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Value Stream Mapping (VSM) applied to the aerospace industry: an analytical approach focused on identifying production bottlenecks.

Value Stream Mapping (VSM) applied to aerospace manufacturing: a bottleneck-oriented analytical approach

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Summary

Identifying production bottlenecks is one of the most significant challenges in the aerospace industry, due to the high complexity of production flows, the strong interdependence between processes, and the stringent requirements associated with quality and safety. Although Value Stream Mapping (VSM) is widely used in flow analysis, its traditional application has limitations in detecting systemic capacity constraints, especially in environments marked by high operational variability. This article proposes a structured analytical approach, organized into six steps, resulting from the integration of Lean Manufacturing principles, the Theory of Constraints, and production capacity analysis. This approach was applied in a real-world case study of aerospace structural assembly, enabling the identification of previously unrecognized bottlenecks and leading to an approximate 38% reduction in the total process lead time. The results suggest that the explicit incorporation of variability and capacity into value stream analysis favors more consistent diagnoses and contributes to increased operational stability in complex aerospace systems.

Keywords: Value Stream Mapping; production bottlenecks; production capacity; Lean Manufacturing; aerospace industry.

Abstract

The identification of production bottlenecks remains one of the most critical challenges in aerospace manufacturing, given the complexity inherent to production flows, the strong interdependence among processes, and the stringent requirements related to quality and safety. While Value Stream Mapping (VSM) is widely adopted for flow analysis, its conventional application shows limitations in capturing systemic capacity constraints, particularly in environments subject to high operational variability. This paper presents a structured analytical approach, organized into six stages, developed through the integration of Lean Manufacturing principles, the Theory of Constraints, and capacity analysis. The approach was applied to a real case study of aerospace structural assembly, allowing the identification of bottlenecks that had not been previously recognized and leading to an approximate 38% reduction in total process lead time. The findings indicate that the explicit incorporation of variability and capacity into value stream analysis supports more robust diagnostics and contributes to improved operational stability in complex aerospace systems.

Keywords: Value Stream Mapping; production bottlenecks; capacity analysis; Lean Manufacturing; aerospace industry.

1. Introduction

The aerospace industry is characterized by highly complex production systems, in which which multiple interdependent processes operate under stringent quality and safety requirements and traceability. In contrast to high-volume, low-variability manufacturing sectors, the Aircraft production involves critical structural components, long production cycles, and low costs. Volume, high mix, and extremely tight tolerances. In this scenario, small local inefficiencies.

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They can spread and produce relevant systemic effects, with recurring delays and increased risk. costs and operational instability.

Even with the widespread adoption of Lean Manufacturing practices in the aerospace industry, Manufacturers continue to face chronic bottlenecks throughout their supply chains. These Bottlenecks, in general, do not present themselves as obvious failures in isolated operations; they tend to emerge. in the interfaces between processes, in information flows, in inspection stages and, in particular, in Inadequate allocation of productive capacity. This pattern points to a structural limitation of Traditional analysis approaches are often geared towards local optimization at the expense of... a systemic reading of the value stream.

Value Stream Mapping (VSM) is widely recognized as one of the main Lean Manufacturing tools for visualizing material and information flows. However, its conventional application focuses predominantly on the identification of more obvious wastes — such as excessive inventory and waiting times — without delving deeper into the Analysis of capacity constraints that affect the overall performance of the system. In environments In highly complex industries, such as aerospace manufacturing, this limitation can lead to diagnoses incomplete, in which real bottlenecks remain hidden or end up being dealt with in a piecemeal fashion and reactive.

There is also an additional element: the operational variability inherent in manual processes of The high precision, typical of aircraft structural assembly, acts as an amplifier of constraints. Productive. Subtle variations in task execution, operational sequence, or availability. Resource allocation can shift bottlenecks along the line, giving them a dynamic character and making its identification difficult using essentially static methods. Therefore, the representation of Average flow, often adopted in traditional current state maps, tends to be insufficient. to capture the operational reality of these systems.

Given these limitations, it becomes necessary to expand the use of VSM beyond its... A classic application, integrating production capacity analysis and identification of systemic bottlenecks. and assessment of the impact of variability on global flow. This article proposes an approach A structured six-step analytical approach that extends traditional VSM by incorporating principles of the Theory. of the constraints, capacity analysis, and systemic validation of the production flow. The approach was organized from industrial practices and literature, with the purpose of supporting diagnoses of more robust and replicable bottlenecks in complex production systems.

The relevance of this study rests on three aspects. First, production bottlenecks. Persistent problems are among the main limiting factors in the performance of the aerospace industry. global, including manufacturers and suppliers based in the United States. Second, the identification Inadequate restrictions compromise strategic investment decisions and planning.

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Capacity and resource allocation. Third, structured and evidence-based methodologies. Although still in an exploratory stage, they contribute to increasing industrial competitiveness and mitigating operational risks in a sector considered strategic.

