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Prioritizing Key Performance Indicators for the Mining Industry in Kerala: An AHP Approach

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Abstract
The main aim of this study is to examine the interconnections among performance indicators in Small and Medium Scale Enterprises (SMEs) within the mining industries in Kerala, India. A hierarchical model for performance metrics is introduced, starting with the identification of performance indicators through a systematic process. Following this, a comprehensive questionnaire-based survey is conducted within the mining and mineral industries in Kerala to identify the significant indicators specific to the sector. In this context, the Analytic Hierarchy Process (AHP) serves as a valuable multi-criteria decision-making approach for the evaluation of performance indicators. The primary objective of this article is to scrutinize performance indicators that assess the performance of SMEs and provide a comparative rating against their peers. Distinguishing itself from conventional approaches, this study directly engages manufacturers to gauge the relevance of four main factors and twelve sub-factors (performance indicators) through the application of the Analytic Hierarchy Process.

Keywords
Analytic Hierarchy Process, Key Performance Indicators, Small and Medium Enterprises, Sustainability, Multi criteria decision making.

Introduction

India's mining sector is a significant contributor to the country's GDP, employing millions and supporting numerous ancillary industries. However, the sector faces challenges such as environmental sustainability, regulatory compliance, and socio-economic factors, particularly in states like Kerala, where ecological sensitivity and community welfare are paramount. The state of Kerala is known for its stringent environmental regulations aimed at preserving its rich biodiversity and ecological balance (Kumar & Nirmala, 2015; Singh et al., 2008). These regulations impact how industries, including sand manufacturing, operate within the region. Additionally, the socio-economic landscape in Kerala places a strong emphasis on sustainable development and community welfare, which necessitates that industries not only comply with regulatory standards but also adopt practices that contribute to local social and economic goals.

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This research focuses on identifying and prioritizing key performance indicators (KPIs) that are essential for the sand mining sector in Kerala. Given the specific environmental, regulatory, and socio-economic context, the study aims to provide tailored insights that can help local SMEs enhance their operational efficiency and sustainability (Bhadu et al., 2022). By employing the Analytic Hierarchy Process (AHP) methodology, this study prioritizes KPIs that are critical for achieving these objectives.

Performance Optimization in Mining Industry

Optimizing performance in the mining industry is crucial for ensuring operational efficiency, sustainability, and profitability. The sector faces significant challenges, including fluctuating commodity prices, stringent regulatory requirements, and growing environmental concerns. Addressing these challenges effectively and remaining competitive in the global market necessitates a systematic approach to performance optimization (Sharma et al., 2005).

By evaluating KPIs using methodologies such as the Analytic Hierarchy Process (AHP), mining companies

can identify key areas for improvement, streamline operations, and enhance productivity. This process helps mitigate risks, reduce costs, and maximize resource utilization, contributing to overall operational resilience and long-term sustainability. Additionally, performance optimization fosters innovation and continuous improvement within the industry, driving technological advancements and enhancing safety standards.

KPIs provide valuable insights into various aspects of operational efficiency, safety, environmental stewardship, and stakeholder satisfaction. By quantifying and measuring critical performance aspects, KPIs enable mining companies to assess their performance against established benchmarks, identify areas for improvement, and make informed decisions (Gani et al., 2021).

The systematic evaluation of KPIs is instrumental in guiding strategic decision-making and resource allocation. Leveraging methodologies like AHP allows companies to prioritize KPIs based on their importance and impact, focusing efforts on the most critical areas for improvement. This approach maximizes the effectiveness of performance optimization initiatives, ensuring mining companies can meet stakeholder expectations, comply with regulations, and achieve sustainable growth in a rapidly evolving landscape. Moreover, the sand mining sector in Kerala operates within a unique context characterized by stringent environmental regulations, specific socio-economic factors, and distinct resource management policies. These factors necessitate tailored KPIs that address the region's specific challenges and opportunities (Singh et al., 2021).

Novelty of the Study

The study focuses on SMEs in the mining industry in the state of Kerala, India, and presents several novel contributions to the state of the art in performance measurement methodologies, particularly within the context of regional and sector-specific industries. Firstly, the novelty of this work lies in its application of the AHP methodology to the mining sector in Kerala. While AHP has been widely utilized in various industries for decision-making and performance evaluation, its application specifically to the mining industry in Kerala represents a novel adaptation of the methodology to a unique industrial context.

Secondly, the study contributes novel insights into the KPIs that are most relevant and impactful for SMEs operating in Kerala's mining industry. By conducting the study within the state of Kerala, the research accounts for the specific environmental, regulatory, and socio-economic factors that distinguish the sand manufacturing sector in this region, thereby providing tailored and context-specific KPIs that may not be directly applicable to other regions or industries (Swarnakar et al., 2021).

Furthermore, the novelty of this work extends to its potential implications for informing strategic decision-making and performance improvement initiatives within Kerala's mining SMEs. By identifying and prioritizing KPIs through a structured and data-driven methodology, the study offers novel insights that can guide SMEs in allocating resources, setting targets, and implementing strategies to enhance their overall performance and competitiveness within the regional market (Hudson et al., 2001).

The structure of the paper is as follows: Section 2 presents a review of relevant literature, Section 3 describes the methodology, Section 4 discusses the results, and Section 5 provides conclusions and recommendations.

