

A RISK-ADJUSTED MULTI-METRIC SUPPLIER EVALUATION MODEL INTEGRATING PERFORMANCE AND STABILITY INDICATORS IN AUTOMOTIVE MANUFACTURING

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Abstract - Supplier performance evaluation in manufacturing environments is traditionally based on aggregated key performance indicators (KPIs), often emphasizing defect frequency and delivery reliability. However, such approaches frequently neglect temporal stability, which represents a critical dimension of operational risk. This study proposes a risk-adjusted multi-metric supplier evaluation framework integrating performance magnitude and temporal consistency within a unified mathematical formulation. The proposed Supplier Risk-Adjusted Performance Index (SRPI) combines weighted KPI aggregation with a variability-based stability factor derived from the coefficient of variation. By embedding temporal dispersion directly into the evaluation logic, the model enables differentiation between consistently performing suppliers and those exhibiting volatile performance patterns despite comparable average results. The framework was applied to a simulated dataset reflecting realistic operational conditions observed in automotive manufacturing environments. Comparative analysis demonstrates that the inclusion of stability adjustment leads to measurable ranking displacement when compared to traditional performance-based evaluation. Suppliers characterized by elevated variability experience downward ranking corrections, while stable suppliers improve their relative positioning. A performance-stability matrix further supports risk-based supplier segmentation, providing enhanced managerial visibility beyond conventional defect-centric assessment. Sensitivity analysis confirms the robustness of the proposed formulation under moderate weighting variations. The findings suggest that incorporating temporal stability into supplier monitoring systems enhances risk awareness and supports more resilient supplier management strategies in quality-sensitive manufacturing contexts.

Keywords: Supplier performance evaluation, Supplier Risk-Adjusted Performance Index (SRPI), performance variability, Temporal stability, Multi-criteria decision-making (MCDM), Automotive.

1. Introduction

Supplier performance evaluation represents a critical component of manufacturing and automotive supply chain management. In high-reliability industries, where product quality directly impacts safety, operational efficiency, and brand reputation, organizations rely on structured performance measurement systems to monitor and control supplier behaviour [12]. Traditionally, defect-based metrics such as Parts Per Million (PPM) have been

widely adopted as primary indicators of supplier quality performance.

Although PPM provides a clear quantitative measure of non-conformity rates, recent studies highlight its significant limitations when used as a standalone metric [10]. PPM captures only defect occurrence and does not reflect other essential dimensions of supplier performance, such as delivery reliability, responsiveness to corrective actions, or long-term improvement capability [5]. As a result, relying exclusively on PPM may generate incomplete supplier assessments and potentially

lead to suboptimal sourcing or supplier development decisions.

In response to these limitations, the literature increasingly supports multi-criteria supplier evaluation models. Quantitative frameworks integrating operational and strategic indicators have been proposed using methods such as the Analytic Hierarchy Process (AHP), TOPSIS, and composite weighted scoring systems [4]. These approaches aim to provide a more comprehensive evaluation of supplier capabilities beyond defect rates.

However, a critical aspect remains insufficiently addressed in existing models: the integration of performance stability and variability over time. Most evaluation frameworks rely on aggregated average values and do not explicitly account for performance volatility across reporting periods. In practical manufacturing environments, two suppliers may present similar average PPM values while exhibiting substantially different levels of consistency. Such variability directly influences operational planning, inspection effort, escalation frequency, and overall supply risk.

Manufacturing systems characterized by high product complexity and tight tolerance requirements, particularly in the automotive sector, require not only performance excellence but also predictability. Stability in defect rates, corrective action lead time, and delivery reliability contributes to reduced uncertainty and improved production continuity.

To address this gap, this study proposes a Risk-Adjusted Supplier Performance Index (SRPI) that integrates normalized performance indicators with a volatility-based stability factor. The proposed framework combines a composite performance score with a variability penalty derived from the coefficient of variation calculated over multiple time periods. By incorporating a stability dimension into the evaluation process, the model shifts supplier assessment from reactive defect monitoring toward risk-oriented performance intelligence.

