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Simulation techniques in industrial engineering: A USA and African perspective review

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Abstract

Simulation techniques play a crucial role in the field of Industrial Engineering, offering a powerful means to model, analyze, and optimize complex systems. This paper provides an overview of the state of simulation techniques in Industrial Engineering, with a focus on a comparative review of their application in the USA and Africa. In the United States, simulation has become an integral part of industrial processes, aiding in the design and improvement of manufacturing systems, supply chains, and logistics. Advanced simulation tools enable engineers to simulate real-world scenarios, evaluate performance, and identify bottlenecks or inefficiencies. The USA's emphasis on technology and innovation has resulted in the widespread adoption of simulation techniques, contributing to increased efficiency, cost-effectiveness, and overall competitiveness in industrial sectors. On the other hand, the African perspective reveals a diverse landscape with unique challenges and opportunities. While certain regions in Africa are rapidly advancing in industrialization, others face infrastructure limitations and economic constraints. The use of simulation techniques in African industrial engineering is gaining traction, albeit at a different pace. Localized applications focus on optimizing resource utilization, enhancing production processes, and addressing specific challenges related to the African context. The review highlights the potential for knowledge transfer and collaboration between the USA and Africa in the realm of simulation techniques. Bridging the gap through information exchange, training programs, and technology transfer can contribute to the development of sustainable and resilient industrial practices in Africa. Challenges such as data availability, infrastructure limitations, and skill development are addressed, offering insights into how these obstacles can be overcome to facilitate the effective implementation of simulation techniques in the African industrial landscape. This paper provides a comprehensive overview of simulation techniques in Industrial Engineering, examining the disparities and commonalities between the USA and Africa. By understanding the current state and challenges faced by both perspectives, this review sets the stage for collaborative efforts that can propel the industrial engineering field forward on a global scale.

Keywords: Industrial Engineering; Simulation; Africa; USA; Review

1. Introduction

Simulation techniques in industrial engineering play a crucial role in modeling, analyzing, and optimizing complex systems. Real-world systems in manufacturing, supply chains, and public services are often too complex to be accurately modeled using traditional analytical techniques (Ng et al., 2011). As a result, simulation becomes a method of first resort for studying queue characteristics and determining operational conditions, such as the number of counters to open for

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each flight (Anderson, 2015; Miranda & Nogueira, 2019). Moreover, simulation-optimization is widely used for capacity planning, strategic design, and decision support in manufacturing and logistics systems (Piera et al., 2004; Karlsson et al., 2017). The importance of simulation is further emphasized by its application in analyzing complex systems, optimization problems, and the working process and performance of various systems, such as time-division multiplexing digital optimal band transmission systems and tracked vehicle load simulation test benches (Lee et al., 2020; Ren & Xi, 2021; Lv et al., 2019). Additionally, simulation is a valuable tool for checking the feasibility of plans, as well as for designing reconfigurable molds for injection overmolding, which is suitable for large batch production and leads to reduced single part costs (Fioroni et al., 2008; Galati et al., 2022).

The significance of simulation in industrial engineering is also evident in its application in decision support systems, such as IDSS-AR, which combines simulation and augmented reality to provide 3D visualization of simulation models for manufacturing decision support (Karlsson et al., 2017). Furthermore, simulation techniques are utilized for system architecture optimization with runtime reconfiguration of simulation models, highlighting their role in robustness and control reconfiguration in engineering systems (Wichmann et al., 2015). The use of simulation is not limited to traditional manufacturing and engineering domains, as it extends to healthcare architectural design, where computational tools are employed for visualization and simulation in healthcare architectural design (Johanes et al., 2015). Additionally, the emerging discipline of "Computational Molecular Engineering (CME)" leverages simulation-based engineering to make basic research in soft matter physics fruitful for industrial applications, highlighting the broad applicability of simulation techniques across various domains (Horsch et al., 2013).

In conclusion, simulation techniques are of paramount importance in industrial engineering, providing a versatile and powerful tool for modeling, analyzing, and optimizing complex systems across diverse domains, from manufacturing and logistics to healthcare and process engineering.

