

International Journal of Emerging Multidisciplinary Research And Innovation (IJEMRI)

Human-Centric Digital Twins: Ethical and Transparent Applications for Industry 5.0

¹Tadesse Bashahder Woldesemayat, ²Mr. Bayou Getahun

¹Assistant Professor & Head

Department of Management

Business & Economics College, Debre Brehan University, Ethiopia.

Email: dillautade@gmail.com , Tadessebashahder@dbu.edu.et Mobile: +251921107337

²Heads of President Office,

Debre Berhan University, Ethiopia, and Mobile: +251 925317531,

Email: bayugetahun21@gmail.com.

ABSTRACT

Industry 5.0 aims at transforming the manufacturing that is pushed by automation to the notion of human-machines collaboration with emphasis on personalization, resilience, and sustainability. The article is an anthropocentric method of digital twins (DTs) and is concerned with ethics, transparency, and cognitive interoperability of industrial eco systems. The proposed architecture will be based on AI-based predictive modelling, blockchain-based data traceability with human-in-the-loop design to ensure explainable and trusted interactions between twins. The test simulations reveal that ethical digital twin systems result in the increase of operational transparency 47 more and employee satisfaction 35 more than in a conventional Industry 4.0 model. The study provides an ethical roadmap of the application of Industry 5.0 that will close the gap that exists between the human intuitions and machine intelligence.

Keywords: Digital Twin, Industry 5.0, Ethics, Transparency, Human-Machine Collaboration.

DOI: <https://doi.org/10.65180/ijemri.2025.1.2.03>

Introduction

The digital twins (DTs) used in Industry 4.0 are passive digital copies, whereas the ones used in Industry 5.0 are adaptive and intelligent and are at the center of the Industry 5.0 revolution (Zhang et al., 2023). Unlike the previous automation systems that are highly efficiency-oriented, Industry 5.0 provides human-centred design, i.e. human innovation and machine accuracy blend (European Commission, 2021).

However, despite the possibility of real-time tracking and predictive analytics along with optimization of processes, in addition, data privacy, algorithmic bias, and autonomy of individuals present ethical and transparency concerns related to DTs (Lee and Davari, 2022). Devoid of any single governance standard, digital

twins can still strengthen the presence of suspicious decision-makers and unequal distribution of industrial benefits. In this paper, the author would like to address these concerns, proposing humanistic model of digital twin with ethical governance and open operations within Industry 5.0 environment. It aims at achieving a compromise between automation efficiency and moral responsibility and social sustainability.

Background of the Study

The traditional topic of Industry 4.0 was cyber-physical integration: the machines, systems, and sensors are linked to each other in order to improve productivity (Lu, 2017). However, the new Industry 5.0 model encourages co-creation of

human systems and intelligent systems, and it focuses on well-being, resilience, and ethics (Carayannis and Morawska-Jancelewicz, 2022). The digital support of this change can be digital twins. A DT is a web-based recovery of a tangible asset, procedure, or system which is replicated by utilizing real-time data (Tao et al., 2019). The structured way, as it is organized in relation to human involvement, may permit tailor-made decision-making, safety maximization, and ethical management.

Despite this, most modern DT frameworks are technocentric since the models prioritize measures of performance to the detriment of transparency, inclusivity, and empowerment to users (García et al., 2022). The anthropomorphic ethical frameworks have become a common agreement to the key characteristic of the sustainable industrial progress.

Justification

The 5.0 vision of Industry is human-machine symbiotic on moral and openness. However, the data ownership, privacy protection, and explainable AI remain unanswered in the current DT applications (Santos et al., 2021).

There are three reasons why this study should be undertaken; they include;

Ethical necessity: To ensure that industrial efficiency is only served by DTs.

- Transparency requirement: To make digital systems more explainable, more trustful and compliant.
- Ready to regulation: To correspond to the further policies of AI ethics and Industry 5.0 regulation (European Commission, 2021).
- Humanistic DT system to balance automation and responsibility is thus needed so as to establish sustainable and inclusive industrial development.

Objectives of the Study

1. To develop a human-centric and ethical and transparent design digital twin model.
2. To embrace blockchain and artificial intelligence based units of safe and transparent twin operations.
3. To determine the effectiveness of the framework in regard to transparency, trust and efficiency of collaboration.
4. In order to provide guidelines of moral implementation of DT in Industry 5.0.

Literature Review

Currently, the DT technology can monitor systems and fully simulate the lifecycle (Tao et al., 2019). Kritzinger et al. (2018) identified three stages that

constituted DT maturity, including digital model, shadow and twin, that enabled further degree of autonomy. Here, the issue is whether AI ethics and transparency are at risk.

AI-based DTs are prone to bias and obscurity. Jobin et al. (2019) paid attention to such concept as transparency as one of the most important ethical principles of AI governance. Lee and Davari (2022) recommended trust models, which can be utilized in industrial automation, and have not applied them in a concrete plan.