The main contributions of this research are:

- Development of a quantitative supplier evaluation model integrating performance and stability dimensions;
- Formal mathematical formulation of a risk-adjusted composite index;
- Validation through a realistic industrial dataset simulation representing an automotive supplier base;
- Practical implementation guidelines for manufacturing quality management systems;

2. Literature Review

Supplier evaluation has progressively evolved from transactional monitoring toward structured decision-support systems that integrate multiple

performance dimensions. In manufacturing and automotive contexts, supplier performance is increasingly treated as a multi-criteria problem, where quality outcomes must be balanced with delivery reliability, corrective-action responsiveness, process maturity, and broader collaboration objectives [9].

A substantial body of research addresses supplier selection and evaluation using multi-criteria decision-making (MCDM) approaches. Analytic Hierarchy Process (AHP) is frequently applied to structure evaluation criteria and derive weights that reflect decision-maker priorities in industrial settings [6]. Hybrid frameworks further strengthen comparability by combining weighting and ranking logic, enabling consistent evaluation across heterogeneous criteria and decision contexts [1]. In quality management-oriented research, integrated approaches such as QFD combined with fuzzy TOPSIS have also been proposed to incorporate both qualitative and quantitative perspectives into supplier evaluation and selection [8]. These studies collectively confirm the maturity of quantitative methods for aggregating multiple criteria into supplier rankings or selection decisions.

Beyond classical operational criteria, sustainability and long-term collaboration have become increasingly relevant dimensions in supplier evaluation. Several frameworks extend supplier assessment by incorporating “green” and sustainability criteria, frequently using integrated MCDM methods and fuzzy or multi-objective formulations to address trade-offs between environmental and operational performance [11][2]. Additionally, structural modelling approaches have been used to identify and analyze the interdependencies among key performance indicators supporting sustainable manufacturer-supplier collaboration, emphasizing that supplier evaluation systems should reflect not only metric selection but also KPI relationships and managerial influence pathways [3].

While the literature provides robust methodological foundations for multi-metric aggregation, supplier evaluation is also increasingly linked to the concept of supplier monitoring. Comparative studies highlight that selection criteria and monitoring criteria may differ in practice, and that effective supplier management requires continuous performance tracking and differentiated managerial actions such as targeted audits, escalation prioritization, and supplier development planning [9].

This distinction is particularly relevant in automotive manufacturing environments, where supplier portfolios include both mature suppliers and developing suppliers, and where performance

drift can occur due to process changes, capacity constraints, or variability in incoming material characteristics.

A recurring limitation across many existing evaluation frameworks is the reliance on aggregated or average performance values over a reporting period. Although multi-criteria approaches broaden supplier assessment beyond defect frequency alone, temporal dynamics are typically simplified, and supplier performance is often represented by static snapshots or mean values within the evaluation window [6][9]. From an operational perspective, however, stability and consistency over time influence risk exposure and planning predictability. Performance measurement research has shown that KPI interpretation may be affected by contextual and stakeholder-related factors, reinforcing the need for robust, systematic performance measurement structures rather than single-metric judgments [7].

Consequently, despite the maturity of MCDM-based supplier evaluation methods and the growing emphasis on supplier monitoring, the explicit integration of temporal stability into supplier scoring indices remains comparatively limited in practical manufacturing-oriented frameworks. This motivates the development of a risk-adjusted, multi-metric supplier evaluation model in which classical weighted aggregation is complemented by a variability-based stability factor. Such an approach supports a more risk-aware interpretation of supplier performance, particularly in automotive manufacturing systems where predictability is critical for production continuity and quality assurance.

3. Methodology

This section presents the formal development of the proposed risk-adjusted supplier evaluation model. The objective of the methodology is to construct a quantitative framework capable of integrating heterogeneous performance indicators while explicitly accounting for temporal stability. The model is structured in three sequential stages. **First**, relevant supplier performance indicators are defined and normalized to enable comparability. **Second**, a weighted composite performance score is computed to reflect overall supplier performance level. **Third**, a stability adjustment mechanism based on performance variability over time is introduced to capture temporal consistency and risk exposure. Unlike purely descriptive multi-criteria evaluation approaches, the proposed model integrates statistical dispersion directly into the aggregation logic. By combining performance magnitude and stability within a single mathematical formulation, the framework enables a risk-adjusted interpretation of supplier performance in automotive manufacturing environments.

The following sub-sections describe the definition of indicators, normalization procedures, composite score formulation, and stability adjustment mechanism.