Literature review

Studies on KPIs have been conducted to bridge knowledge gaps and discover industry expectations for equipment evaluation. In the competitive mining industry, the ability to innovate and introduce new products is crucial for staying ahead of the competition and adapting to evolving market demands. New product designs can lead to improved efficiency, reduced environmental impact, and enhanced safety measures, thereby increasing the SMEs market share and profitability (Nicholas et al., 2011; Salgado et al., 2018; Woschke & Haase, 2016).

Accurate demand forecasting is essential for optimizing inventory levels, minimizing stock outs, and reducing holding costs. By closely aligning inventory levels with actual sales demand, SMEs can improve operational efficiency, enhance customer satisfaction, and maximize profitability (Chan et al., 2017; Muchaendepi et al., 2019). Efficient utilization of storage facilities is critical for minimizing warehousing costs, optimizing space usage, and ensuring timely availability of inventory. Monitoring capacity utilization rates enables SMEs to identify underutilized or over utilized storage areas, leading to better resource allocation and improved operational efficiency (Afriyie & Morrison, 2023; Kumar et al., 2016; Talamante-Lugo et al., 2019). Monitoring downtime due to maintenance activities is essential for minimizing production disruptions, maximizing equipment uptime, and reducing maintenance costs. By identifying the root causes of downtime and implementing preventive maintenance

measures, SMEs can improve equipment reliability, prolong asset lifespan, and enhance overall operational efficiency (Baglee & Knowles, 2008; Bakri et al., 2021; Sidhu et al., 2020).

Ensuring product reliability is paramount for maintaining customer trust, reducing warranty claims, and safeguarding brand reputation. By monitoring the failure rate of products, SMEs can identify design flaws, manufacturing defects, or material weaknesses, enabling them to implement corrective actions and improve product quality and reliability (Fatimah et al., 2013; Vinayak & Kodali, 2014). Ensuring that products meet quality specifications is crucial for maintaining customer satisfaction, reducing rework costs, and preventing defects. Monitoring the percentage of products that conform to specifications helps identify areas for improvement in manufacturing processes and quality control measures (Sahoo & Yadav, 2017, 2018). Customer satisfaction is a key driver of business success and long-term profitability. Measuring overall customer satisfaction through surveys or feedback mechanisms provides valuable insights into customer preferences, expectations, and areas for improvement, enabling the SME to enhance customer relationships and loyalty (Kusuma, 2014; Simatupang et al., 2021).

Monitoring transportation costs per unit or distance travelled helps optimize logistics operations, minimize transportation expenses, and improve supply chain efficiency. Lower transportation costs contribute to overall cost savings and competitiveness (Banomyong & Supatn, 2011; Kot et al., 2020).A well-established distribution network with extensive coverage and reach in target markets is essential for reaching customers efficiently, reducing lead times, and enhancing market penetration. Monitoring the coverage and reach of the distribution network helps identify gaps and opportunities for expansion (Kherbach & Mocan, 2016; Taschner, 2016).

In today's environmentally conscious market, the perception of a product's environmental friendliness can significantly impact consumer preferences and purchasing decisions. Monitoring and promoting the eco-friendliness of products can enhance brand reputation, attract environmentally conscious customers, and contribute to sustainable business practices (Koirala, 2019).Compliance with waste management regulations and environmental standards is essential for minimizing environmental impact, avoiding penalties, and maintaining a positive corporate image. Monitoring compliance with waste management regulations ensures legal adherence and responsible waste disposal practices (Arevalo-Barrera et al., 2019; Prasetya et al., 2019; Woodard, 2021).Promoting recyclable products contributes to environmental sustainability, reduces resource consumption, and minimizes waste generation. Monitoring the percentage of product materials that are recyclable reflects the SME's commitment to eco-friendly practices and circular economy principles (Yolin, 2015).

The mining industry is characterized by its complex and multifaceted operations, which necessitate effective performance optimization strategies to ensure sustainability, profitability, and safety. Existing research on performance optimization and KPIs in the mining sector has explored various aspects of operational efficiency, safety management, environmental sustainability, and stakeholder engagement (Gackowiec et al., 2020; Lamjahdi et al., 2021).

Several studies highlight the impact of regional regulatory frameworks, environmental sustainability practices, and socio-economic conditions on industrial operations. In Kerala, the emphasis on ecological preservation, resource management, and community welfare significantly influences the operational strategies of local industries, including the sand mining sector (Humsa & Srivastava, 2015).

While many KPIs are applicable across various manufacturing sectors, certain KPIs are particularly pertinent to the mining industry. For instance, ore grade and recovery rates are critical for assessing the efficiency of mineral extraction processes. In the context of sand manufacturing in Kerala, KPIs such as environmental impact measures, resource utilization efficiency, and compliance with regulatory standards are of paramount importance due to the region's stringent environmental regulations and socio-economic conditions.

Another area of focus in the literature is the development of performance optimization frameworks and methodologies tailored to the mining industry. Researchers have proposed various approaches, including data analytics, simulation modelling, and optimization techniques, to enhance operational efficiency, mitigate risks, and improve decision-making processes. However, these frameworks often lack a systematic and integrated approach to evaluating the relative importance of different KPIs and prioritizing them accordingly.