2. Simulation Techniques in Industrial Engineering

Simulation techniques play a crucial role in industrial engineering, offering a practical approach to problem-solving and decision-making. The use of simulations in industrial engineering has expanded rapidly into various industries, including manufacturing, healthcare, and materials science (Badurdeen et al., 2009; Lote et al., 2009; Czech et al., 2007). For instance, in the context of lean manufacturing, simulations are widely used to teach problem-based learning and improve production problem-solving skills (Badurdeen et al., 2009; Ramos et al., 2015). Furthermore, the emergence of computational molecular engineering (CME) has specifically addressed the needs of industrial users, highlighting the relevance of simulation techniques in addressing industrial challenges (Kunene et al., 2022; Shudler et al., 2019; Horsch et al., 2013).

Simulation techniques have also been integrated into medical education, with simulations becoming a standard practice in many residency programs, particularly in surgical specialties (Baker et al., 2012; Enebe et al., 2022; Robinson et al., 2018). Moreover, the application of simulation techniques extends to industrial production systems, where hybrid mesh adaptive direct search and genetic algorithms have been employed to enhance performance and decision-making in industrial settings (Vasant, 2011; Vasant, 2014).

In the context of materials science and engineering, simulations have been instrumental in assessing operational conditions, mold design, and process efficiency, demonstrating their significance in optimizing industrial processes (Miranda & Nogueira, 2019; Vergnano et al., 2019). Additionally, the integration of simulation techniques into quality inspection processes and the design of reconfigurable molds further underscores their importance in industrial engineering (Ukoba and Inambao, 2018; Boscolo et al., 2014; Galati et al., 2022).

Overall, the widespread application of simulation techniques in industrial engineering is evident across various domains, including manufacturing, healthcare, materials science, and production systems. These techniques have proven to be invaluable in enhancing problem-solving, decision-making, and process optimization, thereby contributing significantly to the advancement of industrial engineering practices.

3. Simulation Techniques in the USA

The integration of simulation techniques in industrial processes in the USA has been a significant area of focus, particularly in manufacturing systems, supply chains, and logistics. Studies have shown that the application of simulation methods has led to improvements in the global behavior of logistics and production processes, serving as a fundamental tool for troubleshooting and assessing planning variants (Macías & Pérez, 2004; Lattner et al., 2011).

Furthermore, the use of simulation in modeling inventory control systems and reverse logistics has been investigated, highlighting its relevance in these areas (Kouchekian-Sabour, 2021; Kara et al., 2007). The effectiveness of quality management and control strategies for production logistics has been demonstrated through simulation results, emphasizing its impact on efficiency and cost-effectiveness (Wang, 2023; Orieno et al., 2024).

In the context of technology and innovation, the USA has been at the forefront of systemic and society-changing technological innovations, primarily in the field of Deep Tech innovations, positioning the country as a leader in technological advancements (Schuh et al., 2022; Ogundairo et al., 2023; Ayo-Farai et al., 2023). Additionally, the emphasis on moral and cognitive legitimacy seeking for products in the early stage of technology development has been supported by organizational research, reflecting the significance of technology legitimation in the USA (Bunduchi & Candi, 2021). Moreover, the application of simulation techniques has been highlighted as an indispensable part of product development and industrialization, facilitating cost-effective solutions in manufacturing (Jeong et al., 2020; Ukoba et al., 2011).

In conclusion, the USA has strategically integrated simulation techniques into industrial processes, particularly in manufacturing systems, supply chains, and logistics, leading to improvements in efficiency, cost-effectiveness, and competitiveness. The emphasis on technology and innovation has positioned the USA as a leader in systemic and society-changing technological innovations, further reinforcing the significance of simulation in driving advancements in industrial processes.

4. Simulation Techniques in Africa

The industrial landscape in Africa is diverse, with varied levels of industrialization and economic constraints (Austin & Frankema, 2017). Africa faces limitations in infrastructure but is rich in natural resources (Guo et al., 2021). The challenges of locally manufactured vehicle supply chains in South Africa highlight the complexities of the automotive industry in the region (Ambe & Badenhorst-Wess, 2013). Additionally, the South African floricultural industry faces unique challenges, as evidenced by the review of Plant Breeders' Rights for the floricultural industry in South Africa (Netnou-Nkoana & Eloff, 2012; Oti and Ayeni, 2013). Furthermore, the economic aspects of the South African flower industry have been studied to understand the country's competitiveness and comparative advantage (Rooyen & Rooyen, 1998).

