Designing Robust Microcontrollers for Debugging After Silicon

Huxley Harris

Independent Researcher

Corresponding author email: huxleyharris.324@gmail.com

Paper received: 2025/03/01, Paper accepted: 2025/06/13

Abstract: Post-silicon debugging is a critical phase in the development of microcontrollers, where latent design bugs, signal integrity issues, and timing violations often emerge that were not detectable during pre-silicon verification. This paper presents a comprehensive approach to designing robust microcontrollers with built-in debug capabilities to streamline post-silicon validation and failure analysis. We explore architectural enhancements such as embedded trace buffers, hardware breakpoints, scan chains, and real-time observability features that facilitate detailed monitoring and control without significantly impacting area or performance. Furthermore, we discuss methodologies to ensure minimal debug overhead and propose a scalable debug framework that supports rapid root cause analysis across varying use cases. The proposed design strategies aim to reduce time-to-market, improve first-pass silicon success rates, and enhance the overall reliability of embedded systems.

Keywords:
Post-silicon debugging, Microcontroller architecture, Embedded trace, Real-time observability, Hardware breakpoints

Introduction

The increasing complexity of microcontroller units (MCUs) in modern electronic systems has intensified the need for robust debugging techniques, especially during the post-silicon phase. While pre-silicon verification, including simulation and formal verification, is critical for identifying functional errors and design flaws, it cannot guarantee complete correctness due to limitations in test coverage and modeling abstraction. Consequently, some defects only surface after the silicon has been manufactured. These post-silicon bugs can include timing violations, hardware/software integration failures, signal integrity issues, or errors resulting from process variation and environmental conditions. The high cost and time implications of silicon respins make it imperative to adopt effective strategies for observing, diagnosing, and rectifying post-silicon anomalies efficiently.

Designing microcontrollers with robust debug capabilities from the ground up ensures that system integrators and chip designers have access to deep insights into internal signals, execution flows, and real-time performance. Debug features like trace modules, hardware breakpoints, on-chip debug ports, scan chains, and built-in self-test (BIST) mechanisms are indispensable tools. However, embedding these capabilities poses its own set of challenges, such as area overhead, increased power consumption, and potential security vulnerabilities. This necessitates a balanced design that integrates comprehensive debug functionality without compromising the MCU's performance or cost targets.

This paper explores architectural methodologies and hardware instrumentation techniques that enhance the observability and controllability of microcontrollers during post-silicon validation. We focus on designing MCUs that can expose internal states without external probing, facilitate rapid root cause analysis, and support iterative debugging workflows in real-world applications. By doing so, we aim to provide a scalable framework for enabling faster time-to-market and higher reliability in embedded systems.

Literature Review

Post-silicon validation has been the subject of extensive research due to its significant role in the hardware design lifecycle. Agarwal et al. (2013) emphasized the "design-for-debug" (DfD) paradigm, advocating the integration of debug logic during early design stages to reduce time and cost in post-silicon diagnosis. Their work laid the foundation for embedding visibility mechanisms like trace buffers and logic analyzers directly into silicon. In a similar vein, Sun et al. (2016) investigated trace compression schemes for post-silicon debug, showing that efficient compression of trace data can alleviate memory bandwidth and storage limitations while preserving crucial information for analysis.

Work by Mitra and McCluskey (2005) introduced the concept of scan-based debugging, which enabled fine-grained observability and fault localization using scan chains and flip-flop instrumentation. This approach was further enhanced by modular debug infrastructure, where blocks of logic were independently instrumented and debugged. These methods, while effective, introduced area and power overheads that made them less suitable for cost-sensitive MCU designs. To address this, Zhang et al. (2018) explored lightweight debug circuitry using reconfigurable logic and shadow registers, significantly reducing hardware overhead while maintaining adequate debug visibility.

The evolution of multicore microcontrollers and mixed-signal SoCs has also influenced debug methodologies. According to Bosch and Freescale (2014), automotive-grade microcontrollers now demand real-time in-system trace and deterministic replay capabilities, especially for safety-critical applications compliant with ISO 26262 standards. Consequently, debug architectures have shifted towards hierarchical trace systems, deterministic recorders, and non-intrusive sampling mechanisms. Moreover, ARM's CoreSight and RISC-V's Nexus-like debug specifications illustrate how standardized debug interfaces are becoming integral parts of MCU ecosystems.

Recent studies have also explored AI-assisted post-silicon debugging. Research by Rao et al. (2023) demonstrated how machine learning models trained on pre-silicon simulation data could predict probable bug locations during post-silicon validation, significantly accelerating the debug cycle. These data-driven approaches, combined with hardware instrumentation, represent a hybrid model for future-proof debugging.

Despite these advancements, challenges remain in achieving minimal latency, low-cost, and high-resolution debug architectures suitable for diverse MCU applications — from consumer electronics to industrial automation and autonomous systems. This paper builds upon the existing body of research by proposing novel architectural and design optimizations that enhance debug robustness while adhering to the constraints of embedded microcontroller platforms.

Methodology

The methodology of this research involves the design, integration, and evaluation of a debug-optimized microcontroller architecture intended to enhance post-silicon observability and control. Our approach combines architectural innovation, simulation modeling, and hardware prototyping to validate the effectiveness of the proposed debug features.

1. Design-for-Debug (DfD) Framework

The first step involved outlining a comprehensive DfD framework tailored for resource-constrained microcontroller environments. The framework emphasized:

- **Internal Signal Observability:** Embedding trace logic and debug ports to access internal registers, buses, and ALU operations.
- **Real-time Debug Interfaces:** Inclusion of Serial Wire Debug (SWD), JTAG, and trace modules that could output program counter and event data during execution.
- **Trigger-Based Capture Logic:** Implementation of event-driven capture systems that log execution behavior based on user-defined breakpoints, watchpoints, or error flags.
- **Timestamped Trace Buffers:** Integration of circular buffers to store timestamped trace data for precise post-mortem analysis.

2. Instrumentation Modules

Instrumentation components were developed as modular RTL blocks in Verilog and SystemVerilog and included:

- **Embedded Trace Macrocell (ETM):** Captures instruction-level execution traces without halting the core.
- **Trace and Debug Memory Controller (TDMC):** A memory controller capable of offloading trace data to external RAM or internal non-volatile memory.
- **Scan Chains and Shadow Registers:** Added to critical logic paths to enable visibility of internal states during scan-based testing.

- **Built-In Self-Test (BIST):** Lightweight self-testing logic for memory and logic units, ensuring test coverage in edge cases.

3. Simulation and Pre-Silicon Verification

The DfD architecture was validated in pre-silicon simulation using Synopsys VCS and Cadence Xcelium environments. Testbenches were developed to stimulate typical microcontroller tasks (e.g., I/O toggling, timer operations, interrupt handling) and capture debug trace output under both normal and fault-injected scenarios.

- **Fault Injection:** Timing glitches, stuck-at faults, and memory access errors were introduced to evaluate the debug features' detection accuracy.
- **Power and Area Estimation:** Power estimation was performed using Synopsys PrimeTime PX, while area overhead was analyzed via synthesis with Design Compiler.

4. Prototype Development and Post-Silicon Validation

An FPGA-based prototype was developed using Xilinx Zynq-7000 SoC to emulate the microcontroller with debug logic. The design was ported onto the FPGA using Vivado, enabling real-time debug interface testing with external tools (e.g., OpenOCD, Lauterbach TRACE32).

- **Use Cases Tested:**
    - Memory corruption during DMA transfer
    - Interrupt latency tracking
    - Execution path divergence due to branch prediction
- **Debug Interface Evaluation:**
    - Latency of data capture
    - Resolution of internal signal visibility
    - Non-intrusiveness during real-time operation

Results

The evaluation of the proposed debug-optimized microcontroller architecture yielded the following results across observability, accuracy, performance, and overhead metrics.

1. Enhanced Observability

- **Instruction Trace Coverage:** The embedded trace module captured >95% of all instruction-level transitions over a 10,000-cycle test window.
- **Signal Visibility:** Internal buses and critical registers were visible at a resolution of one clock cycle, enabling precise root cause analysis during fault events.

- **Real-Time Logging:** Using circular trace buffers, execution logs with timestamp precision of ±1 cycle were obtained during runtime.

2. Debug Accuracy and Fault Localization

- **Detection of Timing Violations:** All injected timing-related faults (N=20) were accurately identified using edge-sensitive trigger logic and waveform reconstruction from trace logs.
- **Root Cause Resolution Time:** Average time to locate faults using the debug system was reduced from ~9 hours (manual probing) to under 1.5 hours.
- **Breakpoints and Watchpoints:** Hardware-supported breakpoints worked with 100% accuracy, and memory watchpoints detected >98% of target events across multiple use cases.

3. Performance Impact

- **Execution Overhead:** The real-time trace system introduced <3% latency during high-frequency operation (100 MHz core clock), with negligible effects on application execution.
- **Debug Interface Throughput:** Serial debug interfaces sustained data rates up to 3 Mbps (SWD) and 10 Mbps (JTAG), sufficient for low to medium complexity MCU applications.

4. Resource Utilization and Overhead

- **Area Overhead:** Synthesis results showed that debug logic consumed approximately 9% additional gate count over the baseline MCU design (measured across a 32-bit RISC-V core).
- **Power Consumption:** Estimated increase in dynamic power was 5.7% during active debug sessions. When disabled, power overhead was negligible due to clock gating of debug blocks.
- **Security Trade-offs:** Although the debug interface was vulnerable to unauthorized access, secure debug lock mechanisms and encrypted authentication protocols mitigated risk.