Despite the wealth of research on performance optimization in the mining sector, several gaps persist in the literature. Firstly, there is a lack of standardized methodologies for identifying, measuring, and evaluating KPIs that are specific to the SMEs in the mining industry. Many existing studies focus on isolated aspects of performance without considering the interconnectedness of different performance factors or the unique contextual factors that influence mining operations.

Furthermore, there is limited research on the systematic evaluation of KPIs using methodologies such

as the AHP. While AHP has been widely used in other industries for decision-making and performance evaluation, its application to the SMEs in the mining sector remains relatively unexplored. This gap in the literature presents an opportunity to employ AHP as a systematic and rigorous approach to prioritizing KPIs based on their relative importance and impact on overall performance.

Methodology- Identification of Key Performance Indicators

The methodology for identifying KPIs for an SME in the mining industry involves a systematic approach to ensure alignment with business objectives and stakeholder needs. Initially, a broad range of performance indicators relevant to mining operations are brainstormed, covering aspects such as production output, safety, environmental impact, regulatory compliance, and community relations. Stakeholder consultation plays a crucial role in gathering input on priorities and expectations, ensuring that the identified indicators resonate with stakeholders' interests. A comprehensive literature review supplements this process, drawing on existing research, industry reports, and best practices to inform the selection of relevant performance indicators. In addition, the selection of KPIs for this study was guided by the specific environmental, regulatory, and socio-economic context of Kerala. This ensures that the KPIs are relevant and actionable for the local sand mining sector.

To ensure a robust and contextually relevant selection of Key Performance Indicators (KPIs) for the sand mining sector in Kerala, a structured survey was conducted involving a panel of 15 industry experts. The survey instrument included a combination of demographic questions, Likert-scale ratings for 25 potential KPIs, and open-ended questions for qualitative insights. The expert panel comprised mining engineers, environmental scientists, regulatory officials from the Kerala State Pollution Control Board and the Department of Mining and Geology, and industry consultants. These experts brought a wealth of experience, ranging from 8 to 25 years, in various facets of the sand processing and mining industries.

The survey was administered in two phases. Initially, the questionnaire was distributed via email in June 2021. Following the collection of responses, a series of virtual consensus meetings were held from September 2021, utilizing the Delphi method. During these meetings, experts reviewed the aggregated results and re-evaluated their ratings to achieve consensus. Consensus was defined as at least 75% agreement on the top 12 KPIs, and this threshold was surpassed with over 80% agreement among the experts. This rigorous methodological approach ensured that the selected KPIs were not only theoretically sound but also highly relevant to the specific environmental, regulatory, and socio-economic context of Kerala.

A cross-functional team comprising representatives from various departments collaborates to generate insights and ideas, leveraging their diverse perspectives to enrich the discussion. Data collection and analysis are conducted to assess current performance levels and identify areas for improvement. Statistical analysis, benchmarking, and comparison with industry standards inform the filtering and prioritization of performance indicators, considering factors such as measurability, reliability, feasibility, and alignment with business objectives.

Through a rigorous selection process, the initial list of performance indicators is consolidated into a final set of 12 KPIs that best represent the SME's performance objectives and priorities as shown in Table 1. These KPIs are actionable, measurable, and aligned with the organization's strategic goals and values. Documentation of the finalized KPIs, along with their definitions, measurement methods, targets, and responsible parties, ensures clarity and accountability. Effective communication of the finalized KPIs to relevant stakeholder's fosters buy-in and facilitates their implementation. By following this methodology, the SME in the mining industry can systematically identify, filter, and consolidate a set of KPIs that effectively measure and drive performance improvement across various aspects of its operations, ultimately contributing to its long-term success and sustainability. The finalized KPIs are listed in the Table 1.

Each of these indicators plays a specific role in assessing and improving different aspects of mining operations, including environmental sustainability, operational efficiency, and community impact. Tailoring strategies to address these indicators can contribute to responsible and efficient mining practices.

In this study, the shortlisting of Key Performance Indicators (KPIs) was carried out through a multi-step process to ensure their relevance and applicability to the sand mining sector in Kerala. Initially, a broad set of 25 potential KPIs was identified through an extensive literature review and consultations with 15 industry experts. These experts, representing diverse backgrounds, provided ratings on the importance of each KPI using a Likert scale.

The Analytical Hierarchy Process (AHP) was employed to prioritize the KPIs based on the aggregated expert ratings, ensuring a balanced evaluation. Subse-

Table 1
Key Performance Indicators for chosen main factors

Main Factors	Key Performance Indicators
Production	1. New Product Design: Number of new product designs developed within a specific period.
	2. Inventory Management: Accuracy of demand forecasting compared to actual sales.
	3. Storage Facility: Capacity utilization rate of storage facilities.
	4. Maintenance: Downtime percentage due to maintenance activities.
Quality	5. Product Reliability: Failure rate of products within a specified period.
	6. Conformance to Specification: Percentage of products meeting quality specifications.
	7. Customer Satisfaction Index : Overall customer satisfaction index derived from surveys or feedback mechanisms.
Delivery	8.Transportation Facility: Transportation cost per unit or per distance travelled
	9. Distribution Network: Coverage and reach of distribution network in target markets.
Environment	10. Eco Friendly Product: General perception of the product's environmental friendliness.
	11. Waste Management: Compliance with waste management regulations and environmental standards.
	12. Recyclable Products: Percentage of product materials that are recyclable.

quent consensus meetings using the Delphi method led to the final selection of 12 KPIs, achieving over 75% agreement among the experts. The selected KPIs were prioritized for their contextual relevance to Kerala's unique environmental, regulatory, and socio-economic conditions, with a strong focus on operational efficiency and sustainability.

