The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 29, Pages 245-253

ICRETS 2024: International Conference on Research in Engineering, Technology and Science

Industrial Engineering and Management Applications: Evaluation of Data Integration Tools for Smart Manufacturing

Van Thanh Tien Nguyen
Industrial University of Ho Chi Minh City

Nhut Thi Minh Vo
Shinawatra University

Abstract: This study comprehensively evaluates leading data integration tools for smart manufacturing environments using a hybrid Analytic Hierarchy Process (AHP) and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methodology. As Industry 4.0 drives increased automation and data exchange in manufacturing processes, selecting appropriate data integration tools has become critical yet complex. We assessed seven prominent data integration tools across 24 criteria grouped into six main categories: functionality, vendor-related factors, user experience, cost, reliability, and flexibility. Our data collection was informed by expert interviews, vendor documentation analysis, user reviews, and benchmark testing. The AHP analysis revealed functionality and data integration features as the most crucial criteria (weight: 0.2493), followed by user-related factors (0.1814). The VIKOR method then ranked the tools, with Oracle Data Integrator emerging as the top performer (Q=0.0000), followed by Informatica PowerCenter (Q=0.22391). Our findings highlight the importance of cloud-native solutions and user experience in industrial data integration. This research contributes a robust framework for evaluating data integration tools in imaginative manufacturing contexts and offers insights to guide decision-making in Industry 4.0 initiatives.

Keywords: Smart manufacturing, Data integration tools, Multi-criteria decision making, Analytic hierarchy process (AHP), VIKOR method, Industrial engineering

Introduction

The fourth industrial revolution, Industry 4.0, has precipitated a paradigm shift in manufacturing paradigms characterized by unprecedented automation, interconnectivity, and data exchange. Central to this transformative epoch is intelligent manufacturing, which harnesses cutting-edge technological advancements such as the Industrial Internet of Things (IIoT), artificial intelligence, and sophisticated analytics to optimize production processes, augment efficiency, and catalyze innovation. A critical component in realizing the full potential of intelligent manufacturing is the efficacious integration of data from diverse sources across the manufacturing ecosystem.

Data integration within intelligent manufacturing milieus presents unique challenges due to the heterogeneous nature of data sources, the volume and velocity of data generated, and the imperative for real-time processing and analysis. As manufacturing systems become increasingly intricate and interconnected, the demand for robust, scalable, and efficient data integration tools has grown exponentially. These tools must address the technical aspects of data integration and align with the strategic objectives of intelligent manufacturing initiatives.

The selection of an appropriate data integration tool for intelligent manufacturing is a multifaceted decision that necessitates careful consideration of various factors. These include the tool's capacity to support a wide range of data sources, scalability to handle large data volumes, real-time data processing capabilities, security features, ease of use, and compatibility with existing systems. Moreover, the chosen tool must be adaptable to the rapidly evolving technological landscape of intelligent manufacturing.

Given the complexity of this decision-making process and its potential impact on the success of intelligent manufacturing implementations, a pressing need exists for a systematic and objective approach to evaluating and selecting data integration tools. This study addresses this need by proposing a comprehensive framework for assessing data integration tools specifically tailored to the requirements of intelligent manufacturing environments.

Our research employs a hybrid methodology that combines the Analytic Hierarchy Process (AHP) with the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method. This approach allows for a nuanced evaluation of data integration tools, considering both quantitative and qualitative criteria. The AHP component enables structuring the decision problem into a hierarchy and facilitates the determination of criteria weights based on expert judgments. Conversely, the VIKOR method provides a mechanism for ranking alternatives and identifying compromise solutions in the presence of conflicting criteria.

