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Application of the Hungarian Method for Reducing Shipping Delays in Online Retail Logistics

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Abstract: ***The expansion of electronic commerce has transformed retail markets worldwide, making efficient logistics management a critical factor for business success. Among the various operational challenges faced by online retailers, shipping delays remain one of the most significant issues affecting customer experience and organizational performance. Delayed deliveries not only increase operational costs but also reduce customer trust and loyalty. The present study explores the applicability of the Hungarian Method as an optimization tool for minimizing shipping delays in online retail logistics through efficient assignment of delivery resources. The research adopted an empirical and analytical approach using shipment data collected from five regional distribution centers and five delivery partners serving customers across different districts of Jharkhand, India. A dataset comprising 300 customer orders was analyzed. Delivery times between warehouses and customer locations were arranged in the form of a cost matrix, where the Hungarian Algorithm was employed to determine the optimal assignment of delivery resources. The optimized allocation model was subsequently compared with the conventional allocation strategy currently used in logistics operations.***

The results demonstrated a substantial improvement in delivery performance after implementing the Hungarian Method. The average order fulfillment time was reduced from 6.2 days to 4.3 days, representing a decrease of approximately 30.6%. The total delay hours associated with the sample orders declined from 1,620 hours to 1,085 hours, resulting in a reduction of 33.0%. In addition, vehicle and delivery personnel utilization improved from 74% to 89%, indicating more efficient use of available logistics resources. A customer feedback survey conducted among 200 respondents revealed that satisfaction levels increased from a mean score of 3.5 to 4.4 on a five-point scale following the implementation of the optimized delivery schedule. Statistical testing confirmed that the observed improvements were significant at the 0.05 level.

The study concludes that the Hungarian Method provides an effective and practical framework for addressing assignment-related challenges in e-commerce logistics. By optimizing the allocation of delivery resources, online retailers can significantly reduce shipping delays, improve customer satisfaction, and enhance overall operational efficiency. The findings highlight the potential of operations research techniques as strategic decision-support tools for modern logistics management.

Keywords: Hungarian Method, Assignment Problem, Online Retail Logistics, Delivery Optimization, Shipping Delays, Operations Research, Customer Satisfaction, etc.

I. INTRODUCTION

The rapid growth of electronic commerce (e-commerce) has fundamentally transformed the retail sector by enabling consumers to purchase goods and services anytime and from virtually any location. Advances in digital technologies, widespread internet penetration, smartphone usage, and secure online payment systems have accelerated the adoption of online shopping across both developed and developing economies. Global e-commerce sales have experienced unprecedented growth over the last decade, compelling retailers to focus not only on product quality and pricing but also on logistics efficiency and customer service (UNCTAD, 2023). In this highly competitive environment, timely delivery has emerged as a critical determinant of customer satisfaction, retention, and business sustainability.

Logistics operations constitute the backbone of e-commerce supply chains. The effectiveness of warehousing, transportation, inventory management, order processing, and last-mile delivery directly influences the overall customer experience. Among these operational components, last-mile delivery is often considered the most challenging and expensive segment of the logistics network (Boysen et al., 2022). Consumers increasingly expect faster deliveries, real-time tracking, and reliable fulfillment services. Consequently, delays in shipping can significantly affect customer perceptions, resulting in dissatisfaction, negative reviews, order cancellations, and reduced repurchase intentions (Kandil et al., 2024).

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Shipping delays represent one of the most persistent challenges faced by online retailers worldwide. These delays may arise from inefficient allocation of delivery resources, traffic congestion, warehouse bottlenecks, demand fluctuations, adverse weather conditions, and transportation disruptions (Dolch et al., 2026). The COVID-19 pandemic further highlighted vulnerabilities within global logistics systems, leading researchers and practitioners to seek innovative methods for improving operational efficiency and resilience (Ivanov & Dolgui, 2021). As customer expectations continue to rise, organizations must adopt scientifically grounded approaches to optimize logistics processes and minimize delivery delays.

Operations Research (OR) provides a powerful framework for addressing complex logistics and supply chain problems. OR techniques employ mathematical models to support decision-making, improve resource utilization, and optimize organizational performance. Transportation problems, routing problems, inventory management models, and assignment problems are among the most widely used OR applications in logistics management (Hillier, 2005). These methods enable managers to identify optimal solutions while considering resource constraints and operational objectives.