While financial KPIs were considered, the expert panel prioritized those metrics that directly impact the operational and environmental performance of sand processing operations. Future research will aim to integrate financial KPIs with the current framework to address the comprehensive performance evaluation needs of SMEs in this sector.

Analytic Hierarchy Process

The AHP is a theory-driven approach used to make judgements in multiple criteria decision making. Thomas Saaty proposed it in the 1970s, and it has been the subject of much research and improvement since then (Saaty, 2008). The AHP technique simplifies decision-making by breaking down the issue into a set of criteria and sub-criteria that can be compared and contrasted using a weighted score. For this technique, Saaty created a comparison method by modelling a hierarchical choice issue framework with several mutually incompatible criteria (Saaty, 1977).

To summarize, the AHP is a systematic decision-making process that takes into account previous information, future forecasts, and intuitive leaps, all within the boundaries of a clearly defined approach based on good mathematical theories. AHP is often utilized to handle a certain kind of problem that necessitates prioritizing viable solutions. Multi-criteria approaches provide a useful framework for modelling preferences and collecting, storing, and organizing all relevant data. AHP may be used to make decisions with a broad variety of uncertainties, given a wide range of objectives, criteria, and stakeholders, due to its comprehensive nature. Each set of criteria and alternatives in the hierarchy is believed to be operationally separate from the other sets (objectives and criteria). Each level of the hierarchy presupposes that the criteria and options included inside it are operationally separate from those contained in the levels above it. The AHP offers a well-structured, systematic analysis and supports decision making by considering both qualitative and quantitative factors. The AHP model is excellent for disentangling complicated situations since it takes into account multiple linked elements.

The rationale for employing AHP in the evaluation of KPIs in the mining sector lies in its ability to provide a structured and systematic framework for decision-making under uncertainty. AHP allows decision-makers to decompose complex decision problems into a hierarchical structure, prioritize criteria and alternatives, and quantify subjective judgments through pairwise comparisons. By applying AHP to the evaluation of KPIs, mining companies can systematically assess the relative importance of different per-

formance factors, consider the perspectives of various stakeholders, and make informed decisions to optimize performance effectively.

Analytic Hierarchy Process – Procedure

The process of employing AHP begins with a comprehensive identification of key criteria and alternatives pertinent to performance optimization in the mining industry as detailed in the previous section. Once the criteria and alternatives are identified, they are structured hierarchically to systematically decompose the complex decision-making problem. This hierarchical arrangement begins with the overarching objective of performance optimization in the mining industry at the highest level, followed by the criteria at the next level, and finally, the alternatives at the lowest level. This hierarchical structuring enables a structured and logical approach to evaluating the relative importance of each criterion and alternative in achieving the overarching objective of performance optimization as shown in Figure 1.

Once the hierarchy has been defined, the following step is to rank the metrics in order of importance. The AHP approach was employed to accomplish this purpose. The AHP technique was used to calculate the relative importance of various criteria for the mining industry Following that, a questionnaire was created that allowed respondents to compare their firms to others in the sector and distributed it to 12 senior executives at the firm. The senior executives were chosen based upon their significant expertise in the appropriate pitch. The next step involves pairwise comparisons, where stakeholders systematically assess and rank the relative importance of each criterion and alternative against one another. The Consistency Ratio (CR) was used to evaluate each expert's paired comparisons. Because there are no CR values bigger than 0.1, it passes the consistency test.

If the comparison is still inconclusive, it must be repeated. To estimate the relative weights of the replies to each question, geometric mean averaging was employed. Using Saaty's 1-9 choice scale, a preference matrix was created and the pairwise comparison judgments are then consolidated into matrices, which serve as the foundation for deriving the relative weights of criteria and alternatives.

The consistency test was applied to all of the combined pairwise comparison matrices as shown in Table 2, 4 and Table 5. The results show that the CR values are close to 0.1, implying that all pairwise comparisons are credible as shown in Table 3 and Table 6. This figure is well within Saaty's tolerance range. This outcome implies that the experts were consistent in the significant weights they assigned to the numerous indicators used to assess the sector's overall sustainable manufacturing performance.