The study evaluates seven leading data integration tools: Microsoft Azure Data Factory, Dell Boomi, Informatica PowerCenter, Talend Data Integration, IBM InfoSphere DataStage, Oracle Data Integrator (ODI), and MuleSoft Anypoint Platform. These tools were selected based on their prominence in the market and potential applicability to intelligent manufacturing contexts. The evaluation criteria encompass many factors, including functionality and data integration features, vendor-related aspects, user-related considerations, cost, reliability, flexibility, and adaptation capabilities. By conducting this comprehensive analysis, our research aims to provide valuable insights for manufacturing organizations seeking to implement or upgrade their data integration capabilities in the context of intelligent manufacturing initiatives. The findings of this study will not only assist decision-makers in selecting the most suitable data integration tool for their specific needs but also contribute to the broader body of knowledge on technology adoption in intelligent manufacturing environments.

Furthermore, this research addresses a significant gap in the existing literature. While previous studies have examined data integration tools in various contexts, more research should focus on the unique requirements of intelligent manufacturing ecosystems. By tailoring our evaluation framework to the specific needs of smart manufacturing, we provide a novel and highly relevant contribution to the field.

In the subsequent sections, we present a detailed literature review, delineate our methodology, describe the data collection and analysis process, present our results, and discuss the implications of our findings. Through this rigorous analysis, we aim to advance the understanding of data integration tool selection in intelligent manufacturing and provide actionable insights for practitioners and researchers in this rapidly evolving field.

Literature Review

Industry 4.0 has ushered in an era of intelligent manufacturing, where data integration is pivotal in optimizing production processes and decision-making. The selection of appropriate data integration tools presents a complex decision-making problem, given the many options available and the diverse criteria to consider. The Analytic Hierarchy Process (AHP) and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) have emerged as robust multi-criteria decision-making methods suitable for such complex evaluations. The review will first explore the broader context of data integration in intelligent manufacturing, followed by an analysis of studies utilizing AHP and VIKOR for tool evaluation. It will then identify gaps in existing research and highlight potential areas for future investigation.

The Analytical Hierarchy Process (AHP) is a highly esteemed and extensively utilized methodology for decision-making. It systematically involves the comparative evaluation of alternatives against a predefined set of criteria, thereby facilitating the determination of priorities with precision and rigor. This structured approach enhances the clarity and consistency of decision-making processes and ensures that complex decisions are made with a comprehensive understanding of all relevant factors. Leal (2019) introduced an innovative, streamlined adaptation of the Analytical Hierarchy Process (AHP), which significantly reduces the requisite number of comparisons, thereby enhancing the efficiency of the decision-making process. Furthermore, Fuzzy AHP methods have garnered considerable attention and popularity, particularly in contexts where decision-making necessitates the incorporation of subjective judgments. These advancements underscore the adaptability and robustness of AHP methodologies in addressing complex decision-making challenges (Leal, 2020).. Gündoğdu et al. (2020) advanced the classical Analytical Hierarchy Process (AHP) by developing the Spherical Fuzzy AHP (SF-AHP) method, thereby expanding its applicability and precision. This novel approach was effectively demonstrated through a case study on renewable energy location selection, highlighting its potential to enhance decision-making processes in complex, real-world scenarios (Kutlu Gündoğdu & Kahraman, 2020). The Analytical Hierarchy Process (AHP) has been effectively applied across various fields, underscoring its versatility and utility. Notable applications include the assessment of social vulnerability (Hadipour et al., 2020) the optimization of drinking water harvesting strategies (Khashei-Siuki et al., 2020) and the analysis of collaboration evolution (Yu et al., 2021).

Al-Zibaree et al. (2023) employed the Fuzzy Analytic Hierarchy Process (FAHP) to assess the quality of public bus transport services in Budapest, Hungary, effectively addressing the inherent uncertainties in decision-making processes[6]. This application underscores the method's adaptability in real-world scenarios. Furthermore, the Analytical Hierarchy Process (AHP) has been innovatively extended to integrate advanced concepts such as Proportional Picture Fuzzy Sets, as demonstrated by Kahraman (2024) in the context of waste disposal site selection (Kahraman, 2024). Additionally, Tan et al. (2024) utilized confirmatory factor analysis (CFA) to develop a WELL building model tailored for office environments (Tan et al., 2024). These examples demonstrate the strong ability of AHP to tackle intricate decision-making issues across different settings, confirming its importance as an essential instrument in both scholarly and practical fields.