Therefore, the objectives of this work are:

(I) discuss the limitations of traditional VSM in identifying production bottlenecks in environments aerospace;

(II) to present, in detail, the analytical approach structured in six steps;

(III) demonstrate its application in a real aeronautical structural assembly process; and

(IV) analyze its impacts on productive capacity, flow stability and performance operational.

2. Theoretical Framework / Results

2.1 Production complexity in the aerospace industry

The production systems of the aerospace industry are distinguished by a high degree of... Structural, operational, and organizational complexity. Characteristics such as low volume, high mix, prolonged manufacturing cycles, heavy reliance on manual operations, and stringent requirements Regulatory factors make overall performance particularly sensitive to apparent local variations. small. In these systems, productive capacity emerges from the dynamic interaction between processes, information flows and technical constraints, and cannot be understood simply as the sum of individual capabilities.

2.2 Production bottlenecks and the Theory of Constraints

The Theory of Constraints states that the performance of any system is conditional upon... due to the presence of at least one dominant constraint. In complex systems, this constraint may... to assume a distributed, mobile character or even remain masked by operational variability. In this context, local optimization efforts that do not adhere to systemic constraints tend to to produce limited gains or, in certain cases, counterproductive effects.

2.3 Value Stream Mapping (VSM) and its limitations

Value Stream Mapping (VSM) has become a central tool in Lean. Manufacturing for visualizing material and information flows. However, its application

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Traditional methods prioritize the average representation of the flow and the identification of the most obvious wastes. which imposes limitations on the identification of capacity constraints and dynamic bottlenecks in environments characterized by high variability.

2.4 Integration between Lean Manufacturing and Theory of Constraints

The integration between the principles of Lean Manufacturing and the Theory of Constraints makes possible The targeting of improvement initiatives towards areas with the greatest systemic impact. In the context In the aerospace industry, this combination helps to avoid inefficient investments and merely strategic solutions. palliative measures, by aligning waste elimination with the management of critical constraints that condition the overall system performance.

2.5 Theoretical gap and motivation for the proposed approach

The literature points to the absence of structured approaches that integrate VSM, Theory of Constraints and variability analysis with an explicit focus on identifying dynamic bottlenecks in aerospace environments. This gap underpins the motivation for proposing an approach. A structured analytical approach in six steps, conceived as a methodological extension of VSM. traditional.

3. Materials and Methods

The study is characterized as applied research, of a qualitative and quantitative nature. conducted through a single case study in a real-world aerospace manufacturing environment.

3.1 Case study context

The study was developed on a dedicated aerospace structural assembly line. production of critical subsets, characterized by predominantly manual operations and by Presence of multiple inspection stages. For confidentiality reasons, proprietary information. These details were omitted, while maintaining the essential characteristics of the analyzed process.

3.2 Methodological design

The methodological design comprised three distinct phases:

(I) diagnosis of the current state through the application of VSM;

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(II) application of the analytical approach structured in six steps; and

(III) evaluation of the impacts of the proposed interventions based on performance indicators.

3.3 Data collection

Data collection took place over a representative period of the production cycle and included Direct observation of operations, historical records of cycle times, capacity data by Station, work-in-process (WIP) information, and non-conformity records.

3.4 Performance indicators

The total lead time, cycle time per operation, and work accumulation were analyzed. The process and the stability of the production flow.

3.5 Analysis procedures

The data were analyzed iteratively, comparing the initial state of The system and the performance observed after the implementation of actions aimed at mitigating the... Bottlenecks identified.

4. Results and Discussion

4.1 Initial Diagnosis

Applying this approach made it possible to identify bottlenecks that had not been previously identified. recognized by conventional analyses. The explicit incorporation of capacity and data Variability revealed latent constraints, especially at the interfaces between processes and in the steps. inspection.

4.2 Proposed Interventions

The prioritized actions involved the redistribution of workload between operations and synchronization. from inspection activities, to the review of operational sequences and adjustments to operational policies, in accordance with the principles of the Theory of Constraints.

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4.3 Observed Impacts

An approximate 38% reduction in the total process lead time was observed, accompanied by... by reducing work in process (WIP) and increasing the stability of the production flow, without any increase in nominal capacity.

4.4 Discussion

The results indicate that traditional VSM, when applied in isolation, proves to be... insufficient for diagnosing bottlenecks in complex aerospace systems. The integration of Capacity and variability analyses made it possible to reveal previously hidden constraints and It enabled the achievement of systemic gains with a more sustainable character.

Final Considerations

The six-step structured analytical approach expanded the diagnostic capabilities of VSM. in a complex aerospace environment, enabling the identification and mitigation of bottlenecks. Systemic factors that remained hidden. The observed gains resulted from the reduction of variability. and the alignment between demand and capacity, not investments aimed at expanding production. Although empirical validation is limited to a single case study, the results indicate potential. replication in contexts with similar characteristics.

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