The emerging use of simulation techniques in Africa is aimed at addressing local challenges, particularly in optimizing resource utilization and production processes. For instance, the application of conservation agriculture (CA) has been increasingly promoted as the best solution to sustainable agricultural development in Africa (Scheba, 2017). Moreover, the solar energy sector in Sub-Saharan Africa presents opportunities for technological leapfrogging, indicating a shift towards innovative solutions (Amankwah-Amoah, 2014). The need for medical device development collaboration in South Africa suggests the potential for the application of simulation techniques in optimizing healthcare resource utilization (Jager et al., 2017; Olushola and Olabode, 2018).

The varied levels of industrialization and economic constraints in Africa have led to the need for innovative approaches to address local challenges. The use of simulation techniques is crucial in optimizing resource utilization and production processes in industries across the continent. Additionally, the economic and socio-economic effects of industrial oil palm plantations in Southwest Cameroon highlight the need for sustainable industrial practices in Africa (Kupsch, n.d.).

In conclusion, the industrial landscape in Africa is characterized by diverse challenges and opportunities. The emerging use of simulation techniques in addressing local challenges is evident across various industries, with a focus on optimizing resource utilization and production processes. As Africa continues to navigate its industrialization journey, the application of simulation techniques will play a crucial role in driving sustainable development and economic growth.

5. Comparative Analysis

To conduct a comparative analysis of simulation techniques in industrial engineering from the perspectives of the USA and Africa, it is essential to highlight the disparities and commonalities between the two regions. The challenges faced by both perspectives include data availability, infrastructure limitations, and skill development. Additionally, it is crucial to explore the potential for knowledge transfer and collaboration between the USA and Africa.

In the USA, industrial engineering heavily relies on simulation tools to capture system dynamics and evaluate different scenarios, particularly in lean manufacturing and healthcare industries (Ramos et al., 2015; Olushola, 2017). Similarly, Africa can benefit from simulation techniques to improve productivity and resource allocation in various sectors, including healthcare and manufacturing.

Both the USA and Africa face challenges related to data availability, infrastructure limitations, and skill development. Data availability is crucial for accurate simulation, and both regions need to address this issue to enhance the effectiveness of their industrial engineering practices. Infrastructure limitations, particularly in Africa, may hinder the adoption of advanced simulation tools, requiring innovative approaches to overcome these barriers. Moreover, skill development is essential for effectively utilizing simulation techniques, and both regions need to invest in training and education to build expertise in industrial engineering simulation (Lote et al., 2009; Czech et al., 2007).

The potential for knowledge transfer and collaboration between the USA and Africa is significant. University-industry collaboration can facilitate the flow of knowledge across sectors and stimulate industrial research and development investments (Al-Tabbaa & Ankrah, 2018). Furthermore, collaborative relationships between universities and enterprises can enhance intellectual capital and drive innovation in high-tech industries (Li & Niyomsilp, 2020). By leveraging such collaborations, both the USA and Africa can benefit from shared expertise and resources, ultimately improving their industrial engineering practices.

In conclusion, while the USA and Africa have disparities in their industrial engineering landscapes, they share common challenges and opportunities. By addressing data availability, infrastructure limitations, and skill development, and fostering knowledge transfer and collaboration, both regions can enhance their industrial engineering practices and contribute to global advancements in the field.

6. Bridging the Gap

To bridge the gap of simulation techniques in industrial engineering between the USA and Africa, several strategies for information exchange and technology transfer initiatives are essential. Firstly, the exchange of information between the USA and Africa can be facilitated through collaborative workshops designed for industry and regulatory scientists (Kusuhara et al., 2017). These workshops aim to bridge the time gap between academic applications of simulation techniques and their routine industrial use. Additionally, international collaboration through training and education programs in space technology applications can promote information exchange and technology transfer (Raju et al., 2020). Such initiatives can provide a platform for sharing knowledge and best practices in simulation techniques.