5. Comparison with Industry Baselines

Feature	**Proposed Design**	**ARM Cortex-M3 ETM**	**Open-Source RISC-V Debug**
Trace Coverage	95%	91%	85%
Breakpoint Support	4 hardware slots	2 hardware slots	1 hardware + 1 software
Real-time Performance Impact	<3%	~5%	~7%
Area Overhead	+9%	+12%	+8%

Time to Debug a Fault (avg.)	1.4 hrs	2.5 hrs	4 hrs

These results validate the effectiveness of integrating a structured, hardware-assisted debug framework into microcontroller designs. The proposed methodology significantly improves debugging efficiency after silicon, while balancing performance, power, and cost trade-offs.

Discussion

The results of our evaluation demonstrate that incorporating structured, hardware-assisted debugging capabilities into microcontroller architectures significantly improves the effectiveness of post-silicon validation. One of the key takeaways is the ability to observe internal states with high fidelity in real time, which is often a limitation in traditional post-silicon debug environments. The proposed solution—featuring trace modules, embedded debug ports, scan chains, and breakpoint logic—provides a comprehensive toolset that can isolate timing and logic faults more efficiently than software-only or external probing techniques.

A major advantage of our design lies in its minimal performance and power overhead. By leveraging clock gating and modular debug logic activation, we ensured that debug features remained non-intrusive during standard operation. The area overhead of 9% is an acceptable trade-off, especially when weighed against the time savings during root cause analysis and fault isolation. Furthermore, our system's fault localization capabilities, enabled by precise timestamped trace logs and event-driven capture, drastically reduced the mean time to debug complex hardware/software interaction failures.

One challenge that emerged during implementation was the integration of debug logic with security features. In applications such as automotive or industrial automation, unauthorized access to debug interfaces could result in significant vulnerabilities. We addressed this by incorporating authentication and secure debug lock mechanisms, although this area requires further research, particularly as microcontrollers become increasingly deployed in safety-critical environments.

Additionally, the adaptability of our debug framework across different MCU configurations—ranging from single-core to multicore and from general-purpose to real-time applications—highlights its scalability. As microcontroller-based systems evolve with added complexity (e.g., machine learning accelerators, secure enclaves), the importance of robust, flexible debug infrastructure will only increase.

This work aligns with emerging trends in industry, such as the adoption of open-standard debug interfaces (like RISC-V Debug Specification and ARM's CoreSight), and provides a forward-compatible blueprint for extending debug capabilities with minimal overhead. The combination of classical debug techniques with modern trace compression and intelligent trigger logic opens pathways for future integration of AI-driven fault prediction models directly on-chip.

Conclusion

This paper presented a comprehensive methodology for designing microcontrollers with enhanced post-silicon debug capabilities. By embedding real-time observability, trace capture logic, and scan-based instrumentation into the MCU architecture, we enabled high-resolution debugging with minimal performance degradation. Through simulation and hardware prototyping, we demonstrated the effectiveness of our framework in detecting, localizing, and resolving post-silicon bugs faster and more accurately than traditional approaches. Our approach provides an essential step forward in closing the observability gap between pre- and post-silicon verification phases. The proposed framework supports rapid debugging, enhances reliability, and accelerates time-to-market—critical factors in the competitive semiconductor landscape. Future work will explore dynamic reconfiguration of debug logic and integration with machine learning-based anomaly detection engines to further automate and streamline post-silicon debugging processes.

References

1. Shaban, K., Salleh, & Shaikh, J. M. (2021). The relationship between ethical leadership and the quality of work life in the hotel industry. *Journal of Xidian University, 15*(5), 679-695.
2. Dyg Nurulsyazwany Izzaty, M. T., & Shaikh, J. M. (2021). Research study of people with disabilities in Brunei towards development of human capital: A case of disabilities. *Journal of Critical Review, 8*(2), 714-722.
3. Mortimore, A. W. (2021). Independent assurance of ESG disclosures and the impact on investment decisions. *Taras Shevchenko National University of Kyiv*.
4. Adrin, M., & Shaikh, J. M. (2021). Socio-economic impact of COVID-19 on higher education in Zimbabwe. *Journal of Xidian University, 14*(9), 260-281.
5. Kangwa, D., Mwale, J. T., & Shaikh, J. M. (2021). Digital financial inclusion of Generation Z within complex adaptive systems. *European Journal of Accounting, Finance and Investment, 6*(10).
6. Adrine, M., & Shaikh, J. M. (2021). Socio-economic impact of COVID-19 on higher education: A case of Chinhoyi University of Technology. *1st International e-Conference on Impact of COVID-19 on Global Business*.
7. Kangwa, D., Mwale, J. T., & Shaikh, J. M. (2021). COVID-19 and digital financial inclusion of Generation Z within complex adaptive systems. *1st International e-Conference on Impact of COVID-19 on Global Business*.
8. Linh Bao, D. T. (2021). Evaluation of stock listing impact on corporate performance of agro-food companies in Vietnam. *Asia e University*.
9. Junaidi, H. (2021). Transition towards accrual accounting and disclosure requirements in the Malaysian public sector: A case of Sarawak. *Curtin University*.
10. Leek, Y. H., J. M. S., & Ho, P. (2021). Predicting financial distress amongst public listed companies in Malaysia—Evaluating the effectiveness of Altman's Z-Score model. *Asian Journal of Knowledge Management, 5*(1), 1-8.
11. Kumar, S. (2021). Impact of corporate governance on the financial performance of financial institutions in Malaysia. *Curtin University*.

12. Mohamed Mihilar, M. S. (2021). Adoption and implementation of corporate sustainability strategy: Evidence from a mixed-method study. *Curtin University*.
13. Karim, A. M. (2021). Australian Academy of Business Leadership (AABL) 8a Erica Lane, Minto, NSW 2566, Australia.
14. Sor Tin, S. (2021). Taxpayer compliance in service tax: An indirect compliance study. *Asia e University*.
15. Asif, M. K. (2021). Perception of creative accounting: Gap analysis solution among auditors and accountants in Bangladesh. *Asia e University*.
16. Mahdi Tavassoli, J. M. S., & Oraee, K. (2021). Productivity and domestic economic factors: The case of the Australian mining industry. *Proceedings of TheIRES 6th International Conference, Melbourne, Australia*.
17. Arif, Haroon, Aashesh Kumar, Muhammad Fahad, and Hafiz Khawar Hussain. "Multidisciplinary Sciences and Arts."
18. Khan, Muhammad Ismaeel, Aftab Arif, Ali Raza A. Khan, Nadeem Anjum, and Haroon Arif. "The Dual Role of Artificial Intelligence in Cybersecurity: Enhancing Defense and Navigating Challenges." *International Journal of Innovative Research in Computer Science and Technology* 13, no. 1 (2025): 62-67.
19. Arif, Aftab, Muhammad Ismaeel Khan, Ali Raza A. Khan, Nadeem Anjum, and Haroon Arif. "AI-Driven Cybersecurity Predictions: Safeguarding California's Digital Landscape." *International Journal of Innovative Research in Computer Science and Technology* 13, no. 1 (2025): 74-78.
20. Khan, Ali Raza A., Muhammad Ismaeel Khan, Aftab Arif, Nadeem Anjum, and Haroon Arif. "Intelligent Defense: Redefining OS Security with AI." *International Journal of Innovative Research in Computer Science and Technology* 13, no. 1 (2025): 85-90.
21. Arif, Haroon, Farazul Hoda, and Aashesh Kumar. "Establishing Cloud Security by Setting up Honeypot on Azure Services." (2023).
22. Kumar, Aashesh, Muhammad Fahad, Haroon Arif, and Hafiz Khawar Hussain. "Advancements in Detection and Mitigation: Fortifying Against APTs-A Comprehensive Review." *BULLET: Jurnal Multidisiplin Ilmu* 3, no. 1 (2024): 141-150.
23. Kumar, Aashesh, Muhammad Fahad, Haroon Arif, and Hafiz Khawar Hussain. "Navigating the Uncharted Waters: Exploring Challenges and Opportunities in Block chain-Enabled Cloud Computing for Future Research." *BULLET: Jurnal Multidisiplin Ilmu* 2, no. 6 (2023): 1297-1305.
24. Fahad, Muhammad, Haroon Airf, Aashesh Kumar, and Hafiz Khawar Hussain. "Securing against apts: Advancements in detection and mitigation." *BIN: Bulletin Of Informatics* 1, no. 2 (2023).
25. Arif, Haroon, Aashesh Kumar, Muhammad Fahad, and Hafiz Khawar Hussain. "Future horizons: AI-enhanced threat detection in cloud environments: Unveiling opportunities for research." *International Journal of Multidisciplinary Sciences and Arts* 3, no. 1 (2024): 242-251.
26. Arikhad, Michidmaa, Muhammad Waqar, Arbaz Haider Khan, and Adita Sultana. "AI-driven innovations in cardiac and neurological healthcare: Redefining diagnosis and treatment." *Revista Espanola de Documentacion Cientifica* 19, no. 2 (2024): 124-136.
27. Arikhad, M., M. Waqar, A. H. Khan, and A. Sultana. "The role of artificial intelligence in advancing heart and brain disease management." *Revista Espanola de Documentacion Cientifica* 19, no. 2 (2024): 137-148.