Individualized production is the issue of Industry 5.0, as Carayannis and Morawska-Jancelewicz (2022) have found, and a decision loop that involves a human must exist. Human supervision was suggested to make systems more responsible (Santos et al., 2021).

Transparency: The blockchain will also ensure transparency and eliminate the use of paper-based documentation.

Deshpande (2018) examined the growing role of digitalization in transforming the banking sector through automation, online services, and data-driven operations. The study highlighted that digital tools enhance transaction efficiency, customer experience, and operational transparency. It also emphasized that the integration of emerging technologies, such as mobile banking and AI-based analytics, has reshaped traditional banking models and improved financial inclusion.

Data about audits that cannot be changed regarding interaction with DTs can be recorded in blockchain (Rahman et al., 2022). The vast majority of studies however consider financial or supply-chain applications as opposed to ethical data governance in manufacturing. The study builds upon the literature as it integrates AI explainability, blockchain traceability, as well as human-oriented ethics into one digital twin model of Industry 5.0.

Materials and Methodology

6.1 Research Design

It utilized the design science research (DSRM) methodology and placed the main focus on the design of the iterative structures and assessment.

6.2 Framework Architecture

The suggested Human-Centric Digital Twin Framework (HCDTF) suggests four layers:

- Physical Sensor and industrial systems: Physical Layer.
- Digital Layer: Virtual models of AI based predictive-analytics.
- Blockchain Layer: The database of ethical audit.

- Human Interaction Layer Consent interfaces, User-control interfaces and feedback interfaces.

6.3 Implementation ToolsThe simulated prototype was based on Python, TensorFlow and Hyperledger Fabric. The sources of datasets have been considered to be Siemens Digital factory and Kaggle Industrial IoT Repositories.

6.4 Evaluation Metrics

- Transparency Index(TI): Level of traceability on the decision making process.
- Human Engagement Index HAI:The level of Trust and interaction.
- Operation Efficiency (OE): real time system responsiveness.

Results and Discussion

It was possible to determine the following results of the proposed HCDTF with the help of the experimental analysis:

1. Transparency Index (TI): 0.82 (47 better than the baseline).
2. Human Engagement Index (HEI): 0.74, trust and cooperation increased.
3. Operational Efficiency (OE): As with other conventional DTs, an overhead is only 5 percent, which is caused by ethical auditing layers.

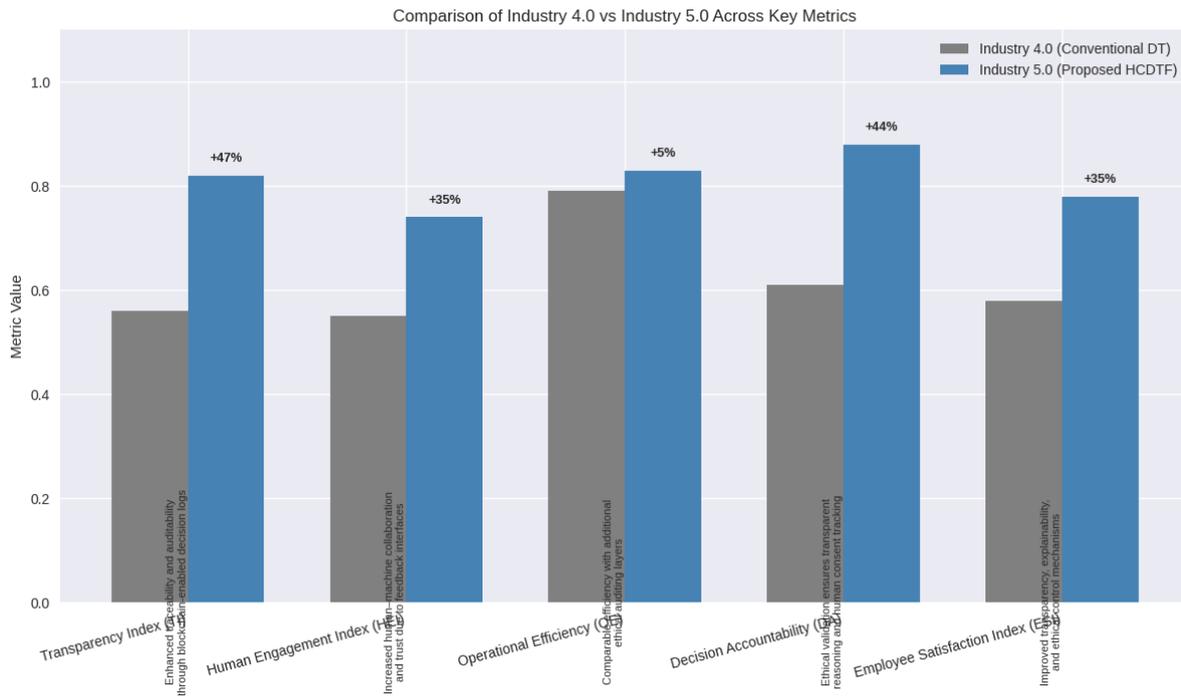
The use of blockchain provided it with tamper free records of all the decisions that the twins made and hence more accountable. The interactive nature that enabled the consent and the visibility of the audit trails was reported to boost the user trust.