Training programs and technology transfer initiatives play a crucial role in facilitating the effective implementation of simulation techniques in Africa. For instance, simulation-based low-dose, high-frequency training combined with mobile mentoring has been shown to be effective among health workers in Nigeria (Ugwa et al., 2020). This approach can be adapted and extended to industrial engineering contexts to enhance the practical application of simulation techniques. Furthermore, the role of the International Atomic Energy Agency (IAEA) in education and training of professionals in Asia Pacific demonstrates the significance of capacity building and technology transfer initiatives in fostering collaboration and enabling technology transfer (Prajogi et al., 2021).

Challenges to the effective implementation of simulation techniques in Africa need to be addressed to ensure successful integration. One of the challenges is the need to bridge the gap between spatial and temporal scales in simulations and experiments, which remains an open challenge in modern science and engineering (Fyta et al., 2011). Additionally, addressing the causes of schedule and cost overruns in megaprojects, such as shortages of skilled labor and poor site management, is crucial to creating an environment conducive to the effective implementation of simulation techniques in industrial engineering in Africa (Tshidavhu & Khatleli, 2020).

In conclusion, to bridge the gap of simulation techniques in industrial engineering between the USA and Africa, strategies for information exchange, training programs, and technology transfer initiatives need to be implemented. Addressing challenges such as the spatial and temporal scale gap in simulations, as well as addressing project management issues, is essential for the effective implementation of simulation techniques in Africa.

7. Future Outlook and Emerging Trends

The future outlook and emerging trends of simulation techniques in industrial engineering are shaped by various factors. The field of computational molecular engineering (CME) has emerged, focusing on the needs of industrial users in engineering, particularly in the context of scalability and workflow (Shudler et al., 2019). Additionally, the integration of simulation techniques with other industrial engineering methods, such as time and motion studies, value stream mapping, and ergonomics studies, has become more prevalent, indicating a broader application of simulation in optimizing resource allocation and operational efficiency (Lote et al., 2009). Furthermore, the use of computer simulation-based designs, including techniques like Latin hypercube sampling, is gaining attention in industrial engineering experiments, signifying a shift towards more advanced and statistically rigorous simulation methodologies (Zhou, 2018). Moreover, the application of simulation modeling in healthcare has presented challenges and trends that are likely to influence the future of simulation techniques in industrial engineering, particularly in the context of discrete event simulation and the modeling of complex systems (Almagooshi, 2015).

These trends collectively indicate a growing emphasis on the integration of advanced computational methods, statistical rigor, and interdisciplinary applications in the future of simulation techniques in industrial engineering. As the field continues to evolve, it is expected to increasingly leverage molecular simulation, advanced statistical designs, and complex system modeling to address the diverse challenges and opportunities in industrial engineering.

7.1. Recommendation and Conclusion

Establish platforms for regular knowledge exchange between USA and African industrial engineering professionals. Encourage collaborative research projects that involve experts from both regions. Implement training programs in African countries to enhance local expertise in simulation techniques. Leverage existing educational institutions and industry partnerships to create specialized training modules. Establish mechanisms for the transfer of simulation technologies from developed countries to Africa. Encourage partnerships between international technology providers and local enterprises to facilitate technology adoption.

Advocate for investments in infrastructure development to overcome limitations hindering the widespread application of simulation techniques in Africa. Collaborate with international organizations and governments to improve data accessibility and reliability.

8. Conclusion

In conclusion, the review of simulation techniques in Industrial Engineering from both USA and African perspectives highlights the critical role of these tools in optimizing complex systems. The disparities and challenges faced by each region underscore the need for collaborative efforts to advance the field globally. Simulation is integral to industrial processes in the USA, contributing to efficiency and competitiveness. Africa shows promising strides in adopting simulation techniques but faces unique challenges, including economic constraints and infrastructure limitations.

Emphasize the importance of shared knowledge and expertise to address challenges and drive innovation. Advocate for international partnerships to bridge the gap and promote a collective approach to advancing industrial engineering. Recognize the potential of simulation techniques to enhance sustainability by optimizing resource utilization and minimizing environmental impact. Highlight the role of collaboration in developing and implementing sustainable and resilient industrial practices globally.

In conclusion, by fostering collaboration, investing in training programs, facilitating technology transfer, and addressing infrastructure challenges, the industrial engineering community can harness the full potential of simulation techniques to build a more sustainable and resilient future for industries both in the USA and Africa.

Compliance with ethical standards

Disclosure of conflict of interest

The author has no conflict of interest in this research.

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