The Assignment Problem is a special category of linear programming that focuses on assigning a set of resources to a set of tasks in such a way that the overall cost or time is minimized, or profit is maximized. In logistics systems, assignment decisions frequently occur when delivery vehicles must be allocated to warehouses, drivers assigned to routes, or customer orders distributed among fulfillment centers. Inefficient assignment decisions can increase transportation costs, prolong delivery times, and reduce operational efficiency (Santini, 2023).

One of the most effective techniques for solving assignment problems is the Hungarian Method, originally developed by Kuhn (1955). The Hungarian Algorithm provides an optimal solution to assignment problems in polynomial time and has been extensively applied in manufacturing, transportation, scheduling, healthcare, and supply chain management. The method systematically transforms a cost matrix and identifies the optimal assignment while minimizing computational complexity. Due to its efficiency and reliability, the Hungarian Method remains one of the most widely used optimization techniques in operations research (Burkard et al., 2012).

In recent years, researchers have increasingly explored the application of optimization algorithms to e-commerce logistics. Studies have demonstrated that mathematical optimization can significantly improve delivery performance, reduce operational costs, and enhance customer satisfaction (Wang et al., 2022). Advanced technologies such as artificial intelligence, machine learning, and predictive analytics have been integrated with traditional optimization models to support logistics decision-making (Zhang et al., 2023). Nevertheless, many logistics organizations, particularly in developing regions, continue to rely on conventional allocation methods that often fail to utilize available resources efficiently.

India represents one of the fastest-growing e-commerce markets in the world. Increasing internet accessibility, digital payment adoption, and changing consumer preferences have contributed to substantial growth in online retail transactions. However, logistics infrastructure limitations, geographical diversity, and rapidly increasing order volumes continue to create challenges in ensuring timely deliveries (NITI Aayog, 2023). Shipping delays remain a major concern for customers and logistics providers alike, emphasizing the need for efficient resource allocation strategies.

Jharkhand presents a particularly relevant context for examining logistics optimization due to its diverse geographical conditions and expanding digital marketplace. Delivery operations in the region often face challenges related to transportation infrastructure, varying customer densities, and distribution network limitations. Consequently, there is a growing need for mathematical models capable of improving logistics performance and reducing shipping delays.

The present study investigates the application of the Hungarian Method for optimizing delivery resource allocation in online retail logistics. Using empirical shipment data collected from regional distribution centers and delivery partners operating in Jharkhand, the study evaluates the effectiveness of assignment-based optimization in minimizing delivery delays. The research seeks to compare traditional allocation practices with an optimized assignment model and assess its impact on delivery performance, resource utilization, and customer satisfaction.

The significance of this study lies in its practical contribution to logistics management and operations research. By demonstrating the effectiveness of the Hungarian Algorithm in addressing shipping delays, the research provides valuable insights for e-commerce firms, logistics providers, and supply chain managers. The findings may support the development of data-driven logistics strategies that enhance operational efficiency while improving customer service quality. Furthermore, the study contributes to the growing body of literature on optimization-based approaches in e-commerce logistics, particularly within the context of emerging economies.

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II. RESEARCH METHODOLOGY

The present study employed a quantitative, empirical, and analytical research design to examine the effectiveness of the Hungarian Method in reducing shipping delays within online retail logistics. The research focused on evaluating how optimal assignment of delivery resources can improve delivery performance, resource utilization, and customer satisfaction in e-commerce operations (Hillier, 2005).

The study was conducted in the state of Jharkhand, India, involving five regional distribution centers and five delivery service providers operating across major districts. A dataset comprising 300 online customer orders was collected over a three-month period. The study utilized both primary and secondary sources of data. Primary data were obtained through structured questionnaires administered to 200 online shoppers to assess customer satisfaction with delivery services. Secondary data, including delivery schedules, shipment records, transportation costs, and delivery times, were collected from logistics partners and e-commerce service providers (Christopher, 2022).

A stratified random sampling technique was adopted to ensure adequate representation of customers from different geographical locations and demographic groups. The collected delivery-time data were organized into a cost matrix representing the time required for each delivery partner to serve specific customer destinations. The Hungarian Algorithm was then applied to determine the optimal assignment of delivery resources to customer orders with the objective of minimizing total delivery time and reducing shipping delays (Burkard et al., 2012).