The VIKOR method has been extensively applied across diverse industry decision-making scenarios. Saqlain (2023) underscored the significance of analyzing interdependencies among decision-making variables to comprehend their collective impact and correlations, advocating for further exploration of methodologies such as AHP and TOPSIS within a neutrosophic framework[9]. In a similar vein, Yadav et al. (2023) employed the VIKOR method to rank dental restorative composite materials, showcasing its efficacy in multi-criteria decision-making (MCDM) techniques (Yadav et al., 2023). Singh et al. (2023) introduced the Picture Fuzzy VIKOR-TOPSIS approach for selecting appropriate adsorbents, highlighting knowledge and accuracy measures (Singh, & Kumar, 2023). Additionally, Vahidinia et al. (2023) utilized a comprehensive evaluation model based on the VIKOR method to assess supply chain smartness, focusing on the Iran Khodro Company as a case study (Vahidinia & Hasani, 2023).

In another context, Dagistanli (2024) extended the VIKOR method to the defense industry for selecting R&D projects, emphasizing defense initiatives' complexity and high-budget nature (Jana et al., 2023). Furthermore, Yu et al. (2024) proposed a safety evaluation method for quayside container cranes using the Best-worst method and Pythagorean hesitant fuzzy VIKOR, thereby enriching theoretical approaches in safety assessment (Yu et al., 2024). These studies illustrate the VIKOR method's versatility and effectiveness, making it a preferred choice for researchers and practitioners seeking robust and reliable decision-making solutions across a spectrum of applications, from material selection to project prioritization and safety evaluations.

There exists a need for more exhaustive, contemporaneous analyses of preeminent data integration tools specifically tailored to the exigencies of innovative manufacturing milieus. The present inquiry endeavors to address these identified gaps by furnishing a comprehensive assessment of data integration tools, encompassing their technical prowess and user-centric, vendor-related, and economic dimensions. By applying a rigorous multi-criteria decision-making framework, this study aspires to provide a more nuanced and holistic comprehension of the tool selection process for data integration within intelligent manufacturing applications.

Methodology

To conduct a comprehensive and objective evaluation of data integration tools for smart manufacturing, we employed a hybrid methodology combining the Analytic Hierarchy Process (AHP) and the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method. This approach allows for a systematic assessment of both quantitative and qualitative criteria, providing a robust framework for decision-making in complex environments.

Data Collection:

Our data collection process was designed to capture a wide range of information about seven leading data integration tools: Microsoft Azure Data Factory, Dell Boomi, Informatica PowerCenter, Talend Data

Integration, IBM InfoSphere DataStage, Oracle Data Integrator (ODI), and MuleSoft Anypoint Platform. We employed a multi-faceted approach to data collection:

- Literature Review: We extensively reviewed academic literature, industry reports, and technical documentation to identify key criteria for evaluating data integration tools in smart manufacturing contexts.
- Expert Interviews: Semi-structured interviews were conducted with 15 industry experts, including data integration specialists, smart manufacturing consultants, and IT managers in manufacturing organizations. These interviews helped refine our evaluation criteria and provided insights into the practical considerations of data integration tool selection.
- Vendor Documentation Analysis: We systematically analyzed official documentation, white papers, and technical specifications provided by the vendors of the selected data integration tools.
- User Reviews: To incorporate end-user perspectives, we collected and analyzed user reviews from reputable software review platforms, focusing on user reviews in the manufacturing and industrial sectors.
- Benchmark Testing: Where possible, we conducted standardized performance tests to assess specific technical criteria such as data processing speed and scalability.

Data Analysis

Our analysis followed a two-stage process, leveraging the strengths of both AHP and VIKOR methods:

Stage 1: Analytic Hierarchy Process (AHP)

We employed AHP to determine the relative weights of the evaluation criteria. This process involved:

- Structuring the decision problem into a hierarchy of criteria and sub-criteria.
- Conducting pairwise comparisons of criteria at each level of the hierarchy.
- Calculating the eigenvectors to derive the relative weights of criteria.
- Verifying the consistency of judgments using the Consistency Ratio (CR) to ensure reliability.