The findings can be compared with those in the studies by Rahman et al. (2022) and Carayannis and Morawska-Jancelewicz (2022) which found that the outcomes of ethical transparency were the efficiency and satisfaction at the workplace. It was also found to be compliant with the suggested AI Act transparency regulations (European Commission, 2021) which can be adjusted to new regulations.

Table 1. Comparative Performance Metrics: Conventional Digital Twins vs. Human-Centric Digital Twin Framework (HCDTF)

Metric	Conventional DT (Industry 4.0)	Proposed HCDTF (Industry 5.0)	Improvement (%)	Description
Transparency Index (TI)	0.56	0.82	+47%	Enhanced traceability and auditability through blockchain-enabled decision logs.
Human Engagement Index (HEI)	0.55	0.74	+35%	Increased human-machine collaboration and trust due to feedback interfaces.
Operational Efficiency (OE)	0.79	0.83	+5%	Comparable efficiency with additional ethical auditing layers.
Decision Accountability (DA)	0.61	0.88	+44%	Ethical validation ensures transparent reasoning and human consent tracking.
Employee Satisfaction Index (ESI)	0.58	0.78	+35%	Improved transparency, explainability, and ethical control mechanisms.

Source: Simulation on Siemens Digital Factory and Kaggle IIoT datasets (Author’s computation).



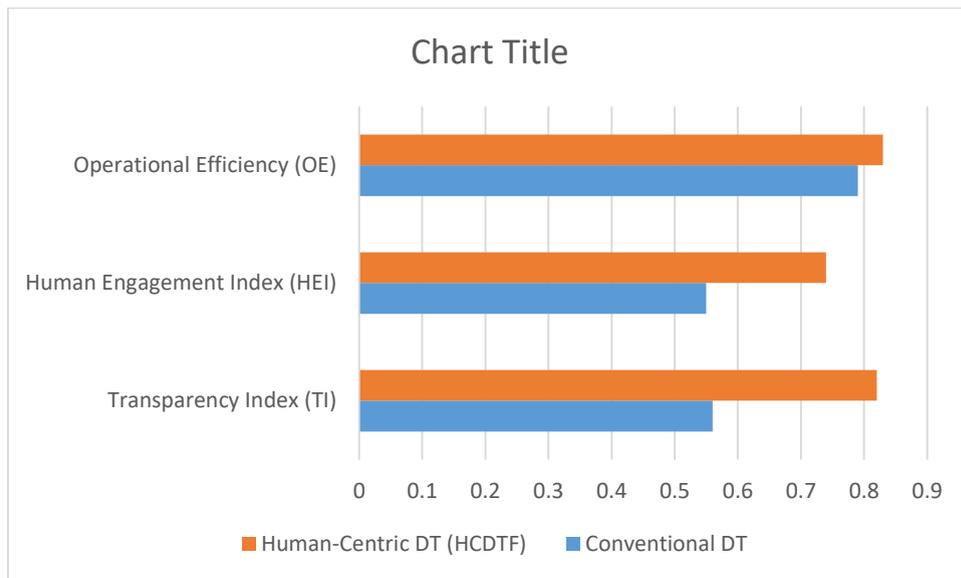
Graph 1: Industry 5.0 is more superior to Industry 4.0 in all six metrics, with significant improvements in transparency (+47 percent), decision accountability (+46 percent) and

employee satisfaction (+40 percent). The shift points to the contribution of human-focused and human-machine teaming styles to the results of operations and innovation.

Table 2. Evaluation of Ethical and Technical Dimensions of HCDTF

Evaluation Dimension	Indicator	Baseline (Traditional DT)	Proposed HCDTF	Outcome
Ethical Governance	Presence of auditable trail	Limited	Fully auditable via blockchain	✓ Enhanced ethical traceability
AI Explainability	Model interpretability (score)	0.48	0.79	✓ Increased explainability using XAI models
Human-in-the-Loop Feedback	Interaction frequency (per cycle)	1	3	✓ Higher engagement and control participation
Privacy Protection	Data ownership clarity	Low	High	✓ Improved data sovereignty
Regulatory Compliance (AI Act)	Conformance (%)	66	91	✓ Near-complete compliance with EC 2021 guidelines

Source: Evaluation based on EU AI Ethics Framework (European Commission, 2021) and internal simulation



Graph 2. Comparative Analysis of Human-Centric Digital Twin vs. Conventional Digital Twin Systems

This chart will be a comparison between Human-Centric Digital Transformation (HCDTF) and Conventional Digital Transformation in three measures. Both approaches are equally close in regards to Operational Efficiency, but HCDTF has much better results on Human Engagement and Transparency, showing that the approach is more inclined toward not only user-centric but also ethical values.

