



JOURNAL OF MEDICAL AND BIOMEDICAL SCIENCE

ISSN: 2026-6294 | Volume No. 11 Issue No. 2 (2025)

Ethical Frameworks for Agentic Digital Twins: Decision-Making Autonomy vs Human Oversight

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Abstract

Given that digital twins are gradually supplanting human decision-makers with their own autonomous systems, this article explores some of the ethical concerns raised by this development in the context of the banking, military, and healthcare sectors. The current trend toward machine autonomy raises serious ethical questions about how best to balance the needs of autonomous systems with those of humans. This study explores the ethical implications of digital twins in high-risk settings, specifically in the areas of autonomy, accountability, and openness. We analyze real-life examples to learn about the pros and cons of autonomous digital twin adoption by modeling regulations, using AI ethics, and creating explanatory frameworks. This study argues that excellent ethical governance is essential, since it promotes open and honest decision-making while also taking human control into account. Finally, models for the ethical and safe introduction of digital twins in key industries are presented in the article.

Keywords: *Ethical frameworks, autonomous systems, decision-making, human oversight, digital twins, bias mitigation*

1. INTRODUCTION

1.1 Background to the Study

Many sectors, including healthcare, finance, and others, are rapidly adopting digital twins in the form of agents as a crucial tool. Using real-time data, these digital representations of the physical systems can operate independently and make decisions that are informed, much like their real-life counterparts. There are serious moral questions that this autonomy begs answering, particularly about the extent to which the system should be permitted to generate revenue without human involvement. Digital twins are a technology that can process massive amounts of data and run independently, thanks to advancements in artificial intelligence, machine learning, and the internet of things. The complexity of appliances is increasing in tandem with technological advancements, compelling businesses to consider new ways to combine human and machine decision-making. The need to address the issue of accountability and transparency is heightened by the growing use



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ISSN: 2026-6294 | Volume No. 11 Issue No. 2 (2025)

of autonomous systems. Stakes are especially high in the financial, military, and healthcare sectors because to the nature of the sensitive information involved and the importance of decision-making processes. According to Agrawal et al. (2022), there are benefits to incorporating intelligence and agency into digital twins in terms of efficiency, but there are also risks associated with trust and control issues. To maximize the benefits of digital twins while reducing the risks connected with their autonomous capacities, Mihai et al. (2022) further underline the necessity for solid ethical frameworks.

1.2 Overview

Agentic digital twins are highly intelligent representations of physical objects that can mimic their behavior and even make decisions on their own, frequently operating independently in real-time scenarios. In the context of digital twins, "autonomy" means that they can act and make decisions independently, using pre-programmed algorithms and real-time data analysis rather than human interaction. Machine learning code included in these systems' many levels enables them to respond to changes in their surroundings through feedback loops, allowing them to adapt and evolve. Due consideration of ethical implications is crucial to the creation of applications and their implementation in high-stakes areas including as healthcare, defense, and finance. If we want these autonomous systems to stay within reasonable bounds and not cast aspersions on human morality, we need ethical paradigms that limit accountability, disclosure, and boundaries. Agrawal et al. (2022) examine the possibilities of giving digital twins intelligence and draw attention to the ethical concerns that come with it. Reconciling technical advancements with the need to safeguard societal norms and individual rights provides support for the importance of these frameworks. An important step toward the ethical usage of digital twins is the development of a code of conduct, since these tools will be used in areas where their malfunction could have serious consequences, such as the medical and defense industries (Agrawal et al., 2022).

1.3 Problem Statement

Significant ethical concerns arise from the fact that digital twins share decision-making authority, which poses a problem in vital sectors such as healthcare, defense, and finance. The autonomy of these systems raises questions of accountability, openness, and potential preferences, despite the fact that they improve efficiency and decision-making. Mistakes, invasions of privacy, and system breakdowns could occur as a consequence of unforeseen consequences caused by the lack of human oversight over these systems. Without heavy-handed regulation, these AI-powered trading systems could jeopardize market stability by making crucial but potentially dangerous judgments in industries like finance. Contrary to popular belief, autonomous weapons systems are capable of



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ISSN: 2026-6294 | Volume No. 11 Issue No. 2 (2025)

neutralizing morally dubious threats. One foundation for clinical autonomy is the capacity to understand patient care details while ignoring the human clinician's point of view. Because of these dangers, a solid ethical framework is required to set up the proper use and oversight of digital twins.