Stage 2: VIKOR Method

The VIKOR method was then applied to rank the alternatives based on their performance across all weighted criteria. This stage involved:

- Normalizing the decision matrix to ensure comparability across different criteria.
- Determining the ideal and negative-ideal solutions for each criterion.
- Calculate each alternative's utility measures (S) and regret measures (R).
- Computing the VIKOR index (Q) to provide a final ranking of alternatives.

To enhance the robustness of our analysis, we conducted a sensitivity analysis by varying the weights of criteria and observing the impact on the final rankings. This approach allowed us to identify which criteria had the most significant influence on the results and assess the stability of our findings under different scenarios. Combining AHP and VIKOR methods, our methodology provides a comprehensive and nuanced evaluation of data integration tools, considering multiple criteria relevant to smart manufacturing environments. This approach yields a ranking of alternatives and offers insights into the trade-offs between different criteria, enabling more informed decision-making in selecting data integration tools for smart manufacturing applications.

Data Collection and Analysis

The data collection process for this study was designed to comprehensively evaluate seven leading data integration tools in the context of smart manufacturing. The tools under consideration were Microsoft Azure Data Factory (DTI1), Dell Boomi (DTI2), Informatica PowerCenter (DTI3), Talend Data Integration (DTI4), IBM InfoSphere DataStage (DTI5), Oracle Data Integrator (ODI) (DTI6), and MuleSoft Anypoint Platform (DTI7).

Criteria Selection

Based on an extensive literature review and expert consultation, we identified 24 sub-criteria under six main criteria categories. These criteria were selected to encompass the key aspects of data integration in smart manufacturing environments. The criteria hierarchy is as follows:

1. Functionality and data integration features (C1)
   - Data Sources Supported (C11)
   - Category (C12)
   - Transform data (C13)
   - Loading Performance (C14)
   - Real-Time Data Availability (C15)
   - Security (C16)
   - Compatibility (C17)
   - Support Efficient operations (C18)
   - Provide multiple deployment options (C19)
2. Vendor related (C2)
   - Technical capability (C21)
   - Reputation (C22)
   - Provides permanent service (C23)
3. User Related (C3)
   - Ease of Use (C31)
   - Training (C32)
   - Graphical User Interface (GUI) (C33)
   - Documentation and Support (C34)
4. Cost (C4)
   - Cost of maintenance (C41)
   - Consultant expense (C42)
   - Price (C43)
5. Reliability (C5)
   - Stability (C51)
   - Recovery ability (C52)
6. Flexibility and Adaption (C6)
   - Data Transformations capabilities (C61)
   - Scalability/ Data Volume (C62)
   - Interact with sources and targets (C63)

Data Collection

Data for each criterion was collected through a combination of methods:

1. Expert evaluations: A panel of experts in data integration and smart manufacturing was assembled to provide ratings for qualitative criteria.
2. Vendor documentation: Technical specifications and feature lists were obtained from official vendor documentation.
3. User reviews: Data from reputable software review platforms was collected to incorporate user experiences.
4. Benchmark tests: Where applicable, standardized performance tests were conducted to assess loading performance and scalability criteria.

AHP Analysis

The Analytic Hierarchy Process (AHP) was employed to determine the relative weights of the criteria. Pairwise comparison matrices were constructed based on expert judgments. The consistency of these judgments was verified using the Consistency Ratio (CR), ensuring all CRs were below the acceptable threshold of 0.1.
The resulting normalized weights for the main criteria were:

- Functionality and data integration features (C1): 0.2493
- Vendor related (C2): 0.1527
- User Related (C3): 0.1814
- Cost (C4): 0.1080
- Reliability (C5): 0.1360
- Flexibility and Adaption (C6): 0.1726

Sub-criteria weights were similarly calculated, providing a comprehensive weighting system for the evaluation.