3.1 Definition of Key Performance Indicators

The proposed model evaluates supplier performance through a structured set of quantitative indicators commonly used in automotive manufacturing monitoring systems. The selection of indicators is based on their operational relevance and measurability in serial production environments. The following Key Performance Indicators (KPIs) are considered:

- Parts Per Million (PPM): frequency of nonconforming parts;
- On-Time Delivery (OTD): percentage of deliveries meeting agreed schedules;
- Corrective Action Lead Time (8D days): average time required to close corrective actions;
- Defect Recurrence Rate: percentage of repeated defect types within the monitoring period;
- Audit Score: standardized audit evaluation reflecting process maturity.

PPM, 8D lead time, and recurrence rate represent “lower-is-better” indicators, while OTD and audit score represent “higher-is-better” indicators.

3.2 Normalization of Performance Indicators

To enable aggregation of heterogeneous KPIs, each indicator is normalized to a dimensionless scale between 0 and 1. For indicators where lower values indicate better performance:

$$x'_i = \frac{(x_{max} - x_i)}{(x_{max} - x_{min})} \tag{1}$$

For indicators where higher values indicate better performance:

$$x'_i = \frac{(x_i - x_{min})}{(x_{max} - x_{min})} \tag{2}$$

Where:

- x_i - observed KPI value for supplier i
- x_{min}, x_{max} - minimum and maximum observed values within the evaluation set
- x'_i - normalized value

This transformation ensures comparability across different measurement units.

3.3. Composite Performance Score

A weighted aggregation is applied to compute the composite Performance Score (PS):

$$PS_i = \sum_{k=1}^n w_k x'_{\{ik\}} \quad (3)$$

Where:

w_k : weight assigned to KPI k $\sum w_k = 1$

For the automotive manufacturing context considered in this study, the following weights are applied:

- PPM: 0.35
- OTD: 0.15
- 8D Lead Time: 0.20
- Recurrence Rate: 0.15
- Audit Score: 0.15

The weighting structure prioritizes defect frequency and corrective action efficiency, reflecting quality risk sensitivity in high-reliability production systems.

3.4. Performance Variability and Stability Factor

To incorporate temporal stability, the coefficient of variation (CV) is calculated for each KPI across the monitoring period:

$$CV_k = \frac{\sigma_k}{\mu_k} \quad (4)$$

Where:

σ_k - standard deviation of KPI k

μ_k - mean value of KPI k

An aggregated Volatility Index (VI) is computed as:

$$VI_i = \sum_{k=1}^n w_k CV_{\{ik\}} \quad (5)$$

The Stability Factor (SF) is then defined as:

$$SF_i = \frac{1}{1 + VI_i} \quad (6)$$

The Stability Factor penalizes high variability and approaches 1 when volatility is low.

3.5. Risk-Adjusted Supplier Performance Index

The final Risk-Adjusted Supplier Performance Index (SRPI) is defined as:

$$SRPI_i = PS_i \cdot SF_i \quad (7)$$

This formulation ensures that supplier ranking reflects both performance level and temporal consistency. Suppliers with strong average performance but high variability will receive lower SRPI values compared to equally performing but more stable suppliers.

The overall computational structure of the proposed model is summarized in Figure 1. The framework integrates performance normalization, weighted aggregation, and stability adjustment into a unified risk-adjusted supplier evaluation architecture.

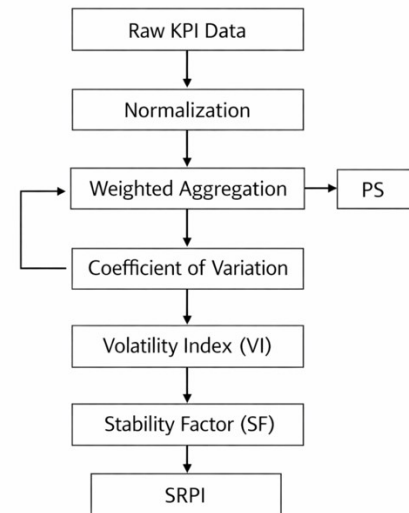


Figure 1: Architecture of the proposed Supplier Risk-Adjusted Performance Index (SRPI) framework

4. Case Study

This section presents the application of the proposed risk-adjusted supplier evaluation model to a simulated automotive supplier dataset. The objective of the case study is to demonstrate the computational procedure and to illustrate how the integration of performance level and temporal stability influences supplier ranking outcomes.