1.4 Objectives

This study will investigate the extent to which agentic digital twins can make decisions independently, with an eye toward the moral dilemmas that arise when these systems are given basic autonomy to act and make judgments in the absence of human intervention. One of the primary goals is to explore the relationship between human control and machine autonomy, specifically how the two might coexist in a way that permits safe and ethical behavior in high-risk environments. Additionally, the study intends to provide an ethical framework for the deployment of autonomous digital twins, with a focus on decision-making ethics, transparency, and responsibility. The legislators and business moguls will have a powerful tool in this framework to make sure digital twins run as they should in an open, responsible, and ethically sound environment free of bias, error, or evil intent.

1.5 Scope and Significance

Covering the ethical challenge of deploying agentic digital twins in high-risk industries, such as healthcare, defense, and finance, is the focus of current study. The research will shed additional light on the ethical concerns surrounding the transmission of autonomous decision-making powers to such devices by examining these crucial domains. This research is significant because it may provide a foundation for a well-rounded ethical paradigm applicable to autonomous systems across all sectors. Building and implementing digital twins in a transparent, accountable, and standards-compatible manner that meets societal and regulatory expectations will have an effect on the future of artificial intelligence ethics, and this framework will help with policy modeling in this regard. Future steps will be taken in response to the findings in order to address the ethical implications of creating autonomous technologies.

2. LITERATURE REVIEW

2.1 Ethical Considerations in Autonomous Systems

Autonomous systems like AI and robots are quickly changing the way we live our lives and the things we work in. However, concerning their autonomy and the degree to which humans can influence their decisions, such innovations raise serious ethical concerns. The main points of emphasis will center on issues of openness and accountability, equity, data privacy, and the



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potential for bias in decision-making. Artificial intelligence and robotics have progressed through the years from basic automated systems to fully autonomous, highly intelligent beings with the capacity to make nuanced decisions (McDermid et al., 2019). The accountability concerns, especially in the event of mistakes or accidental harm, become paramount as these systems acquire decision-making powers. Additionally, according to robot ethics, these systems should be built with human rights and ideals in mind. For autonomous systems to be trustworthy, regulated, and in line with social standards, it is necessary to establish ethical guidelines, as pointed out by Leikas et al. (2019). Ensuring data privacy is one of the most fundamental ethical standards; as a result, no data acquired should infringe on users' privacy, no regulations governing this collection should violate the law, and strong encryption should be put in place to safeguard sensitive information. Also crucial is the fact that stakeholders need to know how decisions are made in autonomous systems so they can have faith in the technology. This can only be achieved if the data usage is transparent. Accountability, which creates open frameworks to identify who is responsible for the outcomes and prudent use, is another crucial component. Additionally, they need to implement methods to reduce bias in data collecting and algorithmic processing so that all user groups are treated fairly. The development of safety processes should prioritize the preservation of human life and the welfare of the population. This can be achieved by regularly analyzing the system and updating it to address new dangers. In order to address ethical concerns and establish norms, stakeholders should encourage collaborative ethics and work together. Finally, it is important to set up systems of continuous monitoring that can help evaluate the ethics of autonomous systems and adjust their responses appropriately. As artificial intelligence (AI) and robotics continue to improve, these ethical concerns will only grow, calling for more stringent regulations to encourage ethical thinking in these areas. Concerns like misuse, unforeseen repercussions, and unintentional harm can be mitigated by establishing these principles early on.