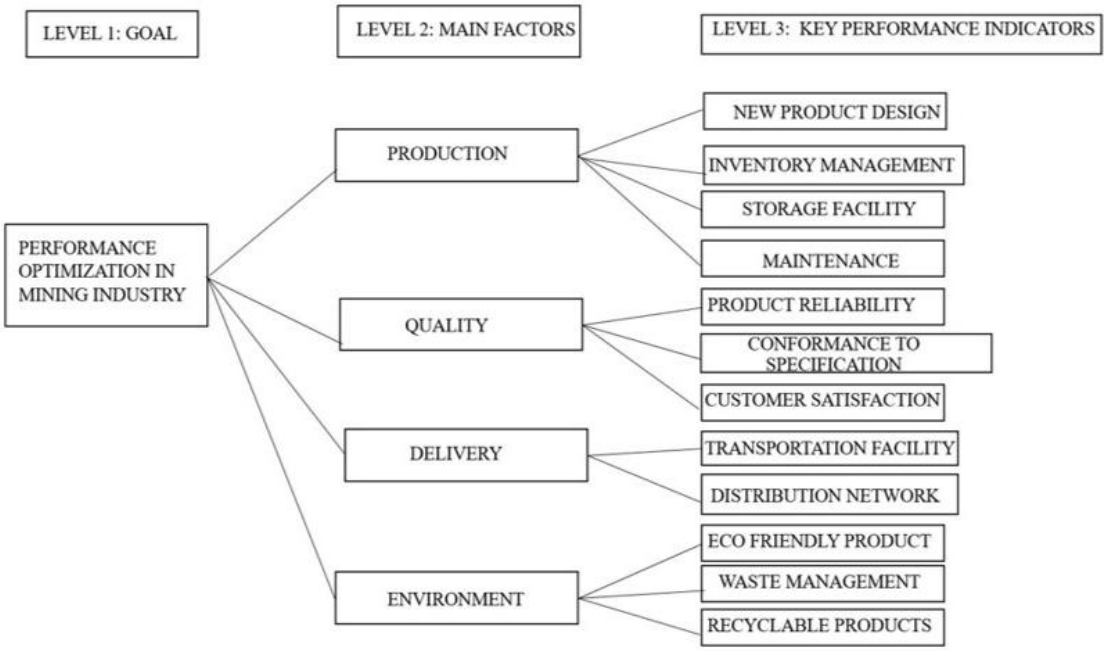

Fig. 1. Constructing the Hierarchy

Table 2
Pairwise Comparison Matrix (Main factors)

	Production	Quality	Delivery	Environment
Production	1	0.5	3.5	2.44
Quality	2	1	3.71	4
Delivery	0.28	0.14	1	1.57
Environment	0.4	0.25	0.67	1

Table 3
Normalized Decision Matrix (Main Factors)

	Production	Quality	Delivery	Environment	Weights	Average Weights	Eigen Value
Production	0.27	0.24	0.39	0.27	0.29	1.21	4.13
Quality	0.55	0.50	0.42	0.45	0.48	1.97	4.10
Delivery	0.08	0.13	0.11	0.17	0.12	0.50	4.02
Environment	0.11	0.12	0.07	0.11	0.10	0.42	4.06

Consistency Index	Random Index	Consistency Ratio
0.03	0.9	0.03

Table 4
Random Index Table

Number of attributes, n	1	2	3	4	5	6	7	8	9	10	11	12
Random Index, RI	–	–	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54

Table 5
Pairwise Comparison Matrix (Key Performance Indicators)

	N P D	I M	S F	M	P R	Cn Sp	C S	T F	D N	Ec Pr	W M	R P
N P D	1	0.28	4.5	4.6	0.28	3.22	0.33	3.33	5.75	0.5	5.75	4.42
I M	3.5	1	6.42	6	0.33	5	0.44	6	6.75	3	7	5
S F	0.22	0.12	1	0.5	0.12	0.33	0.14	0.5	2.38	0.2	2	0.33
M	0.22	0.12	2	1	0.14	0.33	0.14	0.5	3	0.2	3	0.5
P R	3.5	2.78	5.86	7	1	2	2.2	3	6.12	3	5.33	4
Cn Sp	0.33	0.2	3	3	0.5	1	0.22	4	4.22	0.33	4	2
C S	3.22	2.2	7	7	0.44	4.4	1	6	6.71	3	7.1	6
T F	0.29	0.17	2	2	0.33	0.25	0.17	1	3	0.2	3.22	0.5
D N	0.67	0.14	0.42	0.33	0.17	0.25	0.14	0.33	1	0.67	1.57	0.33
Ec Pr	2	0.33	5	5	0.33	3	0.33	5	6	1	5.17	3
W M	0.17	0.14	0.5	0.33	0.2	0.25	0.14	0.33	0.67	0.2	1	0.33
R P	0.22	0.2	3	2	0.25	0.5	0.17	2	3	0.33	3	1
SUM	14.7	7.8	40.7	38.8	4.2	20.5	5.4	32.1	48.6	12.1	48.1	27.4

Table 6
Normalized Decision Matrix (Key Performance Indicators)

	N P D	I M	S F	M	P R	Cn Sp	C S	T F	D N	Ec Pr	W M	R P	Weights	Average Weights	Eigen value
N P D	0.07	0.04	0.11	0.12	0.07	0.16	0.06	0.11	0.12	0.04	0.12	0.16	0.10	1.3	13.49
I M	0.23	0.13	0.16	0.15	0.09	0.24	0.08	0.19	0.14	0.25	0.15	0.18	0.17	2.3	14.16
S F	0.02	0.02	0.02	0.01	0.04	0.02	0.03	0.02	0.05	0.02	0.04	0.01	0.02	0.3	12.51
M	0.01	0.02	0.05	0.03	0.03	0.02	0.03	0.02	0.06	0.02	0.06	0.02	0.03	0.4	12.39
P R	0.23	0.36	0.14	0.18	0.24	0.10	0.41	0.09	0.13	0.25	0.11	0.15	0.20	2.7	13.72
Cn Sp	0.02	0.03	0.07	0.08	0.12	0.05	0.04	0.12	0.09	0.03	0.08	0.07	0.07	0.9	12.83
C S	0.22	0.28	0.17	0.18	0.11	0.21	0.18	0.19	0.14	0.25	0.15	0.22	0.19	2.7	14.08
T F	0.02	0.02	0.05	0.05	0.08	0.01	0.03	0.03	0.06	0.02	0.07	0.02	0.04	0.5	12.32
D N	0.01	0.02	0.01	0.01	0.04	0.01	0.03	0.01	0.02	0.01	0.03	0.01	0.02	0.2	12.66
Ec Pr	0.14	0.04	0.12	0.13	0.08	0.15	0.06	0.16	0.12	0.08	0.11	0.11	0.11	1.5	13.71
W M	0.01	0.02	0.01	0.01	0.04	0.01	0.03	0.01	0.01	0.02	0.02	0.01	0.02	0.2	12.83
R P	0.02	0.03	0.07	0.05	0.06	0.02	0.03	0.06	0.06	0.03	0.06	0.04	0.04	0.6	12.77