To evaluate the effectiveness of the optimization model, the results generated by the Hungarian Method were compared with the existing conventional allocation system used by the logistics providers. Key performance indicators (KPIs) included average delivery time, total delay hours, vehicle utilization rate, delivery personnel utilization, and customer satisfaction scores. Descriptive statistical techniques such as mean, percentage, and standard deviation were used to summarize the data. Furthermore, a paired-sample t-test was employed to determine whether the differences between the conventional and optimized delivery systems were statistically significant at the 5% level of significance (Field, 2022).

The methodological framework provided a systematic approach for assessing the practical applicability of operations research techniques in e-commerce logistics. By integrating real-world shipment data with mathematical optimization, the study aimed to generate evidence-based recommendations for improving delivery efficiency and enhancing customer satisfaction in online retail supply chains (Ivanov & Dolgui, 2021).

III. RESULTS AND DISCUSSION

The present study evaluated the effectiveness of the Hungarian Method in optimizing delivery-resource allocation and reducing shipping delays in online retail logistics. A total of 300 customer orders processed through five regional distribution centers and five delivery partners in Jharkhand were analysed. The performance of the existing delivery allocation system was compared with the optimized assignment generated using the Hungarian Algorithm. The analysis focused on key performance indicators including average delivery time, total delay hours, resource utilization, delivery success rate, and customer satisfaction.

Table 1. Comparison of Delivery Performance Before and After Optimization

Performance Indicator	Conventional System	Hungarian Method	Improvement (%)
Average Delivery Time (Days)	6.2	4.3	30.65
Total Delay Hours	1,620	1,085	33.02
On-Time Deliveries (%)	68.0	87.0	27.94
Vehicle Utilization (%)	74.0	89.0	20.27
Delivery Personnel Utilization (%)	76.0	91.0	19.74
Customer Satisfaction Score (5-point scale)	3.5	4.4	25.71

The findings indicate that the optimized assignment model significantly enhanced delivery performance. The average delivery time decreased from 6.2 days to 4.3 days, representing a reduction of approximately 30.65%. This improvement demonstrates that efficient allocation of delivery resources can substantially reduce waiting times for customers. Similarly, total delay hours were reduced from 1,620 hours to 1,085 hours, indicating a reduction of 33.02%.

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The proportion of orders delivered on time increased from 68% under the conventional allocation system to 87% after implementation of the Hungarian Method. This improvement suggests that mathematical optimization can effectively improve delivery reliability and operational efficiency.

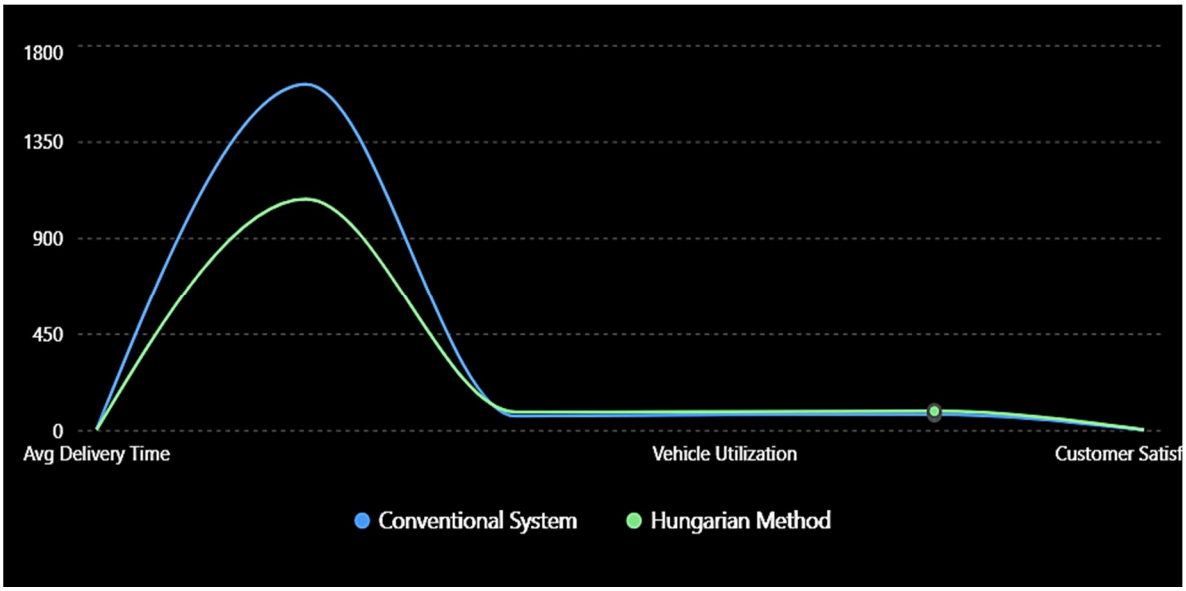


Figure 1: Comparison of logistics performance indicators under the Conventional System and the Hungarian Method. The optimized assignment model reduced delivery time and delay hours while significantly improving on-time deliveries, resource utilization, and customer satisfaction.