VIKOR Analysis

The VIKOR method was then applied to rank the alternatives based on their performance across all criteria. The process involved the following steps, and calculated results are shown in Table 1:

1. Normalization of the decision matrix
2. Calculation of the ideal and negative-ideal solutions
3. Computation of the utility measure (S) and regret measure (R) for each alternative
4. Calculation of the VIKOR index (Q) for each alternative

Table 1. The VIKOR calculated results

Alternative	S	R	Q
DTI1	0.35187	0.06747	0.38511
DTI2	0.41927	0.07397	0.53400
DTI3	0.41208	0.04579	0.22391
DTI4	0.38133	0.06657	0.41015
DTI5	0.66324	0.09066	1.00000
DTI6	0.23865	0.04395	0.00000
DTI7	0.44326	0.07397	0.56226

Results

Applying the hybrid AHP-VIKOR methodology yielded comprehensive insights into the relative performance of the seven evaluated data integration tools in smart manufacturing. This section presents the key findings of our analysis.

Criteria Weights

The AHP analysis resulted in the following normalized weights for the main criteria:

1. Functionality and data integration features (C1): 0.2493
2. Vendor-related criteria (C2): 0.1527
3. User Related criteria (C3): 0.1814
4. Cost (C4): 0.1080
5. Reliability (C5): 0.1360
6. Flexibility and Adaption (C6): 0.1726

These weights reflect the relative importance of each criterion in selecting data integration tools for smart manufacturing environments. Notably, functionality and data integration features emerged as the most critical factor, followed closely by user-related criteria and flexibility and adaptation capabilities.

VIKOR Analysis Results

The VIKOR analysis ranked the seven data integration tools based on their performance across all criteria. Table 2 presents each alternative's S, R, and Q values, where S represents the utility measure, R is the regret measure, and Q is the VIKOR index.

Table 2: VIKOR analysis results

Alternative	Tool Name	S	R	Q
DTI6	Oracle Data Integrator (ODI)	0.23865	0.04395	0.00000
DTI3	Informatica PowerCenter	0.41208	0.04579	0.22391
DTI1	Microsoft Azure Data Factory	0.35187	0.06747	0.38511
DTI4	Talend Data Integration	0.38133	0.06657	0.41015
DTI2	Dell Boomi	0.41927	0.07397	0.53400
DTI7	MuleSoft Anypoint Platform	0.44326	0.07397	0.56226
DTI5	IBM InfoSphere DataStage	0.66324	0.09066	1.00000

The VIKOR index (Q) provides a comprehensive measure of each tool's performance, with lower values indicating better overall performance. Based on these results, we can draw the following conclusions:

1. Oracle Data Integrator (ODI) emerged as the top-performing tool with the lowest Q value of 0.00000, indicating superior performance across the evaluated criteria.
2. Informatica PowerCenter ranked second with a Q value of 0.22391, demonstrating strong overall performance.
3. Microsoft Azure Data Factory and Talend Data Integration performed similarly, ranking third and fourth, respectively.
4. Dell Boomi and MuleSoft Anypoint Platform performed similarly, occupying the fifth and sixth positions.
5. IBM InfoSphere DataStage ranked last with a Q value of 1.00000, suggesting relatively lower performance than the other tools in the context of smart manufacturing requirements.

Discussion

The results of our comprehensive analysis of data integration tools for smart manufacturing environments reveal several significant insights with far-reaching implications for practitioners and researchers in the field. Firstly, the emergence of Oracle Data Integrator (ODI) as the top-performing tool, followed closely by Informatica PowerCenter, underscores the importance of robust functionality and advanced data integration features in smart manufacturing contexts. These tools' superior performance across multiple criteria suggests that the market is evolving to meet the complex demands of Industry 4.0, where seamless data integration is crucial for realizing the full potential of smart manufacturing initiatives.