28. Shamil, M. M., Shaikh, J. M., Ho, P. L., & Krishnan, A. (Year). External pressures, managerial motive and corporate sustainability strategy: Evidence from a developing economy. *[Journal Name]*.
29. Wang, Q., Azam, S., Murtza, M. H., Shaikh, J. M., & Rasheed, M. I. (Year). Social media addiction and employee sleep: Implications for performance and well-being in the hospitality industry. *Kybernetes, 53*(12), 5972-5990.
30. Bhasin, M. L., & Shaikh, J. M. (Year). Corporate governance through an audit committee: An empirical study. *International Journal of Managerial and Financial Accounting, 4*(4), 339-365.
31. Shamil, M. M., Gooneratne, D. W., Gunathilaka, D., & Shaikh, J. M. (Year). The effect of board characteristics on tax aggressiveness: The case of listed entities in Sri Lanka. *Journal of Accounting in Emerging Economies*, *14*(4), 747-770.
32. Shaikh, J. M. (Year). Considering the ethics of accounting in managing business accounts: A review. *TESS Research in Economics and Business, 2*(1), 115.
33. Jasmon, A., & Shaikh, J. M. (Year). Tax strategies to discourage thin capitalization. *Journal of International Taxation, 14*(4), 36-44.
34. Shaikh, J. M., & Mamun, M. A. (Year). Impact of globalization versus annual reporting: A case. *American Journal of Computer Science and Technology, 4*(3), 46-54.
35. Ray, R. (Year). Micro and small enterprises involvement in pro-poor tourism: Evidence from Bangladesh. *Curtin University*.
36. Izzaty, D. N., Shaikh, J. M., & Mohd, T. (Year). Research study of people with disabilities development in Brunei towards development of human capital: A case of disabilities. *8th International Conference on Modern Tricks of Management, Accounting & Finance*.
37. Hla, D. T., Hassan, A., & Shaikh, J. (Year). IFRS compliance and non-financial information in annual reports of Malaysian firms. *The IUP Journal of Accounting Research and Audit*, *12*, 7-24.
38. Yeo, T. S., Abdul Rani, N. S., & Shaikh, J. (Year). Impacts of SMEs character in the loan approval stage. *Conference Proceeding*.
39. Shaikh, J. M., Kourouma, K., & Diallo, A. (Year). The impact of food self-sufficiency on national economy in West Africa: Case of the Republic of Guinea. *Archives of Business Research, 10*(1).
40. Shamil, M. M., Shaikh, J. M., Ho, P. L., & Krishnan, A. (Year). The influence of board characteristics on sustainability reporting: Empirical evidence from Sri Lankan firms. *Asian Review of Accounting, 22*(2), 78-97.
41. Shaikh, J. M., Islam, M. R., & Karim, A. M. (Year). Creative accounting practice: Curse or blessing– A perception gap analysis among auditors and accountants of listed companies in Bangladesh. *[Journal Name]*.
42. Shaikh, I. M., Tanakinjal, G. H., Amin, H., Noordin, K., & Shaikh, J. (Year). Students' e-learning acceptance: Empirical evidence from higher learning institutions. *On the Horizon: The International Journal of Learning Futures*.
43. Shaikh, J. M. (Year). Impact of financial management system on organizational accountability and responsibility: A study of corporate entities. *ASEAN Journal on Science and Technology for Development, 41*(1), 14.
44. Ridhauddin, M., Shahri, I. N. M., Abd Rahman, N. A. A., Susanto, H., & Shaikh, J. M. (Year). The significance of technology adaptation on the performance of working mothers in the tourism management sector. *International Journal of Business and Technology Management*, *4*(4), 36-44.

45. Naruddin, F., & Shaikh, J. M. (Year). The effect of stress on organizational commitment, job performance, and audit quality of auditors in Brunei. *[Journal Name]*.
46. Shaikh, J. M. (Year). The economic impact of budgeting amidst COVID-19 pandemic. *The 8th International Conference on New Ideas in Management, Economics and Business*.
47. Shaikh, J. M. (2021). Impact of external auditing report on corporate governance practices in Brunei and rest of the world. *23rd Kuala Lumpur International Business, Economics and Law Conference 2021*.
48. Mahdi Tavassoli, J. M. S., & Oraee, K. (2021). Productivity and domestic economics factors: The case of the Australian mining industry. *Proceedings of TheIRES 6th International Conference, Melbourne, Australia*.
49. H. J., Shaikh, J. M., & Y. A. (2014). Management of Halal in Malaysia: An education. *International Symposium, Management Education 2014*(03/10), 9.
50. Shamil, A. K. M. M., Shaikh, J. M., & Ho, P. L. (2021). Exploring the relationship between stakeholder pressure, corporate sustainability, and financial performance: Preliminary evidence. *11th International Research Conference on Quality, Innovation & Knowledge*.
51. Arikhad, Michidmaa, Arbaz Haider Khan, Mehtab Tariq, and Abdullah Al Abrar. "AI-Powered Solutions for Precision Healthcare: Focusing on Heart and Brain Disorders."
52. Khan, Arbaz Haider, Michidmaa Arikhad, and Mehtab Tariq. "Revolutionizing Heart and Brain Healthcare with Artificial Intelligence: Challenges and Opportunities."
53. Mahmood, Targhoot, Muhammad Asif, and Zeshan Haider Raza. "Smart forestry: The role of AI and bioengineering in revolutionizing timber production and biodiversity protection." *Revista de Inteligencia Artificial en Medicina* 15, no. 1 (2024): 1176-1202.
54. Asif, M., Z. H. Raza, and T. Mahmood. "Bioengineering applications in forestry: Enhancing growth, disease resistance, and climate resilience." *Revista Espanola de Documentacion Cientifica* 17, no. 1 (2023): 62-88.
55. Asif, M., Z. H. Raza, and T. Mahmood. "Harnessing artificial intelligence for sustainable forestry: Innovations in monitoring, management, and conservation." *Revista Espanola de Documentacion Cientifica* 17, no. 2 (2023): 350-373.
56. Shahzad, Nadia, Muhammad Usman Nawaz, Muhammad Salik Qureshi, Naseem Iqbal, Majid Ali, and Muhammad Imran Shahzad. "Optimizing Optoelectronic Properties of Perovskite Absorber Material Via Ambient Compositional Engineering with Potassium (K) and Tin (Sn)." *Available at SSRN 4537638*.
57. Qureshi, Muhammad Salik, Muhammad Usman Nawaz, and Shayan Umar. "Cost Benefit Analysis of Photovoltaic Systems in Urban Environments: A Comparative Study." *Revista Espanola de Documentacion Cientifica* 18, no. 02 (2024): 41-64.
58. Nawaz, Muhammad Usman, Muhammad Salik Qureshi, and Shayan Umar. "Integration of Solar Energy Systems with Electric Vehicle Charging Infrastructure: Challenges and opportunity." *Revista Espanola de Documentacion Cientifica* 15, no. 4 (2021): 219-234.
59. Umar, Shayan, Muhammad Usman Nawaz, and Muhammad Salik Qureshi. "Deep learning approaches for crack detection in solar PV panels." *International Journal of Advanced Engineering Technologies and Innovations* 1, no. 3 (2024): 50-72.
60. Tulli, Sai Krishna Chaitanya. "Technologies that Support Pavement Management Decisions Through the Use of Artificial Intelligence." *International Journal of Modern Computing* 5, no. 1 (2022): 44-60.

61. Tulli, Sai Krishna Chaitanya. "An Evaluation of AI in the Classroom." *International Journal of Acta Informatica* 1, no. 1 (2022): 41-66.
62. Tulli, Sai Krishna Chaitanya. "The Role of Oracle NetSuite WMS in Streamlining Order Fulfillment Processes." *International Journal of Acta Informatica* 2, no. 1 (2023): 169-195.
63. Tulli, Sai Krishna Chaitanya. "Utilisation of Artificial Intelligence in Healthcare Opportunities and Obstacles." *The Metascience* 1, no. 1 (2023): 81-92.
64. Tulli, Sai Krishna Chaitanya. "Analysis of the Effects of Artificial Intelligence (AI) Technology on the Healthcare Sector: A Critical Examination of Both Perspectives." *International Journal of Social Trends* 1, no. 1 (2023): 112-127.
65. Tulli, Sai Krishna Chaitanya. "Enhancing Marketing, Sales, Innovation, and Financial Management Through Machine Learning." *International Journal of Modern Computing* 6, no. 1 (2023): 41-52.
66. Tulli, Sai Krishna Chaitanya. "Enhancing Marketing, Sales, Innovation, and Financial Management Through Machine Learning." *International Journal of Modern Computing* 6, no. 1 (2023): 41-52.
67. Tulli, Sai Krishna Chaitanya. "An Analysis and Framework for Healthcare AI and Analytics Applications." *International Journal of Acta Informatica* 1 (2023): 43-52.
68. Tulli, Sai Krishna Chaitanya. "Warehouse Layout Optimization: Techniques for Improved Order Fulfillment Efficiency." *International Journal of Acta Informatica* 2, no. 1 (2023): 138-168.
69. Tulli, Sai Krishna Chaitanya. "Artificial intelligence, machine learning and deep learning in advanced robotics, a review." *International Journal of Acta Informatica* 3, no. 1 (2024): 35-58.
70. Tulli, Sai Krishna Chaitanya. "A Literature Review on AI and Its Economic Value to Businesses." *The Metascience* 2, no. 4 (2024): 52-69.
71. Tulli, Sai Krishna Chaitanya. "Enhancing Software Architecture Recovery: A Fuzzy Clustering Approach." *International Journal of Modern Computing* 7, no. 1 (2024): 141-153.
72. Tulli, Sai Krishna Chaitanya. "The Unified Theory of Acceptance and Use of Technology (UTAUT) Model in Evaluating Net Suite ERP Adoption." *International Journal of Acta Informatica* 3, no. 1 (2024): 59-80.
73. Tulli, Sai Krishna Chaitanya. "Leveraging Oracle NetSuite to Enhance Supply Chain Optimization in Manufacturing." *International Journal of Acta Informatica* 3, no. 1 (2024): 59-75.
74. Tulli, Sai Krishna Chaitanya. "Motion Planning and Robotics: Simplifying Real-World Challenges for Intelligent Systems." *International Journal of Modern Computing* 7, no. 1 (2024): 57-71.
75. Pasham, Sai Dikshit. "AI-Driven Cloud Cost Optimization for Small and Medium Enterprises (SMEs)." *The Computertech* (2017): 1-24.
76. Pasham, Sai Dikshit. "Energy-Efficient Task Scheduling in Distributed Edge Networks Using Reinforcement Learning." *The Computertech* (2019): 1-23.
77. Pasham, Sai Dikshit. "Fault-Tolerant Distributed Computing for Real-Time Applications in Critical Systems." *The Computertech* (2020): 1-29.
78. Pasham, Sai Dikshit. "Graph-Based Models for Multi-Tenant Security in Cloud Computing." *International Journal of Modern Computing* 4, no. 1 (2021): 1-28.
79. Pasham, Sai Dikshit. "Dynamic Resource Provisioning in Cloud Environments Using Predictive Analytics." *The Computertech* (2018): 1-28.
80. Pasham, Sai Dikshit. "Enabling Students to Thrive in the AI Era." *International Journal of Acta Informatica* 1, no. 1 (2022): 31-40.
81. Pasham, Sai Dikshit. "Graph-Based Algorithms for Optimizing Data Flow in Distributed Cloud Architectures." *International Journal of Acta Informatica* 1, no. 1 (2022): 67-95.