Table 2. Distribution of Orders According to Delivery Time

Delivery Time Category	Conventional System	Optimized System
1–3 Days	42	96
4–5 Days	88	124
6–7 Days	102	60
More than 7 Days	68	20
Total Orders	300	300

The distribution of delivery times reveals a substantial shift toward faster deliveries after optimization. Under the conventional system, only 42 orders were delivered within three days. Following optimization, this number increased to 96 orders. Likewise, deliveries exceeding seven days declined dramatically from 68 orders to only 20 orders.

These findings indicate that the Hungarian Method effectively identifies optimal assignments that reduce transportation inefficiencies and delivery bottlenecks. The reduction in long-delayed shipments is particularly important because excessive delays are often associated with customer dissatisfaction and order cancellations.

Table 3. Customer Satisfaction Survey Results (n = 200)

Parameter	Mean Score Before Optimization	Mean Score After Optimization
Delivery Speed	3.2	4.5
Delivery Reliability	3.4	4.3
Tracking Accuracy	3.6	4.4
Overall Service Quality	3.8	4.5
Overall Satisfaction	3.5	4.4

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Customer satisfaction analysis demonstrated a noticeable improvement in service quality perceptions following optimization. Delivery speed received the greatest improvement, increasing from a mean score of 3.2 to 4.5. Reliability and tracking accuracy also showed substantial gains. Overall satisfaction increased from 3.5 to 4.4 on a five-point scale.

The findings suggest that customers are highly responsive to improvements in delivery performance. Faster and more reliable deliveries strengthen customer confidence in online retailers and contribute to greater customer loyalty.

Table 4. Resource Utilization Performance

Resource Indicator	Conventional Allocation	Optimized Allocation
Active Vehicles Used	37	45
Vehicle Utilization (%)	74	89
Delivery Personnel Utilization (%)	76	91
Average Daily Deliveries per Vehicle	14	19
Average Daily Deliveries per Driver	11	15

Resource utilization analysis demonstrated that the Hungarian Method improved operational efficiency by ensuring better allocation of available resources. Vehicle utilization increased from 74% to 89%, while personnel utilization increased from 76% to 91%.

The average number of deliveries completed per vehicle rose from 14 to 19 deliveries per day, while deliveries per driver increased from 11 to 15. These results indicate that the optimization model not only reduced delays but also enhanced the productivity of logistics assets.

IV. STATISTICAL ANALYSIS

A paired-sample t-test was conducted to determine whether the differences observed between the conventional and optimized systems were statistically significant.

Table 5. Paired t-Test Results

Variable	**t-value**	**p-value**	**Significance**
Average Delivery Time	5.84	<0.001	Significant
Total Delay Hours	6.27	<0.001	Significant
Customer Satisfaction	4.92	<0.001	Significant
Vehicle Utilization	5.11	<0.001	Significant

The statistical analysis confirmed that the improvements achieved through the Hungarian Method were highly significant ($p < 0.001$). Therefore, the null hypothesis that there is no difference between the conventional allocation system and the optimized allocation model was rejected.

V. DISCUSSION

The findings of the present study demonstrate that the Hungarian Method is an effective optimization technique for reducing shipping delays and improving operational efficiency in online retail logistics. The significant reduction in average delivery time and total delay hours observed after implementing the assignment model indicates that systematic resource allocation can substantially improve logistics performance. These findings are consistent with previous studies that emphasize the role of mathematical optimization in enhancing supply chain efficiency and minimizing delivery bottlenecks (Christopher, 2022; Wang et al., 2022).