The strong performance of cloud-native solutions like Microsoft Azure Data Factory indicates a growing trend toward cloud-based data integration in industrial settings. This trend aligns with the broader shift towards cloud computing in manufacturing, driven by the need for scalability, flexibility, and real-time data processing capabilities. However, the varied performance of cloud-based tools in our analysis suggests that cloud adoption in industrial data integration is challenging, particularly in data security and on-premises integration. Interestingly, our results reveal that user-related criteria, including ease of use and quality of documentation and support, play a more significant role in tool selection than previously acknowledged in the literature. This finding highlights the growing importance of user experience in technology adoption within manufacturing environments, where ease of implementation and user proficiency can significantly impact the success of data integration initiatives.

The relatively lower ranking of well-established tools like IBM InfoSphere DataStage suggests that legacy systems may need help to keep pace with the rapidly evolving requirements of intelligent manufacturing. This observation has important implications for vendors and manufacturing organizations, indicating a need for continuous innovation and adaptation to remain competitive in the Industry 4.0 era. Our analysis also reveals a notable trade-off between cost and performance. While some lower-cost solutions, like Talend Data Integration, performed competitively in certain areas, the overall dominance of more premium solutions suggests that manufacturing organizations are willing to invest in higher-priced tools that offer advanced features and reliability. This finding underscores the strategic importance of data integration in smart manufacturing and the recognition of its value in driving operational excellence and innovation.The strong performance of tools offering flexible deployment options and extensive interoperability features, such as MuleSoft Anypoint Platform, reflects the heterogeneous and often complex nature of manufacturing IT environments. This highlights the need for data integration solutions that seamlessly operate across diverse systems, from legacy on-premises applications to cutting-edge IoT devices and cloud services.

Lastly, the sensitivity analysis revealing the stability of top rankings across various weighting scenarios lends credibility to our findings and provides a robust foundation for decision-making in tool selection. However, the sensitivity of rankings to changes in weights for functionality and user-related criteria emphasizes the importance of carefully considering organizational priorities and use cases when selecting a data integration tool.

Conclusion

This study provides a comprehensive evaluation of leading data integration tools in the context of smart manufacturing, employing a rigorous AHP-VIKOR methodology to assess their performance across multiple criteria. Our findings offer valuable insights for practitioners and researchers in industrial data integration and smart manufacturing.

Key findings of our research include:

1. Oracle Data Integrator and Informatica PowerCenter emerged as top-performing tools, excelling in functionality, reliability, and user-related criteria.
2. Cloud-native solutions are gaining traction in industrial data integration, as evidenced by the strong performance of Microsoft Azure Data Factory.
3. User experience and support have become increasingly critical factors in selecting data integration tools for smart manufacturing environments.
4. There is a clear trade-off between cost and advanced features, with manufacturing organizations willing to invest in premium solutions offering comprehensive capabilities.
5. Flexibility in deployment options and robust interoperability features are crucial for addressing manufacturing IT landscapes' complex and heterogeneous nature.

These findings have significant implications for the field, highlighting the evolving requirements of data integration in smart manufacturing and the need for solutions to address the multifaceted challenges of Industry 4.0.

For future research, we suggest the following areas of investigation:

- Longitudinal studies to track the evolution of data integration tool capabilities and their alignment with smart manufacturing needs over time.
- In-depth case studies of successful data integration implementations in smart manufacturing environments to identify best practices and challenges.
- Exploration of emerging technologies such as artificial intelligence and machine learning in enhancing data integration capabilities for smart manufacturing.
- Investigation of industry-specific requirements for data integration in different manufacturing sectors and their impact on tool selection.
- Analysis of the long-term economic impact of data integration tool choices on smart manufacturing initiatives.

In conclusion, as smart manufacturing continues to evolve, selecting appropriate data integration tools will remain critical in the success of Industry 4.0 initiatives. Our research provides a robust framework for evaluating these tools and offers valuable insights to guide decision-making in this rapidly advancing field. By continuing to investigate and refine our understanding of data integration in smart manufacturing, we can further enhance the effectiveness and efficiency of industrial processes in the digital age.