Consistency Index	Random Index	Consistency Ratio
0.1	1.54	0.07

Following the analysis, the results of the AHP evaluation are interpreted to derive actionable insights and inform decision-making processes within the mining industry. The relative weights of criteria and alternatives provide a basis for prioritizing actions, allocating resources, and formulating strategies to optimize performance effectively.

Results and Discussion

The AHP is employed to determine the importance of various indicators. Here's a breakdown of the key findings:

Product Reliability: Product reliability emerged as the most critical indicator in the AHP study as shown in Table 7, underscoring its foundational importance for sustainable manufacturing practices. Reliable products are essential for building trust and credibility with customers, reducing the risk of product failures, and enhancing brand reputation. In the context of the mining industry, where products are often used as raw materials for process industries, reliability is paramount to ensure safety, and performance. Continuous evaluation of product reliability through rigorous quality control measures, material testing, and process optimization is imperative to meet customer expectations and regulatory requirements.

Actionable points for stakeholders include investing in advanced quality assurance technologies, employee

Table 7
Performance Indicators Ranking

Performance Indicators	Local Weights	Global Weights	Overall Ranking
New Product Design	0.10	0.02834	5
Inventory Management	0.17	0.04855	3
Storage Facility	0.02	0.00709	8
Maintenance	0.03	0.00884	7
Product Reliability	0.20	0.09517	1
Conformance to Specification	0.07	0.03208	4
Customer Satisfaction	0.19	0.09187	2
Transportation Facility	0.04	0.00476	9
Distribution Network	0.02	0.00225	11
Eco Friendly Product	0.11	0.0112	6
Waste Management	0.02	0.00178	12
Recyclable Products	0.04	0.00459	10

training, and customer feedback mechanisms to uphold product reliability standards and foster long-term customer satisfaction and loyalty. The organizations may adopt rigorous quality management systems such as ISO 9001 to ensure consistent product quality and reliability. They should also establish strong quality assurance processes with suppliers to ensure that raw materials meet required standards. Regular inspections and maintenance of equipment can also prevent production defects. The research emphasizes that improved product reliability forms the foundation for an efficient and secure manufacturing process. Continuous evaluation of new product reliability and oversight of all supplied items are deemed essential in today's competitive business environment.

High Customer Satisfaction: High customer satisfaction was identified as the second most important indicator, highlighting its pivotal role in driving business success and sustainability. Satisfied customers are more likely to become repeat buyers, recommend products to others, and contribute to positive word-of-mouth marketing. In the mining industry, where competition is intense and customer expectations are high, maintaining a high level of customer satisfaction is critical for retaining market share and securing new business opportunities. Short turnaround times from order placement to delivery, responsive customer service, and product customization options are key factors influencing customer satisfaction levels. Stakeholders can leverage actionable points such as streamlining order processing workflows, implementing customer relationship management (CRM) systems, and conducting regular customer satisfaction surveys to enhance service quality, responsiveness, and overall customer experience. Companies should develop robust systems for collecting and analyzing customer feedback. This can include surveys, focus groups, and direct customer interactions to understand and meet customer expectations. They should also enhance customer service operations to respond quickly and effectively to customer inquiries and complaints, fostering customer loyalty and satisfaction.

Effective Inventory Control: Effective inventory control ranked third in importance, highlighting its significance in optimizing resource utilization, minimizing costs, and mitigating operational risks. In the mining industry, where raw materials are finite and production processes are capital-intensive, efficient inventory management is essential for balancing supply and demand, reducing stock outs, and avoiding excess inventory levels. Large-scale production can complicate inventory management, leading to shortages, duplicate output, and excessive carrying costs if not managed effectively. Implementing inventory management software, adopting just-in-time (JIT) inventory systems, and conducting regular inventory audits are actionable points for stakeholders to improve inventory control processes and optimize stock levels.

Product Conformity to Specifications: Product conformity to specifications emerged as a significant indicator, emphasizing its role in ensuring product quality, safety, and compliance with regulatory requirements. Non-conformance to specifications can lead to product defects, customer dissatisfaction, and legal liabilities, posing significant risks to business reputation and financial performance. Adhering to quality standards and regulatory requirements is essential for minimizing risks and maintaining market credibility. Establishing comprehensive quality control processes, investing in employee training, and implementing quality management systems (QMS) are actionable points for stakeholders to uphold product conformity standards and mitigate quality-related risks.