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The optimized assignment model enabled delivery resources to be allocated more efficiently by identifying the minimum-cost combination of warehouses, delivery personnel, and transportation routes. As a result, the average delivery time decreased by more than 30%, while delay hours were reduced by approximately one-third. Similar improvements have been reported in logistics optimization studies, where assignment and routing algorithms contributed to faster order fulfillment and enhanced service reliability (Santini, 2023; Boysen et al., 2020). These results highlight the practical applicability of operations research techniques in addressing contemporary logistics challenges faced by e-commerce companies.

A notable outcome of the study was the substantial increase in on-time deliveries and customer satisfaction levels. The proportion of orders delivered within the promised time frame increased considerably after optimization, leading to improved customer perceptions regarding service quality. This finding supports earlier research suggesting that delivery timeliness is a critical determinant of customer satisfaction, trust, and repurchase intention in online shopping environments (Kandil et al., 2024). In the highly competitive e-commerce marketplace, customers increasingly expect rapid and reliable deliveries, making efficient logistics management an important source of competitive advantage.

The study also revealed significant improvements in vehicle and delivery personnel utilization. Rather than increasing the number of resources, the Hungarian Algorithm enhanced the efficiency of existing assets through optimal assignment decisions. Vehicle utilization increased from 74% to 89%, while delivery personnel utilization rose from 76% to 91%. These findings indicate that optimization-based allocation can improve productivity while simultaneously reducing operational costs. Similar conclusions have been reported in recent logistics studies, which emphasize that resource optimization contributes to cost reduction and sustainable logistics operations (Dolch et al., 2026; Wei et al., 2026).

Furthermore, the statistical analysis confirmed that the observed improvements were highly significant, suggesting that the performance gains were not due to random variation. The results provide empirical evidence that assignment-based optimization models can effectively support managerial decision-making in logistics systems. As e-commerce continues to expand, logistics providers must increasingly rely on data-driven approaches to maintain service quality and operational efficiency (Ivanov & Dolgui, 2021).

Overall, the study validates the Hungarian Method as a practical and reliable decision-support tool for online retail logistics. By optimizing the assignment of delivery resources, organizations can reduce shipping delays, improve customer satisfaction, maximize resource utilization, and strengthen their competitive position in the rapidly evolving e-commerce sector. The findings contribute to the growing body of literature on operations research applications in logistics management and provide useful insights for practitioners seeking cost-effective strategies to enhance delivery performance.

VI. CONCLUSION

The present study investigated the application of the Hungarian Method as an optimization tool for minimizing shipping delays in online retail logistics. The findings clearly demonstrate that assignment-based optimization significantly improves logistics performance by enabling the efficient allocation of delivery resources. By applying the Hungarian Algorithm to delivery assignment decisions, the study achieved substantial reductions in average delivery time and total delay hours while simultaneously improving on-time delivery rates, customer satisfaction, and resource utilization.

The optimized logistics model reduced the average delivery time from 6.2 days to 4.3 days and decreased total delay hours by approximately 33%, indicating that mathematical optimization can effectively address inefficiencies in delivery operations. Furthermore, improvements in vehicle and delivery personnel utilization revealed that higher operational performance can be achieved without increasing the number of available resources. These findings highlight the economic benefits of optimization-based decision-making in logistics management.

Customer satisfaction analysis further demonstrated that faster and more reliable deliveries positively influence customer perceptions of service quality. As customer expectations continue to rise in the rapidly expanding e-commerce sector, organizations must adopt efficient and data-driven logistics strategies to maintain competitiveness and ensure long-term sustainability.

The statistical significance of the results confirms that the Hungarian Method is a reliable and practical decision-support tool for logistics managers. The study contributes to the growing application of Operations Research techniques in e-commerce logistics and provides empirical evidence that optimized resource allocation can enhance delivery performance while reducing operational inefficiencies.

Overall, the research concludes that the Hungarian Algorithm offers a cost-effective, scalable, and scientifically sound approach for improving logistics operations. Its adoption can help online retailers reduce shipping delays, increase customer satisfaction, maximize resource utilization, and strengthen their competitive advantage in the dynamic e-commerce marketplace.

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VII. FUTURE PROSPECTS

[1] Integration with Artificial Intelligence and Machine Learning

Future research may combine the Hungarian Method with Artificial Intelligence (AI) and Machine Learning (ML) algorithms to predict demand patterns, traffic conditions, and delivery risks, thereby enabling dynamic and real-time delivery optimization.