The dataset was constructed to reflect realistic monitoring conditions encountered in automotive manufacturing environments. By applying the mathematical framework defined in Section 3, the case study evaluates the practical behavior of the model and its ability to differentiate suppliers beyond traditional performance-based assessment.

4.1 Dataset Description

The dataset used in this study was synthetically generated to reflect realistic operational conditions observed in automotive manufacturing environments. Due to confidentiality constraints associated with industrial supplier performance data, direct access to proprietary datasets was not possible. Therefore, KPI ranges and performance profiles were constructed based on industry-relevant monitoring practices and commonly reported operational intervals in automotive production systems.

The objective of using a simulated dataset is not to replicate a specific company's supplier base, but to evaluate the behaviour of the proposed mathematical framework under realistic variability and performance scenarios.

- PPM: 80 – 2000 defects per million
- On-Time Delivery (OTD): 87% – 99.5%
- Corrective Action Lead Time (8D): 7 – 35 days
- Defect Recurrence Rate: 2% – 22%
- Audit Score: 60 – 95

The dataset intentionally includes suppliers exhibiting distinct performance profiles, such as high-performance but volatile suppliers, moderate yet stable suppliers, and suppliers with inconsistent corrective action response times. This structure enables the evaluation of how the proposed SRPI differentiates suppliers beyond average performance values.

4.2 Computation Procedure

For each supplier, monthly KPI values were normalized using Equations (1) and (2). The composite Performance Score (PS) was computed according to Equation (3), using the predefined weighting structure.

Subsequently, the coefficient of variation was calculated for each KPI across the 12-month period, according to Equation (4). These dispersion values were aggregated into a Volatility Index (VI) using Equation (5), and transformed into a Stability Factor (SF) through Equation (6).

Finally, the Risk-Adjusted Supplier Performance Index (SRPI) was obtained using Equation (7), integrating both performance magnitude and temporal stability.

All computations were performed using a structured spreadsheet model replicating the proposed mathematical formulation.

4.3. Supplier Profiles

To ensure interpretability of the results, suppliers were designed to represent different operational archetypes:

- High performance: high variability
- Moderate performance: high stability
- Strong delivery performance: weak quality stability
- Improving performance trend with residual volatility
- Consistently underperforming suppliers

This differentiation enables the assessment of how the SRPI model adjusts ranking positions compared to traditional performance-only evaluation.

5. Results and Discussion

This section presents the analytical outcomes obtained by applying the proposed SRPI model to the simulated automotive supplier dataset. The objective of the analysis is to evaluate how the integration of temporal stability influences supplier ranking and risk interpretation compared to traditional performance-based assessment.

The results are examined from three complementary perspectives: comparative ranking behaviour, performance-stability interaction, and managerial implications for supplier monitoring and development strategies. Together, these analyses demonstrate the added value of incorporating variability-adjusted performance measurement in manufacturing environments.

5.1. Comparative Ranking Analysis

Application of the proposed model generated observable ranking differentiation when compared to traditional defect-based assessment approaches.

Table 1 summarizes the calculated mean Performance Score (PS_mean), Volatility Index (VI), Stability Factor (SF), and final SRPI values for the evaluated suppliers.

Table 1. Computed performance, volatility, and ranking indicators for evaluated suppliers

Supplier	PS_mean	VI	SF	SRPI	Rank (PS)	Rank (SRPI)	ΔRank (SRPI-PS)
S01	0.84	0.135	0.881	0.740	2	3	↓ 1
S02	0.78	0.082	0.924	0.720	4	4	→ 0
S03	0.86	0.050	0.952	0.819	1	1	→ 0
S04	0.70	0.060	0.943	0.660	6	5	↑ -1
S05	0.73	0.155	0.866	0.632	5	6	↓ 1
S06	0.65	0.095	0.913	0.594	7	7	→ 0
S07	0.90	0.270	0.787	0.708	3	2	↑ -1
S08	0.59	0.070	0.935	0.552	8	8	→ 0
S09	0.53	0.180	0.847	0.449	9	9	→ 0
S10	0.48	0.140	0.877	0.421	10	10	→ 0

The results indicate that suppliers with similar average performance levels may exhibit significantly different SRPI outcomes once temporal variability is incorporated. In particular, suppliers characterized by strong average performance, but elevated month-to-month fluctuations experienced a reduction in final SRPI value due to the stability penalty embedded in the model.