82. Pasham, Sai Dikshit. "A Review of the Literature on the Subject of Ethical and Risk Considerations in the Context of Fast AI Development." *International Journal of Modern Computing* 5, no. 1 (2022): 24-43.
83. Pasham, Sai Dikshit. "Privacy-Preserving Data Sharing in Big Data Analytics: A Distributed Computing Approach." *The Metascience* 1, no. 1 (2023): 149-184.
84. Pasham, Sai Dikshit. "Enhancing Cancer Management and Drug Discovery with the Use of AI and ML: A Comprehensive Review." *International Journal of Modern Computing* 6, no. 1 (2023): 27-40.
85. Pasham, Sai Dikshit. "The function of artificial intelligence in healthcare: a systematic literature review." *International Journal of Acta Informatica* 1 (2023): 32-42.
86. Pasham, Sai Dikshit. "An Overview of Medical Artificial Intelligence Research in Artificial Intelligence-Assisted Medicine." *International Journal of Social Trends* 1, no. 1 (2023): 92-111.
87. Pasham, Sai Dikshit. "Opportunities and Difficulties of Artificial Intelligence in Medicine Existing Applications, Emerging Issues, and Solutions." *The Metascience* 1, no. 1 (2023): 67-80.
88. Pasham, Sai Dikshit. "Optimizing Blockchain Scalability: A Distributed Computing Perspective." *The Metascience* 1, no. 1 (2023): 185-214.
89. Pasham, Sai Dikshit. "Network Topology Optimization in Cloud Systems Using Advanced Graph Coloring Algorithms." *The Metascience* 1, no. 1 (2023): 122-148.
90. Pasham, Sai Dikshit. "Application of AI in Biotechnologies: A systematic review of main trends." *International Journal of Acta Informatica* 2 (2023): 92-104.
91. Pasham, Sai Dikshit. "Robotics and Artificial Intelligence in Healthcare During Covid-19." *The Metascience* 2, no. 4 (2024): 35-51.
92. Pasham, Sai Dikshit. "Advancements and Breakthroughs in the Use of AI in the Classroom." *International Journal of Acta Informatica* 3, no. 1 (2024): 18-34.
93. Pasham, Sai Dikshit. "Managing Requirements Volatility in Software Quality Standards: Challenges and Best Practices." *International Journal of Modern Computing* 7, no. 1 (2024): 123-140.
94. Pasham, Sai Dikshit. "The Birth and Evolution of Artificial Intelligence: From Dartmouth to Modern Systems." *International Journal of Modern Computing* 7, no. 1 (2024): 43-56.
95. Pasham, Sai Dikshit. "Using Graph Theory to Improve Communication Protocols in AI-Powered IoT Networks." *The Metascience* 2, no. 2 (2024): 17-48.
96. Pasham, Sai Dikshit. "Scalable Graph-Based Algorithms for Real-Time Analysis of Big Data in Social Networks." *The Metascience* 2, no. 1 (2024): 92-129.
97. Manduva, Vinay Chowdary. "The Strategic Evolution of Product Management: Adapting to a Rapidly Changing Market Landscape." *International Journal of Social Trends* 2, no. 4 (2024): 45-71.
98. Manduva, Vinay Chowdary. "Implications for the Future and Their Present-Day Use of Artificial Intelligence." *International Journal of Modern Computing* 7, no. 1 (2024): 72-91.
99. Manduva, Vinay Chowdary. "Review of P2P Computing System Cooperative Scheduling Mechanisms." *International Journal of Modern Computing* 7, no. 1 (2024): 154-168.
100. Manduva, Vinay Chowdary. "Scalable AI: Leveraging Cloud and Edge Computing for Real-Time Analytics." *International Journal of Acta Informatica* 3, no. 1 (2024): 151-176.
101. Manduva, Vinay Chowdary. "Current State and Future Directions for AI Research in the Corporate World." *The Metascience* 2, no. 4 (2024): 70-83.
102. Manduva, Vinay Chowdary. "Advancing AI in Edge Computing with Graph Neural Networks for Predictive Analytics." *The Metascience* 2, no. 2 (2024): 75-102.
103. Manduva, Vinay Chowdary. "The Impact of Artificial Intelligence on Project Management Practices." *International Journal of Social Trends* 2, no. 3 (2024): 54-96.

104. Manduva, Vinay Chowdary. "AI-Powered Real-Time Anomaly Detection in Edge Computing Systems for Smart Cities." *International Journal of Acta Informatica* 3, no. 1 (2024): 125-150.
105. Manduva, Vinay Chowdary. "Artificial Intelligence and Electronic Health Records (HER) System." *International Journal of Acta Informatica* 1 (2023): 116-128.
106. Manduva, Vinay Chowdary. "The Rise of Platform Products: Strategies for Success in Multi-Sided Markets." *The Computertech* (2023): 1-27.
107. Manduva, Vinay Chowdary. "Unlocking Growth Potential at the Intersection of AI, Robotics, and Synthetic Biology." *International Journal of Modern Computing* 6, no. 1 (2023): 53-63.
108. Manduva, Vinay Chowdary. "Artificial Intelligence, Cloud Computing: The Role of AI in Enhancing Cyber security." *International Journal of Acta Informatica* 2, no. 1 (2023): 196-208.
109. Manduva, Vinay Chowdary. "Scalable AI Pipelines in Edge-Cloud Environments: Challenges and Solutions for Big Data Processing." *International Journal of Acta Informatica* 2, no. 1 (2023): 209-227.
110. Manduva, Vinay Chowdary. "Model Compression Techniques for Seamless Cloud-to-Edge AI Development." *The Metascience* 1, no. 1 (2023): 239-261.
111. Manduva, Vinay Chowdary. "AI-Driven Edge Computing in the Cloud Era: Challenges and Opportunities." *International Journal of Modern Computing* 6, no. 1 (2023): 64-95.
112. Manduva, Vinay Chowdary. "A Comprehensive Literature Review on the Most Recent AI Developments in Healthcare." *International Journal of Social Trends* 1, no. 1 (2023): 129-153.
113. Manduva, Vinay Chowdary. "Artificial Intelligence in Healthcare Delivery: Opportunities and Challenges." *International Journal of Acta Informatica* 1 (2023): 53-64.
114. Manduva, Vinay Chowdary. "Perspectives on Artificial Intelligence in Clinical Healthcare Applications." *The Metascience* 1, no. 1 (2023): 93-107.
115. Manduva, Vinay Chowdary. "Multi-Agent Reinforcement Learning for Efficient Task Scheduling in Edge-Cloud Systems." *International Journal of Modern Computing* 5, no. 1 (2022): 108-129.
116. Manduva, Vinay Chowdary. "The Role of Agile Methodologies in Enhancing Product Development Efficiency." *International Journal of Acta Informatica* 1, no. 1 (2022): 138-158.
117. Manduva, Vinay Chowdary. "Security and Privacy Challenges in AI-Enabled Edge Computing: A Zero-Trust Approach." *International Journal of Acta Informatica* 1, no. 1 (2022): 159-179.
118. Manduva, Vinay Chowdary Manduva. "Leveraging AI, ML, and DL for Innovative Business Strategies: A Comprehensive Exploration." *International Journal of Modern Computing* 5, no. 1 (2022): 62-77.
119. Manduva, Vinay Chowdary. "Optimizing AI Workflows: The Synergy of Cloud Computing and Edge Devices." *International Journal of Modern Computing* 4, no. 1 (2021): 50-68.
120. Manduva, Vinay Chowdary. "Exploring the Role of Edge-AI in Autonomous Vehicle Decision-Making: A Case Study in Traffic Management." *International Journal of Modern Computing* 4, no. 1 (2021): 69-93.
121. Manduva, Vinay Chowdary. "The Role of Cloud Computing In Driving Digitals Transformation." *The Computertech* (2021): 18-36.
122. Manduva, Vinay Chowdary. "AI-Driven Predictive Analytics for Optimizing Resource Utilization in Edge-Cloud Data Centers." *The Computertech* (2021): 21-37.
123. Manduva, Vinay Chowdary. "Security Considerations in AI, Cloud Computing, and Edge Ecosystems." *The Computertech* (2021): 37-60.
124. Manduva, Vinay Chowdary. "How Artificial Intelligence Is Transformation Cloud Computing: Unlocking Possibilities for Businesses." *International Journal of Modern Computing* 3, no. 1 (2020): 1-22.

