = A_t \times E_{Lc} \quad (3)$$

where L_c represents labor resource capacity, A_t is available technicians and E_l represents labor efficiency rate.

The model integrated these operational variables into a spreadsheet-based analytical framework capable of generating monthly production forecasts under multiple operational scenarios.

Representative datasets were developed to simulate conditions commonly found within aerospace manufacturing operations. The supplier dataset in Table 1 demonstrated that component shortages directly constrained achievable engine production. Bearings and combustion chamber deliveries generated the largest supply chain limitations.

Table 1
Supplier Delivery Data

Supplier	Crit. Comp.	Monthly Req.	Delivered	Deliv. Rel. (%)
Supplier A	Turbine Blades	40	40	100%
Supplier B	Combustor Chamber	40	36	90%
Supplier C	Compressor Module	40	38	95%
Supplier D	Bearings	40	34	85%

Note: Crit. Comp. = Critical Component; Monthly Req. = Monthly Requirement; Delivered = Components Delivered; Deliv. Rel. (%) = Delivery Reliability (%).

In addition to supplier delivery data, manufacturing throughput capacity was evaluated under ideal supply conditions. Assembly Line 1 supported 22 engines/month and Assembly Line 2 supported 18 engines/month, resulting in a combined manufacturing throughput capacity of 40 engines per month.

The results in Table 2 show that reductions in supplier reliability generated proportional decreases in achievable production output. A 15% decrease in supplier reliability reduced engine production by approximately 12%, confirming that supply chain performance is the dominant system constraint.

Table 2
Supplier Reliability Reduction

Supplier Reliability	Projected Output
100%	40 Engines
95%	38 Engines
90%	35 Engines
85%	31 Engines

The labor analysis demonstrated that increasing workforce capacity improved production output, but the effect was smaller compared to supplier-related improvements. This indicates that labor expansion alone cannot fully compensate for supply chain shortages.

The impact of each operational constraint on production capacity was calculated using a sensitivity analysis based on the change from baseline output, expressed as:

$$Impact\,(\%) = \frac{P_b - P_c}{P_b} \times 100 \quad (4)$$

where P_b represents baseline production capacity and P_c is production capacity under each constrained scenario.

The sensitivity analysis data shown in Table 3 evaluates the relative impact of each operational variable on maximum production capacity based on the constraint model. Each variable was individually reduced while holding all other system parameters constant at baseline levels. The resulting change in production output was measured to determine the marginal impact of each constraint.

Table 3
Sensitivity of Production Output

Variable	Constrained Output Pmax	Impact on Production
Supplier component availability capacity	25	38%
Manufacturing throughput capacity	28	30%
Labor resource capacity	32	20%
Testing and inspection capacity	35	12%

Supplier component availability capacity had the greatest influence on production output, with a 38% reduction in total engine production when constrained. Manufacturing capacity represents the second most significant factor at 30%, followed by labor capacity at 20% and testing capacity at 12%. This ranking confirms that the production system is primarily driven by upstream supply chain performance rather than internal operational resources. The analysis demonstrates that improvements in supplier reliability would yield the highest return in overall production capacity, while enhancements in testing or labor capacity alone produce comparatively limited gains.

Conclusions

This study developed a constraint-based production planning framework for aerospace engine manufacturing by integrating supplier availability, manufacturing throughput, labor resources, and testing capacity into a unified model. The results showed that overall production output is primarily limited by the lowest operational capacity within the system.

The analysis identified supplier reliability as the most critical factor affecting production performance, with supplier constraints creating the largest reductions in engine output. While manufacturing, labor, and testing capacities also influenced production, their impact was smaller when supplier limitations existed.

Scenario and sensitivity analyses demonstrated the value of an integrated planning framework for identifying bottlenecks and supporting data-driven production decisions. Overall, the study shows that a unified constraint-based approach improves forecasting, operational decision-making, and management of production uncertainty in complex aerospace supply chains.

References

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