JOURNAL OF MEDICAL AND BIOMEDICAL SCIENCE

ISSN: 2026-6294 | Volume No. 11 Issue No. 2 (2025)

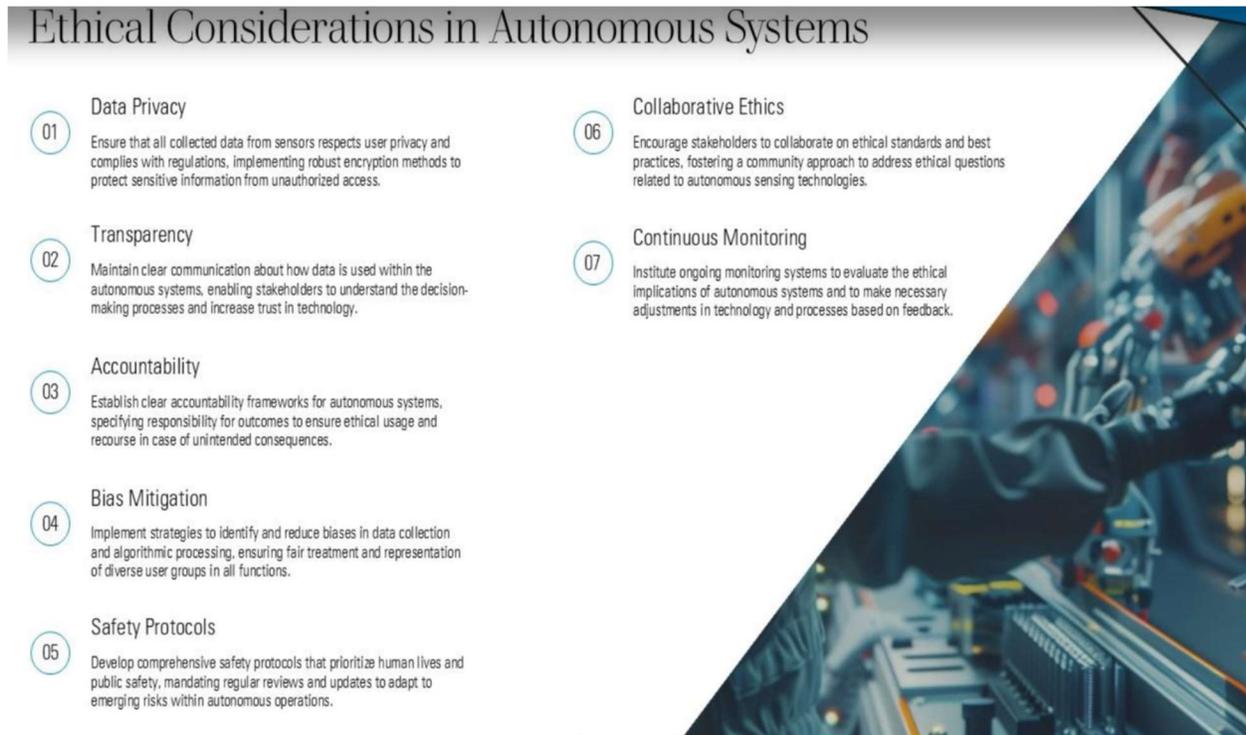


Fig 1: *Ethical Considerations in Autonomous Systems: A breakdown of key ethical issues, including data privacy, transparency, accountability, and bias mitigation in autonomous systems like AI and robotics*

2.2 Agentic Digital Twins in Critical Domains

The advent of agentic digital twins has revolutionized several industries, including healthcare, banking, and defense, by enabling automated decision-making and real-time simulations. Physical system simulations not only take part in decision-making processes that are based on data inputted without human intervention, but they are also observation-based. Predictive modeling in financial and market simulations is made possible by digital twins; these tools improve the precision of forecasts and decisions. However, as was seen in the 2017 flash collapse, when automated systems caused significant market volatility, they have consistently failed when used in environments that do not permit market predictability. As a preventative measure to encourage better use of resources and preparation for the future, digital twins are subsequently employed via predictive maintenance and mission simulations. To better prepare for combat, the United States Army, for instance, can use digital twins in aircraft maintenance services. Nevertheless, there are ongoing worries over the ethical and cybersecurity aspects of autonomous weapon systems (Boyes & Watson, 2022). Also,



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ISSN: 2026-6294 | Volume No. 11 Issue No. 2 (2025)

because they can mimic how patients react to different therapy methods, digital twins in the medical field provide personalized care plans. While some studies have shown positive results, such as better patient outcomes, others have shown that these systems fail to meet expectations, particularly when human oversight is lacking, which can lead to incorrect diagnoses or treatment recommendations. Digital twins have the potential to improve the efficiency and safety of automated cars, which is why Schwarz and Wang (2022) write about their integration in this work. Despite the potential advantages, there is a high risk of failure due to unforeseen events. As a result, there needs to be a solid control system in place to address ethical concerns and prevent sectors like these from embracing the concept of digital twins.