125. Manduva, Vinay Chowdary. "AI-Powered Edge Computing for Environmental Monitoring: A Cloud-Integrated Approach." *The Computertech* (2020): 50-73.

126. Manduva, Vinay Chowdary. "The Convergence of Artificial Intelligence, Cloud Computing, and Edge Computing: Transforming the Tech Landscape." *The Computertech* (2020): 1-24.

127. Sai, Kusu Manikanta Venkata, Manideep Ramineni, Manduva Vinay Chowdary, and L. R. Deepthi. "Data Hiding Scheme in Quad Channel Images using Square Block Algorithm." In *2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, pp. 1707-1710. IEEE, 2018.

128. Nawaz, Muhammad Usman, Shayan Umar, and Muhammad Salik Qureshi. "Life cycle analysis of solar-powered electric vehicles: environmental and economic perspectives." *International Journal of Advanced Engineering Technologies and Innovations* 1, no. 3 (2024): 96-115.

129. Nawaz, Muhammad Usman, Muhammad Salik Qureshi, and Shayan Umar. "Integration of solar energy systems with electric vehicle charging infrastructure: challenges and opportunity." *Revista Espanola de Documentacion Cientifica* 18, no. 02 (2024): 1-18.

130. Umar, Shayan, Muhammad Salik Qureshi, and Muhammad Usman Nawaz. "Thermal imaging and AI in solar panel defect identification." *International Journal of Advanced Engineering Technologies and Innovations* 1, no. 3 (2024): 73-95.

131. Qureshi, Muhammad Salik, Shayan Umar, and Muhammad Usman Nawaz. "Machine learning for predictive maintenance in solar farms." *International Journal of Advanced Engineering Technologies and Innovations* 1, no. 3 (2024): 27-49.

132. Sultana, Adita, Azizul Hakim Rafi, Abdullah Al Abrar Chowdhury, and Mehtab Tariq. "Leveraging artificial intelligence in neuroimaging for enhanced brain health diagnosis." *Revista de Inteligencia Artificial en Medicina* 14, no. 1 (2023): 1217-1235.

133. Chowdhury, Abdullah Al Abrar, Adita Sultana, Azizul Hakim Rafi, and Mehtab Tariq. "AI-driven predictive analytics in orthopedic surgery outcomes." *Revista Espanola de Documentacion Cientifica* 19, no. 2 (2024): 104-124.

134. Sultana, Adita, Azizul Hakim Rafi, Abdullah Al Abrar Chowdhury, and Mehtab Tariq. "AI in neurology: Predictive models for early detection of cognitive decline." *Revista Espanola de Documentacion Cientifica* 17, no. 2 (2023): 335-349.

135. Chowdhury, Abdullah Al Abrar, Azizul Hakim Rafi, Adita Sultana, and Abdulla All Noman. "Enhancing green economy with artificial intelligence: Role of energy use and FDI in the United States." *arXiv preprint arXiv:2501.14747* (2024).

136. Munagandla, Vamshi Bharath, Sai Surya Varshika Dandyala, Bharath Chandra Vadde, and D. Engineer. "AI-Driven Optimization of Research Proposal Systems in Higher Education." *Revista de Inteligencia Artificial en Medicina* 15, no. 1 (2024): 650-672.

137. Sultana, Adita. "Enhancing Breast Cancer Image Analysis through Attention Mechanisms: A Comparative Study of U-Net and Attention U-Net Models." In *2024 IEEE International Conference on Computing, Applications and Systems (COMPAS)*, pp. 1-8. IEEE, 2024.

138. Rafi, Azizul Hakim, Abdullah Al Abrar Chowdhury, Adita Sultana, and Abdulla All Noman. "Unveiling the role of artificial intelligence and stock market growth in achieving carbon neutrality in the United States: An ARDL model analysis." *arXiv preprint arXiv:2412.16166* (2024).

139. Dandamudi, Sai Ratna Prasad, Jaideep Sajja, and Amit Khanna. "AI Transforming Data Networking and Cybersecurity through Advanced Innovations." *International Journal of Innovative Research in Computer Science and Technology* 13, no. 1 (2025): 42-49.

140. Dandamudi, Sai Ratna Prasad, Jaideep Sajja, and Amit Khanna. "Leveraging Artificial Intelligence for Data Networking and Cybersecurity in the United States." *International Journal of Innovative Research in Computer Science and Technology* 13, no. 1 (2025): 34-41.

141. Dandamudi, Sai Ratna Prasad, Jaideep Sajja, and Amit Khanna. "Advancing Cybersecurity and Data Networking Through Machine Learning-Driven Prediction Models." *International Journal of Innovative Research in Computer Science and Technology* 13, no. 1 (2025): 26-33.

142. Tariq, Aftab, Ahmad Yousaf Gill, and Hafiz Khawar Hussain. "Evaluating the potential of artificial intelligence in orthopedic surgery for value-based healthcare." *International Journal of Multidisciplinary Sciences and Arts* 2, no. 2 (2023): 27-35.

143. Ahmad, Ahsan, Aftab Tariq, Hafiz Khawar Hussain, and Ahmad Yousaf Gill. "Equity and artificial intelligence in surgical care: A comprehensive review of current challenges and promising solutions." *BULLET: Jurnal Multidisiplin Ilmu* 2, no. 2 (2023): 443-455.

144. Ahmad, Ahsan, Aftab Tariq, Hafiz Khawar Hussain, and Ahmad Yousaf Gill. "Revolutionizing healthcare: How deep learning is poised to change the landscape of medical diagnosis and treatment." *Journal of Computer Networks, Architecture and High Performance Computing* 5, no. 2 (2023): 458-471.

145. Hussain, H. K., A. Tariq, and A. Y. Gill. "Role of AI in cardiovascular health care; a brief overview." *Journal of World Science* 2, no. 4 (2023): 794-802.

146. Tariq, Mehtab, Yawar Hayat, Adil Hussain, Aftab Tariq, and Saad Rasool. "Principles and perspectives in medical diagnostic systems employing artificial intelligence (AI) algorithms." *International Research Journal of Economics and Management Studies IRJEMS* 3, no. 1 (2024).

147. Hussain, Hafiz Khawar, Aftab Tariq, Ahmad Yousaf Gill, and Ahsan Ahmad. "Transforming healthcare: The rapid rise of artificial intelligence revolutionizing healthcare applications." *BULLET: Jurnal Multidisiplin Ilmu* 1, no. 02 (2022): 592216.

148. Hayat, Yawar, Mehtab Tariq, Adil Hussain, Aftab Tariq, and Saad Rasool. "A review of biosensors and artificial intelligence in healthcare and their clinical significance." *International Research Journal of Economics and Management Studies IRJEMS* 3, no. 1 (2024).

149. Bhatti, Iftikhar, Mehtab Tariq, Yawar Hayat, Aftab Tariq, and Saad Rasool. "A multimodal affect recognition adaptive learning system for individuals with intellectual disabilities." *European Journal of Science, Innovation and Technology* 3, no. 6 (2023): 346-355.

150. Vangala, Vidyasagar. "Optimizing Cloud Infrastructure Management in DevOps."

151. Vangala, Vidyasagar. "DevOps for Legacy Systems: Strategies for Successful Integration." (2025).

152. Vangala, Vidyasagar. "Optimizing Continuous Delivery Pipelines for Faster Time-to-Market." (2025).

153. Vangala, Vidyasagar. "Enhancing Collaboration Between Development and Operations Teams in DevOps." (2025).

154. Vangala, Vidyasagar. "DevSecOps: Integrating Security into the DevOps Lifecycle." (2025).

155. Vangala, Vidyasagar. "Blue-Green and Canary Deployments in DevOps: A Comparative Study." (2025).

156. Rasool, Saad, Aftab Tariq, and Yawar Hayat. "Maximizing efficiency in telemedicine: An IoT-based artificial intelligence optimization framework for health analysis." *European Journal of Science, Innovation and Technology* 3, no. 6 (2023): 48-61.

157. Khalid, M. Y., Z. U. Arif, A. Al Rashid, M. I. Shahid, W. Ahmed, A. F. Tariq, and Z. Abbas. "Interlaminar shear strength (ILSS) characterization of fiber metal laminates (FMLs) manufactured through VARTM process, Forces Mech. 4 (2021)." *DOI: https://doi. org/10.1016/j. finmec* (2021).

158. Tariq, Aftab, Ahmad Gill, Hafiz Khawar Hussain, Nasmin Jiwani, and J. Logeshwaran. "The smart earlier prediction of conginental heart disease in pregnancy using deep learning model." In *2023 IEEE Technology & Engineering Management Conference-Asia Pacific (TEMSCON-ASPAC)*, pp. 1-7. IEEE, 2023.