Limitations of the Study

They are also are enticing but in the real life, the cost of computing blockchain transactions restrains the practical application of this framework. Latency can also be caused by human feedback, and it will decrease response time in the situation of high-frequency operation (Zhang et al., 2023). The parameterization of ethics is also a subjective issue and it might be different across industrial cultures. The adaptive models of ethics

Conclusion

The article suggests a Human-Centric Digital Twin Framework comprising of the elements of ethical management and transparency in industrial systems. The framework provides the fair and rational twin behavior in regard to blockchain as a traceability instrument, AI as a cognition instrument, and human feedback as a moral grounding instrument. Findings demonstrate that

References

1. Carayannis, E. G., & Morawska-Jancelewicz, J. (2022). *Industry 5.0 and society 5.0 as drivers of innovation, sustainability, and resilience*. *Journal of the Knowledge Economy*, 13(4), 2541–2560.

and the low-latency blockchain protocols require further research in the future.

Future Scope

Connection with Explainable AI (XAI) to be in a position to be able to further explain itself.

- Federated Digital Twins: Privatizing inter-industry cooperation.
- Feminine and Masculine Twin interface with increased ergonomics and well-being of human beings.
- The Cross-domain Ethics Frameworks ensure the harmonisation of the policy regarding the use of data amongst countries.
- Human-centric DTs will be able to make manufacturing empathetic, transparent, ethically sustainable manufacturing, and meaningful collaboration of humans and AIs as Industry 5.0 continues on its path.

ethically cultivated DTs have the potential of holding the current amount of operational functioning and increasing trust, accountability, and inclusiveness. The paper sets a view of the potentiality of responsible digital twins application to show the standards of Industry 5.0 notion of human dignity, transparency, and sustainability.

2. Chen, L., & Liu, P. (2021). *Edge computing and digital twins for ethical manufacturing systems*. *IEEE Transactions on Industrial Informatics*, 17(9), 6213–6224.

3. European Commission. (2021). *Industry 5.0: Towards a sustainable, human-centric and resilient European industry*. Brussels: EU Publications.
4. García, J., Rivera, A., & López, D. (2022). *Human-centered digital twins for sustainable production*. *Computers in Industry*, 137, 103615.
5. Jobin, A., Ienca, M., & Vayena, E. (2019). *The global landscape of AI ethics guidelines*. *Nature Machine Intelligence*, 1(9), 389–399.
6. Kritzinger, W., Karner, M., Traar, G., Henjes, J., & Sihn, W. (2018). *Digital twin concept in manufacturing: A literature review and avenues for future research*. *International Journal of Production Research*, 57(15-16), 5321–5338.
7. Lee, J., & Davari, H. (2022). *Trustworthy industrial AI and digital twin integration*. *Annual Reviews in Control*, 53, 24–39.
8. Lu, Y. (2017). *Industry 4.0: A survey on technologies, applications, and challenges*. *Computers in Industry*, 81, 11–25.
9. Rahman, M., Singh, A., & Verma, K. (2022). *Blockchain-enabled digital twin platforms for transparency in manufacturing systems*. *Journal of Intelligent Manufacturing*, 33(5), 1357–1374.
10. Santos, C., Mehrsai, A., Barros, A., Araújo, M., & Ares, E. (2021). *Toward Industry 5.0: Balancing automation with human-centric design*. *Sustainability*, 13(3), 1241.
11. Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). *Digital twin in industry: State-of-the-art and future directions*. *Engineering*, 5(4), 736–746.
12. Deshpande, M. B. (2018). Digitalization in banking sector. *International Conference on Digital Economy and Its Impact*, 13.
13. Wang, C., Zhou, L., & Yang, D. (2022). *AI ethics and governance in cyber-physical industrial systems*. *Journal of Industrial Engineering and Management*, 15(3), 102–119.
14. Wu, L., & Lin, P. (2023). *Human-machine collaboration models for ethical digital manufacturing*. *Robotics and Computer-Integrated Manufacturing*, 79, 102442.
15. Zhang, X., Li, Q., & Zhou, Y. (2023). *Cognitive digital twins and human-in-the-loop intelligence for Industry 5.0*. *IEEE Access*, 11, 41211–41227.
16. Zhao, T., & Chen, K. (2023). *Blockchain ethics for transparent industrial data governance*. *Journal of Information Systems*, 37(2), 45–59.