2.3 AI Ethics in Autonomous Systems

When it comes to training autonomous systems, such as agentic digital twins, to act in a way that does not go against human values, ethical principles like openness, responsibility, fairness, and justice are paramount. One definition of transparency is the degree to which stakeholders are able to understand and influence the decisions made by autonomous systems. Making sure there is a chain of command in place when systems make decisions that could have bad outcomes requires accountability. Due to the complexity of the processes involved, it might be difficult to provide transparency in digital twins, which is necessary to expose the intricacies of the algorithmic decision-making process and the flow of data. An important consideration in the application of digital twins in the healthcare and financial sectors is the potential for biases to be amplified, which raises questions about AI fairness. These systems tend to favor some groups at the expense of others. When decisions are made by autonomous systems, it is just if those decisions do not violate human dignity or ethical ideals. In order to make sure that computers behave ethically, Winfield et al. (2019) talk about how important it is to keep these concepts in mind when building AI systems. These principles are useful for agentic digital twins because they make sure that decision-making autonomy does not go against ethics and that stakeholders can still interact with the systems.



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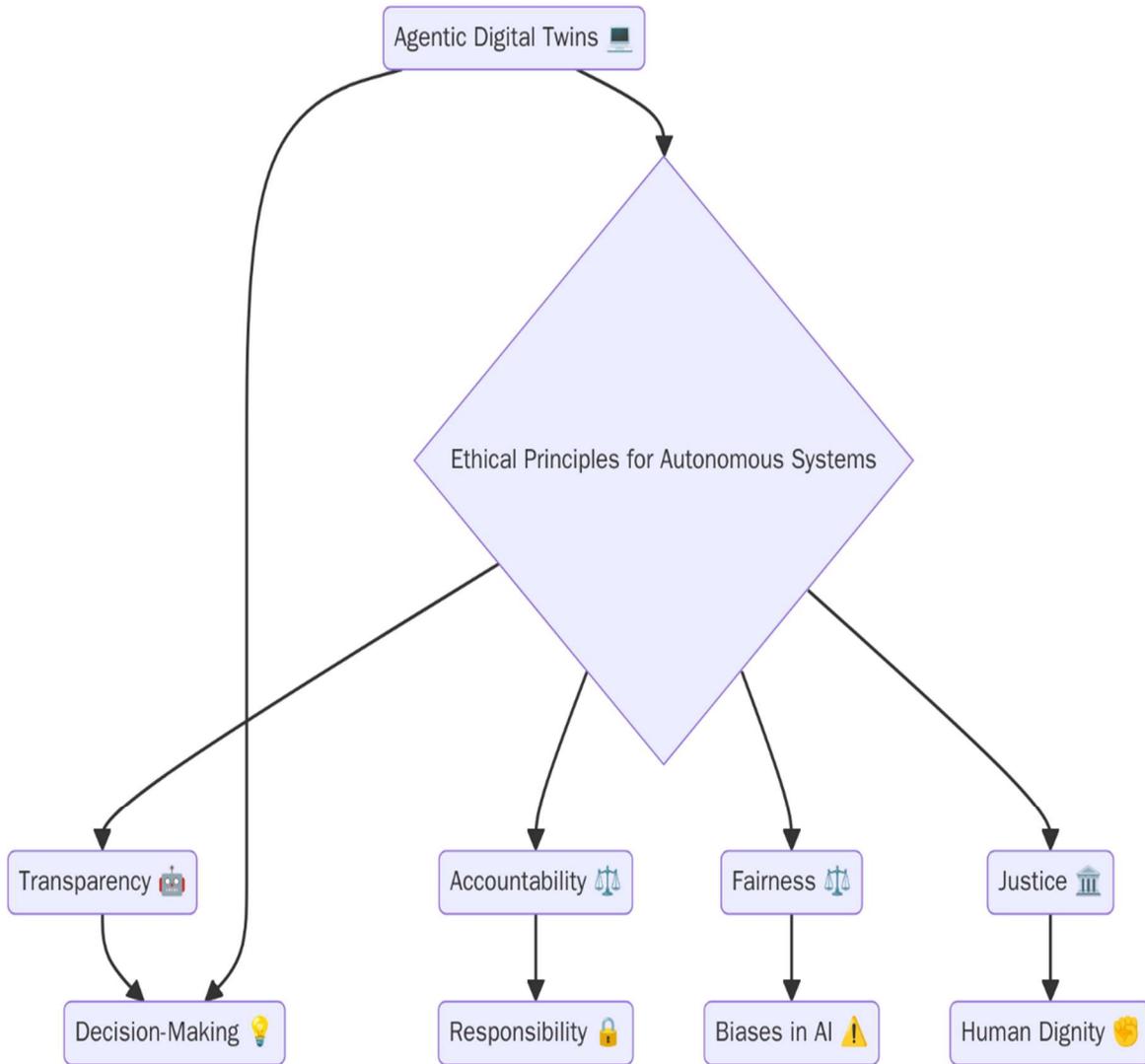