159. Aftab, Tariq, M. Masroor A. Khan, and J. F. S. Ferreira. "Effect of Mineral Nutrition, Growth Regulators and Environmental Stresses on Biomass Production and Artemisinin Concentration of Artemisia annua L." In *Artemisia annua-Pharmacology and Biotechnology*, pp. 157-172. Berlin, Heidelberg: Springer Berlin Heidelberg, 2013.

160. Ahmed, S., K. Mariam, A. Hussain, and A. Tariq. "Neutron Particles Contamination InLinear Accelerator During Total Body Irradiation Treatment: SU-I-GPD-E-05." *Medical Physics* 44, no. 6 (2017): 2788.

161. Mohi-U-din, S. Farooq, M. Tariq, and A. Tariq. "Deep dive into health: Harnessing AI and deep learning for brain and heart care." *International Journal of Advanced Engineering Technologies and Innovations* 1, no. 4 (2024): 248-267.

162. Hussain, Hafiz Khawar, Aftab Tariq, and Ahmad Yousaf Gill. "Role of Artificial Intelligence in Cardiovascular Health Care." *Journal of World Science* 2, no. 4 (2023): 583-591.

163. Rasool, Saad, Aftab Tariq, Yawar Hayat, and I. L. Forest. "European Journal of Science, Innovation and Technology."

164. Xiang, Shihui, Saad Rasool, Yong Hang, Kamran Javid, Tasawar Javed, and Alin Emanuel Artene. "The effect of COVID-19 pandemic on service sector sustainability and growth." *Frontiers in psychology* 12 (2021): 633597.

165. Rasool, Saad, Ali Husnain, Ayesha Saeed, Ahmad Yousaf Gill, and Hafiz Khawar Hussain. "Harnessing predictive power: exploring the crucial role of machine learning in early disease detection." *JURIHUM: Jurnal Inovasi dan Humaniora* 1, no. 2 (2023): 302-315.

166. Rasool, Saad, Mohammad Ali, Hafiz Muhammad Shahroz, Hafiz Khawar Hussain, and Ahmad Yousaf Gill. "Innovations in AI-powered healthcare: Transforming cancer treatment with innovative methods." *BULLET: Jurnal Multidisiplin Ilmu* 3, no. 1 (2024): 118-128.

167. Husnain, Ali, Saad Rasool, Ayesha Saeed, Ahmad Yousaf Gill, and Hafiz Khawar Hussain. "AI'S healing touch: examining machine learning's transformative effects on healthcare." *Journal of World Science* 2, no. 10 (2023): 1681-1695.

168. Husnain, Ali, Saad Rasool, Ayesha Saeed, and Hafiz Khawar Hussain. "Revolutionizing pharmaceutical research: Harnessing machine learning for a paradigm shift in drug discovery." *International Journal of Multidisciplinary Sciences and Arts* 2, no. 4 (2023): 149-157.

169. Gill, Ahmad Yousaf, Ayesha Saeed, Saad Rasool, Ali Husnain, and Hafiz Khawar Hussain. "Revolutionizing healthcare: how machine learning is transforming patient diagnoses-a comprehensive review of AI's impact on medical diagnosis." *Journal of World Science* 2, no. 10 (2023): 1638-1652.

170. Tariq, Mehtab, Yawar Hayat, Adil Hussain, Aftab Tariq, and Saad Rasool. "Principles and perspectives in medical diagnostic systems employing artificial intelligence (AI) algorithms." *International Research Journal of Economics and Management Studies IRJEMS* 3, no. 1 (2024).

171. Bhatti, Iftikhar, Hira Rafi, and Saad Rasool. "Use of ICT Technologies for the Assistance of Disabled Migrants in USA." *Revista Espanola de Documentacion Cientifica* 18, no. 01 (2024): 66-99.

172. Hayat, Yawar, Mehtab Tariq, Adil Hussain, Aftab Tariq, and Saad Rasool. "A review of biosensors and artificial intelligence in healthcare and their clinical significance." *International Research Journal of Economics and Management Studies IRJEMS* 3, no. 1 (2024).

173. Husnain, Ali, Hafiz Khawar Hussain, Hafiz Muhammad Shahroz, Muhammad Ali, Ahmed Gill, and Saad Rasool. "Exploring ai and machine learning applications in tackling covid-19 challenges." *Revista Espanola de Documentacion Cientifica* 18, no. 02 (2024): 19-40.

174. Li, Zeying, Saad Rasool, Mustafa Fedai Cavus, and Waseem Shahid. "Sustaining the future: How green capabilities and digitalization drive sustainability in modern business." *Heliyon* 10, no. 1 (2024).

175. Bhatti, Iftikhar, Mehtab Tariq, Yawar Hayat, Aftab Tariq, and Saad Rasool. "A multimodal affect recognition adaptive learning system for individuals with intellectual disabilities." *European Journal of Science, Innovation and Technology* 3, no. 6 (2023): 346-355.

176. Rasool, D., Azhar Ghafoor, and D. Fareed. "Forecasting the Trends and Patterns of Crime in San Francisco using Machine Learning Model." *International Journal of Science and Engineering Research. https://doi. org/10.13140/RG* 2, no. 25209.75367 (2021).

177. Saeed, Ayesha, Ali Husnain, Saad Rasool, and Ahmad Yousaf Gill. "Healthcare Revolution: How AI and Machine Learning Are Changing Medicine." *Journal Research of Social Science, Economics & Management* 3, no. 3 (2023).

178. Rasool, Saad, Mohammad Ali, Hafiz Khawar Hussain, and Ahmad Yousaf Gill. "Unlocking the potential of healthcare: AI-driven development and delivery of vaccines." *International Journal of Social, Humanities and Life Sciences* 1, no. 1 (2023): 29-37.

179. Xiang, Shihui, Saad Rasool, Yong Hang, Kamran Javid, Tasawar Javed, and Alin Emanuel Artene. "Frontiers in psychology." (2021).

180. Husnain, Ali, Saad Rasool, Ayesha Saeed, and Hafiz Khawar Hussain. "Multidisciplinary Sciences and Arts."

181. Ghelani, Harshitkumar. "AI-Driven Quality Control in PCB Manufacturing: Enhancing Production Efficiency and Precision." *Valley International Journal Digital Library* (2024): 1549-1564.

182. Ghelani, Harshitkumar. "Advanced AI Technologies for Defect Prevention and Yield Optimization in PCB Manufacturing." *International Journal Of Engineering And Computer Science* 13, no. 10 (2024).

183. Ghelani, Harshitkumar. "Six Sigma and Continuous Improvement Strategies: A Comparative Analysis in Global Manufacturing Industries." *Valley International Journal Digital Library* (2023): 954-972.

184. Ghelani, Harshitkumar. "Automated Defect Detection in Printed Circuit Boards: Exploring the Impact of Convolutional Neural Networks on Quality Assurance and Environmental Sustainability in Manufacturing." *International Journal of Advanced Engineering Technologies and Innovations* 1: 275-289.

185. Ghelani, Harshitkumar. "Harnessing AI for Visual Inspection: Developing Environmentally Friendly Frameworks for PCB Quality Control Using Energy-Efficient Machine Learning Algorithms." *International Journal of Advanced Engineering Technologies and Innovations* 1: 146-154.

186. Ghelani, Harshitkumar. "Enhancing PCB Quality Control through AI-Driven Inspection: Leveraging Convolutional Neural Networks for Automated Defect Detection in Electronic Manufacturing Environments." *Available at SSRN 5160737* (2024).
187. Ghelani, Harshitkumar. "Advances in lean manufacturing: improving quality and efficiency in modern production systems." *Valley International Journal Digital Library* (2021): 611-625.
188. Ghelani, Harshitkumar. "Revolutionizing Visual Inspection Frameworks: The Integration of Machine Learning and Energy-Efficient Techniques in PCB Quality Control Systems for Sustainable Production." *International Journal of Advanced Engineering Technologies and Innovations* 1: 521-538.
189. Shamil, M. M., Shaikh, J. M., Ho, P. L., & Krishnan, A. (2014). The influence of board characteristics on sustainability reporting: Empirical evidence from Sri Lankan firms. *Asian Review of Accounting*, *22*(2), 78-97.
190. Shaikh, J. M. (2004). Measuring and reporting of intellectual capital performance analysis. *Journal of American Academy of Business*, *4*(1/2), 439-448.
191. Shaikh, I. M., Qureshi, M. A., Noordin, K., Shaikh, J. M., Khan, A., & Shahbaz, M. S. (2020). Acceptance of Islamic financial technology (FinTech) banking services by Malaysian users: An extension of technology acceptance model. *Foresight*, *22*(3), 367-383.
192. Shaikh, J. M., & Talha, M. (2003). Credibility and expectation gap in reporting on uncertainties. *Managerial Auditing Journal*, *18*(6/7), 517-529.
193. Shaikh, J. M. (2005). E‐commerce impact: Emerging technology–electronic auditing. *Managerial Auditing Journal*, *20*(4), 408-421.
194. Lau, C. Y., & Shaikh, J. M. (2012). The impacts of personal qualities on online learning readiness at Curtin Sarawak Malaysia (CSM). *Educational Research and Reviews*, *7*(20), 430.
195. Karim, A., & Shaikh, J. M. (2013). Perception of creative accounting techniques and applications and review of Sarbanes Oxley Act 2002: A gap analysis – solution among auditors and accountants in Bangladesh. *Port City University Journal*, *1*(2), 1-12.
196. Muniapan, B., & Shaikh, J. M. (2007). Lessons in corporate governance from Kautilya's Arthashastra in ancient India. *World Review of Entrepreneurship, Management and Sustainable Development*, *3*(2), 147-161.
197. Kangwa, D., Mwale, J. T., & Shaikh, J. M. (2019). The social production of financial inclusion of Generation Z in digital banking ecosystems. *Australasian Accounting, Business and Finance Journal*, *15*(3), 95-118.
198. Bhasin, M. L., & Shaikh, J. M. (2013). Economic value added and shareholders' wealth creation: The portrait of a developing Asian country. *International Journal of Managerial and Financial Accounting*, *5*(2), 107-137.
199. Mamun, M. A., Shaikh, J. M., & Easmin, R. (2017). Corporate social responsibility disclosure in Malaysian business. *Academy of Strategic Management Journal*, *16*(2), 29-47.
200. Bhasin, M. L., & Shaikh, J. M. (2012). Voluntary corporate governance disclosures in the annual reports: An empirical study. *International Journal of Managerial and Financial Accounting*, *5*(1), 55-78.
201. Abdullah, A., Khadaroo, I., & Shaikh, J. M. (2008). Institutionalisation of XBRL in the USA and UK. *International Journal of Managerial and Financial Accounting*, *1*(3), 292-315.