Innovative Product Design in Response to Market Demand: Although ranked the lowest among the significant indicators, innovative product design is still recognized as having importance, particularly in meeting market demand and driving business growth. Innovation is essential for staying competitive in the mining industry, where technological advancements, changing customer preferences, and evolving market trends continually reshape the competitive landscape. Developing products that offer unique features, functionalities, or value propositions can differentiate SMEs in the marketplace and create new business opportunities. Actionable points such as fostering a culture of innovation, investing in research and development (R&D) initiatives, and engaging with customers and industry partners to identify emerging market trends and customer insights are essential for driving innovation and sustaining long-term business success.

In addition, the following recommendations are made considering the context-specific analysis of the sand mining sector in Kerala.

Regularly engage with local regulatory authorities to stay updated on new regulations and ensure compliance. Participation in industry associations can also help in influencing policy decisions that impact the sector.

Implement real-time environmental monitoring systems to ensure compliance with local regulations. These systems can track emissions, effluents, and other environmental parameters, providing data for continuous improvement.

Pursue certifications such as ISO 14001 to demonstrate commitment to environmental management and compliance. This can also serve as a differentiator in the market.

Develop CSR programs that address local community needs, such as supporting local education, healthcare, and infrastructure projects. This helps build goodwill and strengthens community relations. This aligns with Kerala's socio-economic expectations and enhances corporate reputation.

Ensure fair labor practices by providing competitive wages, ensuring safe working conditions, and offering training and development programs. This not only complies with local labor regulations but also improves employee satisfaction and productivity.

Maintain transparent communication with stakeholders, including employees, customers, and local communities, about the company's environmental and operational practices.

Regular Performance Reviews: Conduct regular reviews of KPI performance to identify areas for improvement. Use benchmarking against industry standards to set targets and measure progress.

Establish mechanisms for receiving feedback from employees and customers to continuously improve processes and products.

Encourage innovation by creating an organizational culture that supports continuous improvement and employee involvement. Establish innovation hubs or teams dedicated to exploring new technologies and processes.

Partner with local universities and research institutions to stay abreast of the latest advancements in sustainable manufacturing technologies. Collaboration can lead to the development of innovative solutions tailored to the specific needs of the sector in Kerala.

By implementing these recommendations, SMEs in the sand manufacturing sector in Kerala can enhance their environmental and operational performance, ensuring long-term sustainability and compliance with local regulations. These actionable insights are directly derived from the prioritized KPIs identified through the AHP analysis, ensuring that they are both relevant and impactful.

The results from the analysis utilizing AHP technique highlights the critical importance of product reliability, high customer satisfaction, effective inventory control, product conformity to specifications, and innovative product design in achieving sustainable manufacturing in the mining industry in Kerala, India as shown in Figure 2. These interconnected indicators collectively contribute to operational excellence, risk mitigation, and market competitiveness for SMEs operating in the region. These results underscore the importance of aligning business practices with the stringent environmental regulations and sustainable resource management policies prevalent in the region. The prioritization of these KPIs reflects the opera-

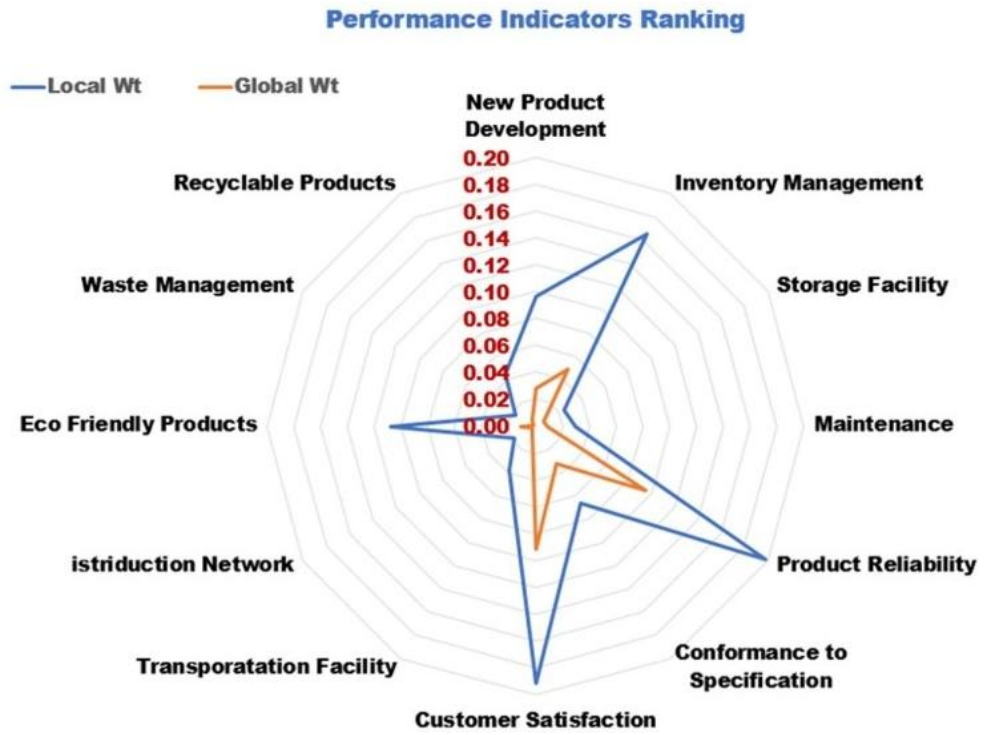

Fig. 2. Performance Indicators Ranking Chart

tional and strategic priorities for sand mining SMEs in Kerala. Ensuring product reliability and customer satisfaction aligns with the region's socio-economic focus on quality and community welfare. Effective inventory control and product conformity to specifications are critical in a regulatory environment that emphasizes sustainability and resource efficiency. Innovative product design underscores the need for continuous improvement and adaptation to local market demands. By implementing actionable points such as investing in quality assurance, inventory management, and innovation capabilities, stakeholders can enhance their performance and resilience, driving economic prosperity, environmental sustainability, and social well-being in the sand processing industry.