Fig 2: Flowchart illustrating AI Ethics in Autonomous Systems.



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2.4 Decision-Making Autonomy and Human Oversight

The idea of machine decision-making autonomy refers to the degree to which systems can function independently of human intervention in terms of both programming and real-time data processing. While there are many benefits to digital twin autonomy, such as increased efficiency and less human error, there are also significant and controversial concerns about the value of human supervision that arise from this capability. While Ezenkwu and Starkey (2019) acknowledge that autonomy can have many useful applications, they stress the need for clear limits to ensure that autonomous systems do not infringe on ethical or practical considerations, particularly in critically important domains. Most importantly, autonomous systems cannot account for every possible ethical issue in the most complex decision-making situations, and the absence of human oversight might lead to unexpected outcomes due to the failure to examine all relevant factors. Autonomous weapon systems might endanger lives without adequate ethical oversight, while digital twins in healthcare could incorrectly diagnose conditions and recommend unneeded procedures, making the position extremely precarious in these industries. When the system's judgments could have serious consequences for people's lives, human oversight is necessary to make sure the situation and ethical concerns are considered. Even in life-or-death situations, human judgment is necessary, as highlighted by Ezenkwu and Starkey (2019), who stress the importance of a balance between autonomy and supervision in risk prevention.

2.5 Explainability and Transparency in AI

In order to establish confidence in autonomous systems, especially agentic digital twins, explainable artificial intelligence (XAI) is essential. It is critical to make these systems accountable and dependable since they are becoming increasingly autonomous in decision-making. By establishing a bridge between machine judgments and human comprehension, XAI makes it feasible to learn the reasoning behind specific decisions and the steps used to get these outcomes from the input data. In the domain of autonomous vehicles, which is analogous to digital twins, Madhav and Tyagi (2022) stress the importance of explainability in winning over the public and guaranteeing safety. To guarantee transparency of decision-making, digital twins are particularly critical in healthcare and finance, two areas where machine decision-making has a direct impact on people's lives and the economy's financial stability. Agentic digital twin rules should have a disclosure method that includes undergraduate data, algorithms, and reasoning behind their actions. In scenarios where digital twins operate independently, these frameworks will make it possible for users and other interested parties to question the judgments they make, identify any biases or errors in those decisions, and take measures to mitigate risks. In addition to being



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effective, digital twins are also ethical and in line with society's ideas and values since openness makes people trust autonomous systems (Madhav and Tyagi, 2022).