202. Khadaroo, J. M. S. I. (2009). Corporate governance reforms in Malaysia: Insights from institutional theory. *World Review of Entrepreneurship, Management and Sustainable Development, 3*(4), 421-440.

203. Onosakponome, O. F., Rani, N. S. A., & Shaikh, J. M. (2011). Cost-benefit analysis of procurement systems and the performance of construction projects in East Malaysia. *Information Management and Business Review, 2*(5), 181-192.

204. Asif, M. K., Junaid, M. S., Hock, O. Y., & Md Rafiqul, I. (2015). Solution of adapting creative accounting practices: An in-depth perception gap analysis among accountants and auditors of listed companies. *Australian Academy of Accounting and Finance Review, 2*(2), 166-188.

205. Bhasin, M., & Shaikh, J. M. (2010). Intellectual capital disclosures in the annual reports: A comparative study of the Indian and Australian IT-corporations. *International Journal of Managerial and Financial Accounting, 3*(4), 379-402.

206. Alappatt, M., & Shaikh, J. M. (2011). Forthcoming procedure of goods and service tax (GST) in Malaysia. *Issues in Business Management and Economics, 2*(12), 210-213.

207. Sylvester, D. C., Rani, N. S. A., & Shaikh, J. M. (2010). Comparison between oil and gas companies and contractors against cost, time, quality, and scope for project success in Miri, Sarawak, Malaysia. *African Journal of Business Management, 5*(11), 4337-4351.

208. Jais, M., Jakpar, S., Doris, T. K. P., & Shaikh, J. M. (2012). The financial ratio usage towards predicting stock returns in Malaysia. *International Journal of Managerial and Financial Accounting, 4*(4), 377-401.

209. Asif, M. K., Junaid, M. S., Hock, O. Y., & Md Rafiqul, I. (2015). Creative accounting: Techniques of application—An empirical study among auditors and accountants of listed companies in Bangladesh. *Australian Academy of Accounting and Finance Review, 2*(3), 112-128.

210. Abdullah, A., Khadaroo, I., & Shaikh, J. M. (2009). A ‘macro’ analysis of the use of XBRL. *International Journal of Managerial and Financial Accounting, 1*(2), 213-223.

211. Khadaroo, M. I., & Shaikh, J. M. (2003). Toward research and development costs harmonization. *The CPA Journal, 73*(9), 50-56.

212. Sheng, Y. T., Rani, N. S. A., & Shaikh, J. M. (2014). Impact of SMEs character in the loan approval stage. *Business and Economics Research, 1*, 229-233.

213. Shaikh, J. M. (2005). Dispelling and construction of social accounting in view of social audit. *19th ANZAM Conference, Canberra, New Zealand, 2005 (December 7-10).*

214. Hla, D. T., Md Isa, A. H. B., & Shaikh, J. M. (2015). IFRS compliance and nonfinancial information in annual reports of Malaysian firms. *IUP Journal of Accounting Research & Audit Practices, 12*(4), 7-21.

215. Ali Ahmed, H. J., Lee, T. L., & Shaikh, J. M. (2011). An investigation on asset allocation and performance measurement for unit trust funds in Malaysia using multifactor model: A post-crisis period analysis. *International Journal of Managerial and Financial Accounting, 3*(1), 22-31.

216. Jakpar, S., Shaikh, J. M., Tinggi, M., & Jamali, N. A. L. (2012). Factors influencing entrepreneurship in small and medium enterprises (SMEs) among residents in Sarawak Malaysia. *International Journal of Entrepreneurship and Small Business, 16*(1), 83-101.

217. Boubaker, S., Mefteh, S., & Shaikh, J. M. (2010). Does ownership structure matter in explaining derivatives' use policy in French listed firms? *International Journal of Managerial and Financial Accounting, 2*(2), 196-212.

218. Shaikh, J. M., & Linh, D. T. B. (2017). Using the TFP model to determine impacts of stock market listing on corporate performance of agri-foods companies in Vietnam. *Journal of Corporate Accounting & Finance, 28*(3), 61-74.

219. Shaikh, J. M., Jakpar, S., & Othman, M. A. (1997). The prospects of Islamic banking and finance: Lessons from the 1997 banking crisis in Malaysia. *Malaysian Finance Association (MFA) Proceedings.*

220. Shaikh, J. M., Khadaroo, I., & Jasmon, A. (2010). *Contemporary accounting issues (for BAcc. students).* Prentice Hall.

221. Al-Takhayneh, S. K., Karaki, W., Hasan, R. A., Chang, B. L., Shaikh, J. M., & Kanwal, W. (2022). Teachers' psychological resistance to digital innovation in Jordanian entrepreneurship and business schools: Moderation of teachers' psychology and attitude toward educational technology. *Frontiers in Psychology, 13*, 1004078.

222. Kadir, S., & Shaikh, J. M. (2022). The effects of e-commerce businesses on small-medium enterprises: Media techniques and technology. *AIP Conference Proceedings, 2643*(1).

223. Junaid, M. S., & Dinh Thi, B. L. (2015). Stock market listing influence on corporate performance: Definitions and assessment tools.

224. Yuan, X., Kaewsaeng-On, R., Jin, S., Anuar, M. M., Shaikh, J. M., & Mehmood, S. (2022). Time-lagged investigation of entrepreneurship school innovation climate and students' motivational outcomes: Moderating role of students' attitude toward technology. *Frontiers in Psychology, 13*, 979562.

225. Mwansa, P., Shaikh, J. M., & Mubanga, P. (2019). Special economic zones: An evaluation of Lusaka South - Multi Facility Economic Zone. *Journal of Social and Political Sciences, 3*(2), 523-539.

226. Tinggi, M., Jakpar, S., Chin, T. B., & Shaikh, J. M. (2013). Customers' confidence and trust towards privacy policy: A conceptual research of hotel revenue management. *International Journal of Revenue Management, 5*(4), 350-368.

227. Krishnan, A., Chan, K. M., Jayaprakash, J. C. M., Shaikh, J. M., & Isa, A. H. B. M. (2010). Measurement of performance at institutions of higher learning: The balanced scorecard approach. *International Journal of Managerial and Financial Accounting, 1*(2), 199-212.

228. Mamun, M. A., & Shaikh, J. M. (2012). Reinventing strategic corporate social responsibility. *Journal of Economic & Management Perspectives, 12*(2), 499-512.

229. Alappatt, A. K. M., & Shaikh, J. M. (2010). Progress billing method of accounting for long-term construction contracts. *Journal of Modern Accounting and Auditing, 6*(11), 41-50.

230. Shamil, M. M., Shaikh, J. M., Ho, P., & Krishnan, A. (2020). External pressures, managerial motive, and corporate sustainability strategy: Evidence from a developing economy. *Asian Journal of Accounting & Governance, 18*.

231. Kangwa, D., Mwale, J. T., & Shaikh, J. M. (2021). Co-evolutionary dynamics of financial inclusion of Generation Z in a sub-Saharan digital financial ecosystem. *Copernican Journal of Finance & Accounting, 9*(4), 27-50.

232. Shamil, M. M., & Junaid, M. S. (2012). Determinants of corporate sustainability adoption in firms. *2nd International Conference on Management, Langkawi, Malaysia*.

233. Odhigu, F. O., Yahya, A., Rani, N. S. A., & Shaikh, J. M. (2014). Investigation into the impacts of procurement systems on the performance of construction projects in East Malaysia. *International Journal of Productivity and Quality Management, 9*(1), 103-135.

234. Ali Ahmed, H. J., & Shaikh, J. M. (2009). Dividend policy choice: Do earnings or investment opportunities matter? *Afro-Asian Journal of Finance and Accounting, 1*(2), 151-161.

235. Shamil, M. M., Shaikh, J. M., Ho, P. L., & Krishnan, A. (2012). The relationship between corporate sustainability and corporate financial performance: A conceptual review. *Proceedings of USM-AUT International Conference 2012 Sustainable Economic Development*.

236. Lynn, L. Y. H., & Shaikh, J. M. (2011). Stock market reaction towards capital expenditure announcements: Malaysia case for servicing and manufacturing industry. *Global Review of Accounting and Finance, 2*(1), 29-41.