Conversely, suppliers with moderate but highly consistent performance benefited from the volatility-adjusted formulation. This confirms that the SRPI framework rewards predictability alongside performance magnitude.

The comparison reveals that performance level alone does not sufficiently represent operational risk exposure. Stability-adjusted evaluation provides a more balanced interpretation of supplier capability.

5.2. Performance–Stability Matrix

To further interpret the interaction between performance magnitude and temporal consistency, suppliers were positioned within a two-dimensional analytical matrix defined by the composite Performance Score (PS_mean) on the horizontal axis and the Stability Factor (SF) on the vertical axis.

This representation enables a structured classification of suppliers according to both effectiveness and predictability. Unlike traditional ranking systems that rely solely on aggregated performance values, the matrix approach highlights the role of stability in operational risk exposure.

The resulting distribution of suppliers is illustrated in Figure 2.

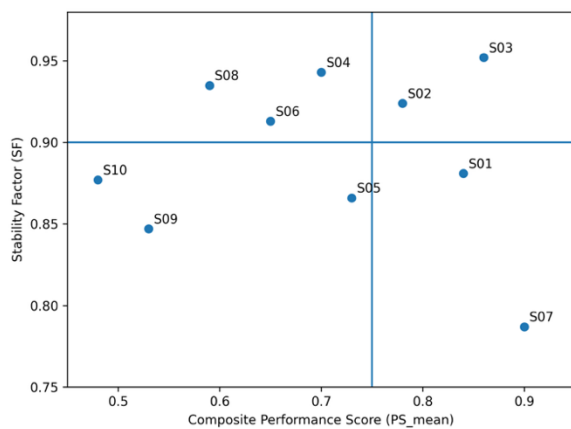


Figure 2. Performance–Stability matrix positioning of evaluated suppliers

As shown in Figure 2, suppliers can be grouped into four operational quadrants:

- High Performance - High Stability (Preferred Suppliers);
- Moderate Performance - High Stability (Reliable but Developing);
- High Performance = Low Stability (Volatile Risk);
- Low Performance - Low Stability (Critical Suppliers).

Suppliers located in the upper-right quadrant demonstrate both strong performance and consistent monthly results, representing low operational risk and high managerial confidence. Conversely, suppliers positioned in the lower-right quadrant exhibit competitive performance levels but elevated variability, indicating potential instability that may require intensified monitoring.

The matrix clearly illustrates that similar average performance scores may correspond to substantially different stability profiles. This differentiation supports risk-based supplier segmentation and provides additional managerial insight beyond traditional performance-only ranking methods.

5.3. Impact of Stability Adjustment

The effect of incorporating the Stability Factor into the evaluation framework was further examined through a direct comparison between performance-based ranking (PS_mean) and risk-adjusted ranking (SRPI).

While the composite performance score reflects the aggregated KPI level, it does not account for temporal variability. The introduction of the stability adjustment modifies ranking outcomes by penalizing suppliers exhibiting elevated performance dispersion.

The comparative ranking results are presented in Figure 3.

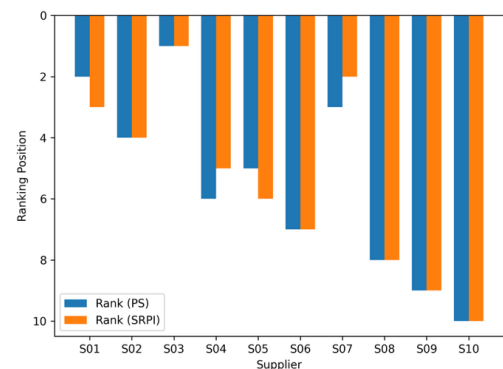


Figure 3. Comparison between performance-based ranking (PS) and stability-adjusted ranking (SRPI)

As illustrated in Figure 3, several suppliers exhibit observable ranking displacement after the stability adjustment is applied. Suppliers characterized by high average performance but elevated variability experience downward ranking corrections in the SRPI-based evaluation.

Conversely, suppliers demonstrating consistent month-to-month performance improve their relative ranking despite not leading in absolute performance scores.