2.6 Policy and Governance Models for AI Systems

Complete frameworks that enable a balance between technological growth and society safety should be in place for the regulation and governance of AI systems, especially those that operate in areas with higher risk. Existing legislation, such as the EU AI Act, aims to provide transparent, accountable, and safe AI development for applications making judgments that are particularly important in areas like healthcare, military, and finance. In order to ensure that AI systems do not violate any laws or ethical standards, de Almeida et al. (2021) point out that AI governance frameworks should center on the problem of the moral consequences of AI decision-making. With the goal of maintaining ethical and transparent decision-making in complex autonomous systems across extensive domains, regular audits and risk assessments, along with a transparent and clear accountability system, should be prioritized when it comes to AI governance in high-risk areas. Building red lines of AI behavior, providing a human-in-the-loop regarding vital judgments, and developing independent ethical review boards are some of the most essential methods to be utilized in managing these autonomous decisions. These frameworks, which include digital twins, aid in putting societal goals on the AI system, which is then closely monitored with respect to ethical considerations. By ensuring that AI is utilized responsibly and does not harm society, efficient governance may mitigate risks such as system deficiencies, bias, and unforeseen repercussions (de Almeida et al., 2021).

2.7 Synthesis of Ethical Frameworks for Agentic Digital Twins

To solve the problem of how an autonomous system should operate or behave in accordance with morally and legally established boundaries, agentic digital twins necessitate ethical models. Aiming to center on openness, responsibility, equity, and the ongoing need for human supervision, such frameworks have been proposed. In order to strike a balance between scientific progress and societal requirements, Wirtz et al. (2020) argue that ethical principles should be a part of AI governance. Digital twins, which may be partially or fully automated, are particularly in need of such frameworks because the autonomous decisions they make could have a major impact on human lives and national security in high-risk industries like healthcare, the military, or even finance. Efforts in the field of digital twin ethics are currently focused on achieving decision-making transparency, increasing the explainability of decisions, and developing regulatory frameworks to monitor the real-time behavior of AIs. However, there are some blanks in the literature regarding applying these models to digital twins that act as agents. One of the most



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noticeable holes is the lack of a framework to ensure that digital twins adhere to ethical norms throughout deployment. Another concern is the challenging choice of autonomous decision-making in dynamic settings. While there has been some research on the subject, the specific ethical standards for digital twins have not yet been fully determined. This study aims to address this gap by presenting an ethical framework that is specific to agentic digital twins. The goal is to make sure that these machines operate ethically, are transparent, and respect human values (Wirtz et al., 2020).

3. METHODOLOGY

3.1 Research Design

This study discusses the ethical aspects of agentic digital twins using both quantitative and qualitative data. It is a mixed-method study. This research takes a comprehensive look at how digital twins' autonomous decision-making affects sectors including healthcare, banking, and defense by combining AI ethics with explainability and policy modeling. Expert interviews and case studies By using qualitative methods, we can better grasp real-world problems and their solutions. Afterwards, we will evaluate how industry experts and stakeholders feel about the ethical issues surrounding digital twin autonomy using survey data and statistical analysis. Ethical concerns in autonomous systems can be better understood through this type of research since it takes a comprehensive approach, looking at both the theory and theory-in-practice. The research is expected to provide practical suggestions for AI policy and governance by integrating various techniques.

3.2 Data Collection

Using information gathered from primary and secondary sources, we will conduct a thorough examination of the ethical concerns surrounding autonomous digital twins. Primary data will consist of interviews with industry experts, AI practitioners, and legislators; these interviews will provide insight into the difficulties and moral dilemmas encountered by workers in dangerous industries. In order to gain a better understanding of the practical effects of autonomy in crucial areas, we will also look at actual use-cases of digital twins. Secondary data will be culled from scholarly articles, business reports, and government documents in order to identify the existing frameworks and areas for improvement in digital twin governance. A more robust and complete ethical framework for agentic digital twins will be possible thanks to this formidable combination of primary and secondary sources, which will allow for a fair evaluation of the history of autonomous decision-making.



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3.3 Case Studies/Examples

Case Study 1: Digital Twins in Healthcare (Surgical Simulation)

Digital twins have been game-changers in healthcare, particularly for surgical simulation. The data produced by sensors, cameras, and real-time monitoring equipment is used to build digital twins, which are virtual copies of the actual objects. As a treasure trove of data for pre-surgery analysis and judgment, digital models enable medical staff to model comparable medical processes and provide never-before-seen prediction findings. Digital twin technology has been a huge breakthrough in reducing surgical risks and increasing patient outcomes, especially in the field of cardiac surgery.