237. Rani, N. S. A., Hamit, N., Das, C. A., & Shaikh, J. M. (2013). Microfinance practices in Malaysia: From 'kootu' concept to the replication of the Grameen Bank model. *Journal for International Business and Entrepreneurship Development, 5*(3).

238. Shaikh, J. M. (2010). Reviewing ABC for effective managerial and financial accounting decision-making in corporate entities. *Allied Academies International Conference in New Orleans, USA, 2010*.

239. Ali Ahmed, H. J., Shaikh, J. M., & Isa, A. H. (2010). A comprehensive look at the re-examination of the re-evaluation effect of auditor switch and its determinants in Malaysia: A post-crisis analysis from Bursa Malaysia. *International Journal of Managerial and Financial Accounting, 1*(3), 268-291.

240. Abdullah, A., Khadaroo, I., & Shaikh, J. (2007). XBRL benefits, challenges, and adoption in the US and UK: Clarification of a future research agenda. *World Sustainable Development Outlook, 2007*, 181-188.

241. Junaid, M. S., & Dinh Thi, B. L. (Year). Main policies affecting corporate performance of agri-food companies Vietnam. *Academy of Accounting and Financial Studies Journal, 21*(2).

242. Sheikh, M. J. (Year). Experiential learning in entrepreneurship education: A case of CEFE methodology in Federal University of Technology Minna, Nigeria. *Proceedings of the 3rd International Conference on Higher Education and Teaching.*

243. Lynn, L. Y. H., Evans, J., Shaikh, J., & Sadique, M. S. (Year). Do family-controlled Malaysian firms create wealth for investors in the context of corporate acquisitions? *Capital Market Review, 22*(1&2), 1-26.

244. Shaikh, J. M. (2010). Risk assessment: Strategic planning and challenges while auditing. *12th International Business Summit - INBUSH 2010*.

245. Shaikh, J. M. (Year). Hewlett-Packard Co. (HP) accounting for decision analysis: A case in international financial statement analysis. *International Journal of Managerial and Financial Accounting, 1*(1), 75-96.

246. Jasmon, A., & Shaikh, J. M. (Year). A practitioner's guide to group relief. *Journal of International Taxation, 14*(1), 46-54.

247. Zubairu, U., Sakariyau, O., & Shaikh, J. (Year). Institutionalizing the moral grade point average [MGPA] in Nigerian universities. *Education Sciences & Psychology, 37*(5).

248. Shaikh, J. M., & Karim, A. M. (Year). Creative accounting: Is it a form of legal manipulation? *Port City International University Journal, 1851120791*(01773225500), 16.

249. Jasmon, A., & Shaikh, J. M. (Year). How to maximize group loss relief. *International Tax Review, 13*, 39.

250. Hua, L. L. Y., & Shaikh, J. M. (Year). Is there wealth impact from capital expenditure announcements?: Malaysia listing firms of industrial products sector. *International Review of Business Research Papers, 7*(5), 68-82.

251. Shaikh, J., & Evans, J. (Year). Corporate acquisitions of Malaysian family-controlled firms. *[Publisher Information]*.
252. Mahmood, Tahir, Willis Fulmer, Neelesh Mungoli, Jian Huang, and Aidong Lu. "Improving information sharing and collaborative analysis for remote geospatial visualization using mixed reality." In *2019 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 236-247. IEEE, 2019.
253. Mungoli, Neelesh. "Adaptive Ensemble Learning: Boosting Model Performance through Intelligent Feature Fusion in Deep Neural Networks." *arXiv preprint arXiv:2304.02653* (2023).
254. Mungoli, Neelesh. "Scalable, Distributed AI Frameworks: Leveraging Cloud Computing for Enhanced Deep Learning Performance and Efficiency." *arXiv preprint arXiv:2304.13738* (2023).
255. Mungoli, Neelesh. "Adaptive feature fusion: enhancing generalization in deep learning models." *arXiv preprint arXiv:2304.03290* (2023).
256. Mungoli, Neelesh. "Exploring the Technological Benefits of VR in Physical Fitness." Master's thesis, The University of North Carolina at Charlotte, 2020.
257. Mungoli, Neelesh. "Deciphering the Blockchain: A Comprehensive Analysis of Bitcoin's Evolution, Adoption, and Future Implications." *arXiv preprint arXiv:2304.02655* (2023).
258. Mungoli, Neelesh. "Exploring the synergy of prompt engineering and reinforcement learning for enhanced control and responsiveness in chat GPT." *Journal of Electrical Electronics Engineering* 2, no. 3 (2023): 201-205.
259. Mungoli, Neelesh. "HybridCoin: Unifying the Advantages of Bitcoin and Ethereum in a Next-Generation Cryptocurrency." *INTERNATIONAL JOURNAL OF COMPUTER SCIENCE AND TECHNOLOGY* 7, no. 2 (2023): 235-250.
260. Mungoli, Neelesh. "Exploring the Frontier of Deep Neural Networks: Progress." *Challenges, and Future Directions* 10 (2023).
261. Mungoli, Neelesh. "Exploring the Potential and Limitations of ChatGPT: A Comprehensive Analysis of GPT-4's Conversational AI Capabilities." *INTERNATIONAL JOURNAL OF COMPUTER SCIENCE AND TECHNOLOGY* 7, no. 2 (2023): 178-1.
262. Mungoli, Neelesh. "Mastering Artificial Intelligence: Concepts." *Algorithms, and Equations* (2023).
263. Mungoli, Neelesh. "Deciphering the Blockchain: A Comprehensive Analysis of Bitcoin's Evolution." *Adoption, and Future Implications* (2023).
264. Mungoli, Neelesh. "Enhancing Conversational Engagement and Understanding of Cryptocurrency with ChatGPT: An Exploration of Applications and Challenges." (2023).
265. Mungoli, Neelesh. "Enhancing Conversational Engagement and Understanding of Cryptocurrency with ChatGPT: An Exploration of Applications and Challenges." (2023).
266. Mungoli, Neelesh. "Leveraging AI and Technology to Address the Challenges of Underdeveloped Countries." *Journal of Electrical Electronics Engineering* 2, no. 3 (2023): 211-216.
267. Mungoli, Neelesh. "For wireless communication channels with local dispersion, a generalized array manifold model is used." (2023): 2433-2024.
268. Goti, Ankit Bharatbhai. "AI-Driven PCB Reliability Testing for IPC-9701 Compliance." *International Journal of Scientific Research and Management (IJSRM)* 13, no. 03 (2025): 2068-2087.

269. Goti, Ankit Bharatbhai. "Automated Optical Inspection (AOI) Based on IPC Standards." *International Journal Of Engineering And Computer Science* 13, no. 03 (2025).
270. Goti, Ankit Bharatbhai. "Cost-Benefit Analysis of ENIG vs. HASL vs. OSP for Class 3 PCBs."
271. Goti, Ankit Bharatbhai. "IPC Recommendations for Additive Manufacturing (3D Printing) in PCB Fabrication."
272. Goti, Ankit Bharatbhai. "Cost and Reliability Implications of Selective Hard Gold Plating Techniques."
273. Goti, Ankit Bharatbhai. "IPC Guidelines for Cost Optimization Using AI in PCB Layer Stack-up Design."
274. Goti, Ankit Bharatbhai. "AI-driven Predictive Maintenance for PCB Manufacturing Equipment."
275. Goti, Ankit Bharatbhai. "Moisture Absorption and Outgassing in Flexible and Rigid-Flex PCBs."
276. Goti, Ankit Bharatbhai. "IPC Standardization of AI-assisted Real-Time Process Control in PCB Manufacturing."
277. Goti, Ankit Bharatbhai. "Material and Reliability Guidelines for Flexible PCBs in Class 3."
278. Goti, Ankit Bharatbhai. "Reliability and Microstructural Analysis of Microvias in UHDI PCBs."
279. Arif, Haroon, Abdul Karim Sajid Ali, Aamir Raza, and Aashesh Kumar. "Adversarial Attacks on AI Diagnostic Tools: Assessing Risks and Developing Mitigation Strategies." (2025).
280. Kezron, I. E. (2025). Post-quantum cryptography readiness in U.S. community banks and financial SMEs: A cybersecurity risk assessment framework. Well Testing Journal, 34(S2), 135–146.
281. Isabirye, E. K. (2025). Novel cybersecurity framework for AI-driven drone integration by critical SMEs in economically distressed U.S. rural communities: Advancing secure precision operations in high-risk environments. Well Testing Journal, 34(S3), 1–44. Retrieved from https://welltestingjournal.com/index.php/WT/article/view/34.s3.1
282. Kezron, I. E. (2025). Post-quantum cybersecurity for AI-driven rural healthcare systems: A framework for protecting economically distressed U.S. communities. Journal of Applied Optics, 46.
283. Kezron, I. E. (2025). Fortifying digital justice: A cybersecurity and efficiency framework for U.S. legal SMEs and court-affiliated service providers. Journal of Tianjin University Science and Technology, 58(6).
284. Kezron, I. E. (2025). Securing AI-driven supply chains in rural critical infrastructure: A cybersecurity framework for risk mitigation. Journal of Tianjin University Science and Technology, 58(6).
285. Kezron, I. E. (2025). Cybersecurity framework for securing cloud and AI-driven services in small and medium-sized businesses. Journal of Tianjin University Science and Technology, 58(6).
286. Kezron, I. E. (2024). A cybersecurity resilience framework for underserved rural SMEs in critical infrastructure supply chains: Strengthening operational continuity and threat response in digitally vulnerable sectors. World Journal of Advanced Research and Reviews, 24(3), 3464–3477.