Conclusions

This article has accomplished its main objective of scrutinizing performance indicators to evaluate the mining industry's performance and providing a comparative rating in comparison to its industry peers. Setting itself apart from traditional methodologies, this study adopts an innovative approach by directly involving industry manufacturers in evaluating the relevance of four main factors and twelve sub-factors, designated as key performance indicators. The application of the AHP enhances the precision of this evaluation process. The findings not only advance our understanding of the mining industry's performance dynamics but also underscore the effectiveness of direct engagement with manufacturers in refining the assessment framework. This approach contributes to a more nuanced and industry-specific evaluation, providing valuable insights for stakeholders aiming to enhance overall performance in the mining sector.

The AHP analysis identified the following KPIs as most critical for the sand mining sector in Kerala: environmental compliance, resource utilization, waste management, and operational efficiency. These KPIs were prioritized based on their direct impact on sustainability and regulatory adherence, which are paramount in the region's socio-economic context. The analysis revealed that focusing on these KPIs can significantly enhance product reliability, customer satisfaction, and overall operational efficiency.

The findings underscore the interconnectedness of these elements and emphasize the importance of an integrated approach to enhance overall operational performance and sustainability in the mining sector. Sustainable manufacturing entails the harmonization of economic, environmental, and social factors to ensure long-term viability and minimize adverse impacts on stakeholders and the environment. The identified KPIs are intrinsically linked and mutually reinforcing.

For instance, ensuring product reliability not only enhances customer satisfaction but also reduces returns, repairs, and associated costs, thereby positively impacting inventory management and operational efficiency. Moreover, high levels of customer satisfaction contribute to brand loyalty, repeat purchases, and positive word-of-mouth, driving business growth and market competitiveness. Additionally, effective inventory management optimizes resource utilization, minimizes waste, and streamlines supply chain operations, aligning with principles of lean manufacturing and resource efficiency.

Furthermore, the emphasis on environmental responsibility, including eco-friendly production practices, waste management, and recyclable product ratios, reflects a commitment to mitigating environmental impact and promoting sustainable resource use. Sustainable manufacturing requires a holistic approach that integrates environmental considerations into decision-making processes, supply chain management, and product design. By prioritizing KPIs using the AHP methodology, SMEs in the mining industry can effectively allocate resources and implement strategies that foster continuous improvement and long-term resilience. While AHP helped identify the most critical KPIs, future studies may employ techniques like ISM, TISM, or DEMATEL to explore the interrelationships between these KPIs. Ultimately, the integration of these interconnected KPIs facilitates the transition towards more sustainable and responsible manufacturing practices, benefiting both the business and wider society.

Implementing effective strategies in product design, specification, and inventory management, while also prioritizing environmental considerations and waste management, will not only contribute to increased customer satisfaction but also support the industry in meeting its reliability goals. A robust distribution network further ensures seamless operations, reinforcing the industry's commitment to responsible and efficient resource utilization. This study serves as a valuable resource for mining enterprises seeking to optimize their processes and contribute to a more sustainable and customer-centric future.

Limitations

This section discusses the constraints of the research, which may have restricted a comprehensive understanding of the issues outlined in this study. While the

study encompassed data from mines in Kerala rather than being confined to a specific region, it predominantly represents information from mines in South Kerala. The selection of respondents for the questionnaire survey employed a judgmental sampling approach, as only a few mines have embraced lean principles, and these implementations are often only partially adopted based on selected practices. Additionally, the term lean implementation is commonly used to describe the application of isolated practices, such as exclusively employing total productive maintenance in a specific department or for a set of mining machinery.

The acknowledged limitations of the research study suggest potential avenues for future investigation, including the exploration of a more extensive participant pool from mines situated in regions beyond Kerala. To enhance generalizability, future questionnaire surveys should employ a probabilistic sampling method.

Future Study

The study's findings offer potential avenues for future research, including conducting case studies on coal mines to assess the impact of the identified research implications on enhancing mine productivity. Modeling lean awareness and implementation strategies, with a focus on improving preparedness within the Indian coal mining industry, could involve creating an integrated lean implementation framework through a well-defined strategic plan. Moreover, in subsequent research, alternative Multi-Criteria Decision Making (MCDM) tools like Fuzzy Cognitive Maps (FCM), Analytic Network Process (ANP), Analytic Hierarchy Process (AHP), Interpretive Structural Modelling (ISM), and the Technique of Order Preference Similarity to the Ideal Solution (TOPSIS) could be employed to assess the foremost challenges faced by the mining industry. Utilizing these tools may yield favourable outcomes in addressing the mentioned limitation. The findings of this study rely on the viewpoints of a specific expert group within the mining organization. However, to broaden the applicability of the framework and enhance generalizability, adjustments may be introduced to make it suitable for other mining industries.

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