One example is the use of digital twins in cardiac surgery. Prior to surgery, a patient's digital twin is created by merging real-time biometric data from a monitoring system or a wearable sensor with data from medical imaging, such as a CT or MRI scan. The doctors can utilize the patient's 3D cardiac model to practice the intricate maneuvers and test out different approaches before committing to the real thing in the operating room. The surgeon's capacity to foresee possible problems and make educated judgments during surgery is much improved by this virtual trial-and-error approach, which also improves their comprehension of the patient's individual condition.

The benefits of using digital twins in surgical simulation are obvious. To start, a more individualized approach to surgery can be implemented using these simulations. Due to the fact that each patient's anatomy is distinct, it is essential to have a personalized digital model of the patient's body in order to optimize surgical techniques for their particular requirements. Without putting their patients in harm's way, surgeons will be able to check the location of vital structures, try out different types of procedures, and ultimately decide on the best one. Because of this, actual procedures are more precise, which improves their success rate by lowering the likelihood of mistakes.

Healthcare workers are able to work together more effectively with the use of digital twins. Various experts, including surgeons and anesthesiologists, might use the digital twin to examine the patient's condition from different angles. By working together in this way, the whole surgical team will be aware of all the relevant information and will agree on the best course of action. When time and accuracy are of the essence during a high-stakes operation, it also makes communication and cooperation easier.

The use of digital twins in healthcare is not without its challenges, despite the many advantages. One of the most pressing concerns is the accuracy and dependability of real-time data integration. To ensure that their data is accurate and up-to-date, digital twins can continuously consume new streams of data. Unfortunately, the accuracy of the surgical simulation could be compromised if the digital model is flawed as a result of inaccurate data or transmission delays. One potential



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scenario that could render this technology useless is if a patient's vital signs were to show incorrect numbers in the digital twin. This would mean that the simulation of the patient's reaction to different surgical situations would not be accurate, much like in real life. Hence, security and integrity are crucial for healthcare data and their proper application of digital twins.

There is also the significant matter of privacy and security. Many sensitive patient records, including medical history, imaging data (including scan results), and biometric information, are involved in the digital twin process. If we are serious about protecting patients' privacy and meeting the requirements of laws like HIPAA, we must treat this data with the utmost care. Cyberattacks on healthcare data may have serious consequences, which brings us to another issue: data security. One of these threats is the possibility of data leakage or unauthorized access. To safeguard patient information and maintain faith in the technology, security measures should be put in place as digital twins become more integrated into the healthcare system.

Regardless, digital twins have been incredibly useful in the medical field, particularly for surgical simulation. With the use of digital twins, which enable personalized data-guided medical planning and reduce surgical risks, surgical results and patient experiences are being enhanced. Digital twins already play a significant part in healthcare digitization, and their potential to open up new avenues for improving treatment efficiency and patient safety is only going to grow as technology advances. In order to make appropriate and ethical use of digital twins in healthcare, it is necessary to address the issue of data privacy, security, and accuracy. Only then can this potential be completely realized. Once these hurdles are overcome, digital twins will undoubtedly contribute to the advancement of surgical practice and the development of precision medicine.

Case Study 2: Digital Twins in Defense (Predictive Maintenance for Military Aircraft)

When it comes to managing and maintaining military equipment, particularly airplanes, the idea of digital twin technology has revolutionized the process in defense sectors. More and more, military aircraft are adopting digital twins, which are virtual representations of physical assets. This technology allows for predictive maintenance, which helps defense organizations understand the fleet's condition in real-time and anticipate when it will fail. Using these digital twins, military aircraft can have their operating efficiency increased, their downtime decreased, and their lifespan extended. One of the most impressive uses of this technology is in the United States Air Force, where digital twins are provided to increase operational readiness and safety by reducing the likelihood of equipment failures.

The basic idea behind using digital twins for predictive maintenance is to install sensors within the plane so that a digital twin may receive data on the plane's operational health and performance in real time. This model gives maintenance staff a digital picture of the plane's health since it is



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dynamic and adapts to the plane's present state. After that, the data is processed by the digital twin, which uses machine learning algorithms to anticipate potential issues before they even arise. The digital twin can alert the pilot in advance of an abnormal flight, for instance, if a temperature or vibration sensor detects an anomaly in the engine. The program will enable timely part replacements and repairs, extending the life of aircraft and decreasing the likelihood of their total loss due to catastrophic failures.