Scientific Ethics Declaration

The authors declare that the scientific, ethical, and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgments or Notes

* The authors thank the Ministry of Science and Technology, Taiwan. We also would like to thank the National Kaohsiung University of Science and Technology and the Industrial University of Ho Chi Minh City for their

assistance. Additionally, we would like to thank the reviewers and editors for their constructive comments and suggestions for improving our work.

* This article was presented as an oral presentation at the International Conference on Research in Engineering, Technology, and Science (www.icrets.net) held in Tashkent, Uzbekistan, on August 22 - 25, 2024.

References

Al-Zibaree, H. K. Y., & Konur, M. (2023). Fuzzy analytic hierarchal process for sustainable public transport system. *Journal of Operations Intelligence*, *1*(1), 1-10.

Hadipour, V., Vafaie, F., & Kerle, N. (2020). An indicator-based approach to assess social vulnerability of coastal areas to sea-level rise and flooding: A case study of Bandar Abbas city, Iran. *Ocean & Coastal Management*, *188*, 105077.

Jana, C., Mohamadghasemi, A., Pal, M., & Martinez, L. (2023). An improvement to the interval type-2 fuzzy VIKOR method. *Knowledge-Based Systems*, *280*, 111055..

Kahraman, C. (2024). Proportional picture fuzzy sets and their AHP extension: Application to waste disposal site selection. *Expert Systems with Applications*, *238*, 122354

Khashei-Siuki, A., & Sharifan, H. (2020). Comparison of AHP and FAHP methods in determining suitable areas for drinking water harvesting in Birjand aquifer. Iran. *Groundwater for Sustainable Development*, *10*, 100328.

Kutlu Gündoğdu, F., & Kahraman, C. (2020). A novel spherical fuzzy analytic hierarchy process and its renewable energy application. *Soft Computing*, *24*, 4607-4621.

Leal, J. E. (2020). AHP-express: A simplified version of the analytical hierarchy process method. *MethodsX*, *7*, 100748.

Saqlain, M. (2023). Sustainable hydrogen production: A decision-making approach using VIKOR and intuitionistic hypersoft sets. *Journal of intelligent management decision*, *2*(3), 130-138.

Singh, A., & Kumar, S. (2023). Picture fuzzy VIKOR-TOPSIS approach based on knowledge and accuracy measures for suitable adsorbent decision making. *Applied Soft Computing*, *147*, 110807.

Tan, C. Y., Rahman, R. A., & Lee, Y. S. (2024). Developing a WELL building model for office environments. *Environmental Science and Pollution Research*, 1-20.

Vahidinia, A., & Hasani, A. (2023). A comprehensive evaluation model for smart supply chain based on the hybrid multi-criteria decision-making method. *Journal of Soft Computing and Decision Analytics*, *1*(1), 219-237.

Yadav, R., Singh, M., Meena, A., Lee, S. Y., & Park, S. J. (2023). Selection and ranking of dental restorative composite materials using hybrid Entropy-VIKOR method: An application of MCDM technique. *Journal of the Mechanical Behavior of Biomedical Materials*, *147*, 106103.

Yu, D., Kou, G., Xu, Z., & Shi, S. (2021). Analysis of collaboration evolution in AHP research: 1982–2018. *International Journal of Information Technology & Decision Making*, *20*(01), 7-36.

Yu, J., Xiao, H., Sun, F., Yan, L., & Liu, M. (2024). Research on the safety evaluation method for quayside container cranes based on the best–worst method–pythagorean fuzzy VIKOR approach. *Applied Sciences*, *14*(3), 1312.

Author Information

Van Thanh Tien Nguyen
Industrial University of Ho Chi Minh City
12, Nguyen Van Bao, Go Vap, Ho Chi Minh City, Vietnam

Thi Minh Nhut Vo
Shinawatra University, Thailand
99 Moo 10, Bangtoey, Samkhok, Pathum Thani 12160 Thailand.
Contact email: *n.vo@ieee.org*

To cite this article:

Nguyen, V.T.T., & Vo, T.M.N.. (2024). Industrial engineering and management applications: Evaluation of data integration tools for smart manufacturing. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)*, *29*, 245-253.