This shift confirms that the Stability Factor operates as a risk-adjustment mechanism rather than a simple performance modifier. The model does not penalize isolated nonconformities but instead responds to structural inconsistency patterns.

The comparative analysis demonstrates that traditional performance-based ranking may overestimate suppliers with fluctuating results, while the proposed SRPI framework provides a more balanced and risk-aware interpretation aligned with manufacturing stability requirements.

5.4. Managerial Implications

The integration of temporal stability into supplier evaluation provides several practical implications for manufacturing organizations, particularly in

quality-sensitive industries such as automotive production.

First, the proposed SRPI model supports risk-based monitoring allocation. Suppliers with acceptable average performance but low stability can be identified early and subjected to intensified follow-up measures, such as increased sampling frequency or targeted process audits. This prevents over-reliance on mean-based performance indicators that may mask structural volatility.

Second, the framework enhances supplier segmentation strategies. Instead of classifying suppliers solely based on defect rates or delivery performance, organizations can distinguish between stable performers, volatile high performers, and consistently underperforming suppliers. This differentiation supports tailored development programs and escalation policies.

Third, the model improves decision transparency. By explicitly incorporating a mathematical stability factor, managerial decisions regarding supplier prioritization, audit planning, or development investment become more defensible and data-driven.

Finally, the SRPI framework aligns with contemporary risk-based quality management principles by embedding variability considerations directly into performance assessment logic. This contributes to more resilient supplier management practices in environments characterized by operational uncertainty and production continuity requirements.

5.5. Sensitivity Analysis

To evaluate the robustness of the proposed model, a sensitivity analysis was conducted by varying the weighting structure assigned to the performance indicators.

Three alternative weighting scenarios were examined:

- Scenario A: Increased emphasis on defect performance (PPM weight increased by 10%)
- Scenario B: Increased emphasis on delivery reliability (OTD weight increased by 10%)
- Scenario C: Reduced impact of the Stability Factor in the final SRPI formulation

The results indicate that moderate variations in performance weights produce limited changes in overall ranking structure. Suppliers characterized by high volatility remain relatively disadvantaged across weighting scenarios, confirming that the stability adjustment exerts a structurally consistent influence.

Furthermore, the differentiation between stable and unstable suppliers persists even under modified weighting configurations. This suggests that the proposed SRPI model is not excessively sensitive to parameter selection and maintains ranking

coherence under reasonable managerial preference shifts.

The sensitivity analysis therefore reinforces the robustness and practical applicability of the framework in real industrial environments, where weighting priorities may evolve depending on strategic objectives or operational constraints.

6. Conclusions

This study proposed a risk-adjusted multi-metric supplier evaluation framework integrating performance magnitude and temporal stability within a unified mathematical formulation. By combining weighted KPI aggregation with a variability-based stability factor, the proposed Supplier Risk-Adjusted Performance Index (SRPI) enables a more balanced interpretation of supplier capability in manufacturing environments.

The results demonstrate that reliance on aggregated performance values alone may lead to incomplete or potentially misleading ranking outcomes. Suppliers exhibiting strong average performance but elevated volatility may represent higher operational risk than stable suppliers with slightly lower KPI levels. The integration of temporal consistency into the evaluation logic therefore enhances risk visibility and supports more informed managerial decision-making.

The proposed framework remains computationally simple and implementable using standard industrial data infrastructures. Its structure allows integration into existing supplier monitoring dashboards without requiring advanced analytics platforms. This practical applicability increases its potential relevance for quality engineering and supplier management functions in automotive manufacturing.

However, several limitations must be acknowledged. The case study is based on a simulated dataset designed to reflect realistic operational ranges observed in international automotive manufacturing environments. Due to confidentiality constraints associated with proprietary supplier performance data, the numerical values were synthetically reproduced while preserving industrial plausibility. Additionally, the weighting structure applied in this study represents a predefined configuration and may vary depending on organizational priorities. Future research may extend the framework by incorporating dynamic weighting strategies, advanced statistical stability metrics, or longitudinal validation using real industrial supplier performance datasets.

Overall, the findings support the view that supplier evaluation systems should incorporate both

performance level and stability considerations. The SRPI model contributes to the advancement of risk-aware supplier monitoring practices and offers a structured foundation for enhanced supplier segmentation and development strategies in manufacturing contexts.

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