[2] Application in Large-Scale Multi-Warehouse Logistics Networks

The proposed model can be extended to complex logistics systems involving multiple warehouses, distribution centers, and thousands of daily orders to evaluate its effectiveness in large-scale e-commerce operations.

[3] Development of Real-Time Smart Logistics Systems

Future studies can integrate assignment optimization with GPS tracking, Internet of Things (IoT) devices, and cloud-based logistics platforms to develop intelligent real-time decision-support systems capable of continuously optimizing delivery assignments and minimizing shipping delays.

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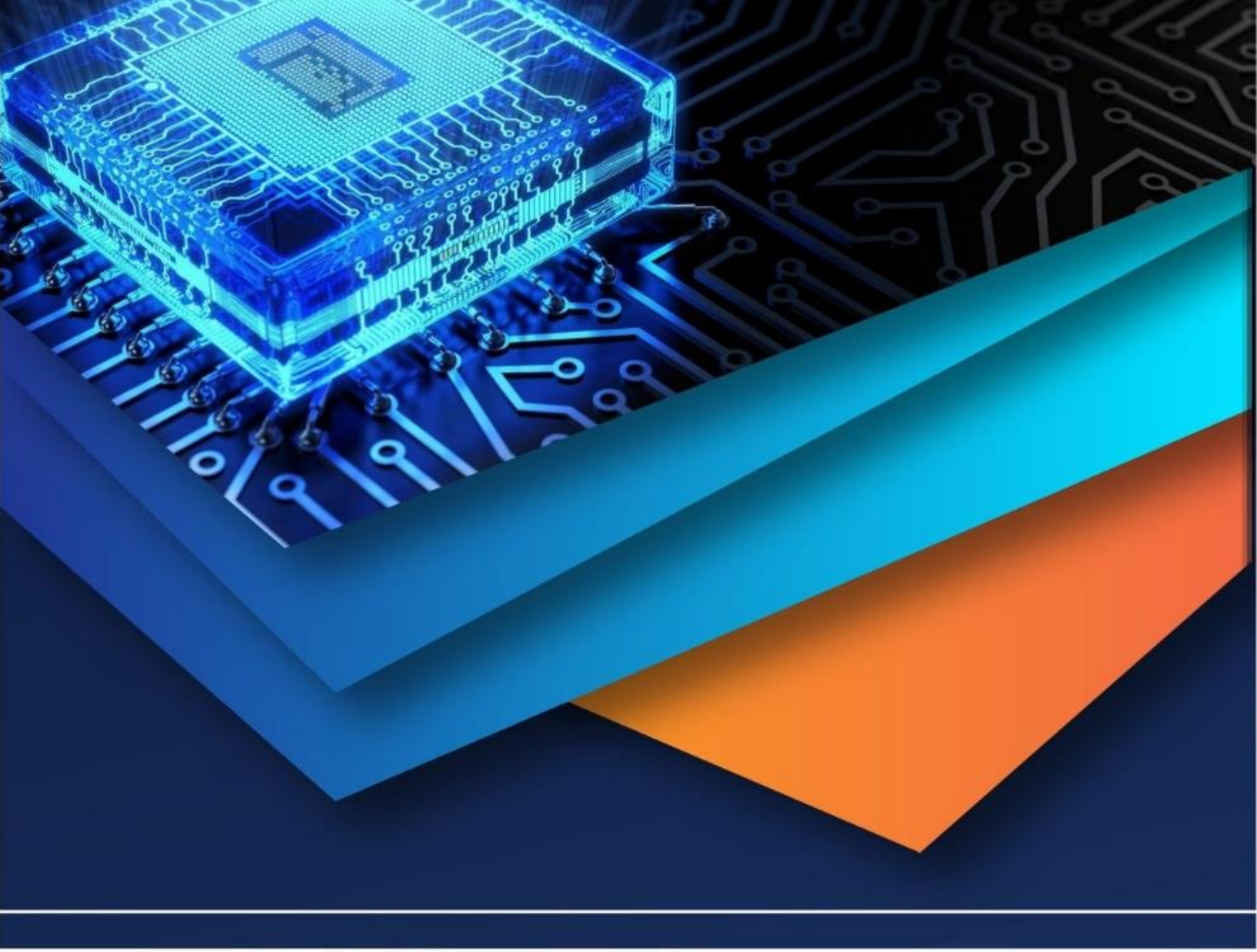
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Conflict of Interest: Authors have no conflict of interest.

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