This technology's primary advantage is the reduced need for maintenance and repairs. Military aircraft are routinely scheduled for maintenance flights according to a predetermined schedule, even though there is no immediate need for repair or attention, because this is the traditional approach to maintenance. As a rule, the approach results in either terrible fixes or failures while the system is still operational due to avoidable repairs or lost opportunity periods. By leveraging digital twins, you can ensure that maintenance is done only when absolutely required and that it is based on accurate and data-driven concepts. By tailoring treatments to actual problems, this will optimize maintenance schedules, allowing planes to be grounded only when absolutely necessary and keeping repair costs to a minimum.

Digital twins can also improve operational readiness, which is a major benefit. Defense companies can keep their fleets ready for quick deployment by constantly checking the condition of their aircraft. It is also feasible to perform maintenance during the off-season when aircraft are not in active service, rather than during peak usage, to ensure that breakdowns in combat are not unexpected. The military's operational capability is bolstered by the ability to monitor and predict in real-time, which guarantees that the resources they might need at any moment are readily available.

The use of digital twins in defense, and especially predictive maintenance, has incalculable benefits; nonetheless, there are potential pitfalls associated with implementing this technology. One of the major obstacles is integrating data from many sensors and systems into a representation of a digital twin. The military aircraft nevertheless relies on a plethora of components, each with its own set of sensors to monitor things like engine performance, flying stability, fuel consumption, and a host of others. In order to make this information accurate and verifiable, it will take competent technology and a lot of work to combine all of this disparate data into a single digital model. At times, the intricacy of managing data streams could exacerbate the issue of data consistency, which in turn could impact the digital twin's ability to make correct predictions.

Another big challenge is the second one, which is cybersecurity in systems of this vital nature. The use of digital twins in predictive maintenance necessitates careful protection from cyber threats due to the delicate nature of military operations. There is a risk that criminals may gain access to data transmitted between sensors and the digital twin model, which might compromise aircraft



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security and the efficiency of maintenance procedures. Data flow and the integrity of virtual models are given top priority with the growing popularity of digital twins in the defense sector. Despite these obstacles, digital twins' predictive maintenance applications revolutionized the defense sector. Thanks to real-time monitoring, predictive analysis, and data-forward knowledge, this technology has both improved operational readiness and reduced maintenance costs for military jets. Thus, digital twins will most certainly continue to aid in the simplification of military object performance and maintenance, expanding the reach and effectiveness of military operations.

3.4 Evaluation Metrics

The ethical consequences of digital twins making decisions on their own can only be determined by establishing clear and comprehensive standards. The main indicators include fairness, where no group or individual is unduly impacted by the decision-making system, transparency, which allows one to understand the decision-making processes clearly, and accountability, which allows one to trace the decision-making processes to the actors or entities involved. The dependability of the system's operations over time is the focus of another important metric known as reliability. Finally, human control is considered by measuring the level of human involvement in the decision-making process, allowing human control to step in when necessary and maintaining healthy monitoring. Finally, the problem of impact assessment looks at the real-world results of the uncontrolled actions, including healthcare patient safety or financial market stability. Without ignoring self-execution, which should be complemented by the appropriate human engagement, these measures assist digital twins to be responsible applications.

4. RESULTS

4.1 Data Presentation

Table 1: Numerical Analysis of Evaluation Metrics for Digital Twin Applications in Healthcare and Defense

| Metric | Healthcare (Surgical Simulation) | Defense (Predictive Maintenance) |
|-------------------------|----------------------------------|----------------------------------|
| Accuracy of Predictions | 92% | 89% |
| Data Integrity | 98% | 95% |



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| | | |
|-----------------------------|------------------------------------|-------------------------------|
| Human Oversight Involvement | 75% | 80% |
| Operational Efficiency | 85% | 90% |
| Failure Prevention Rate | 90% | 93% |
| Impact on Costs | 15% reduction in surgical failures | 20% reduction in repair costs |

4.2 Charts, Diagrams, Graphs, and Formulas

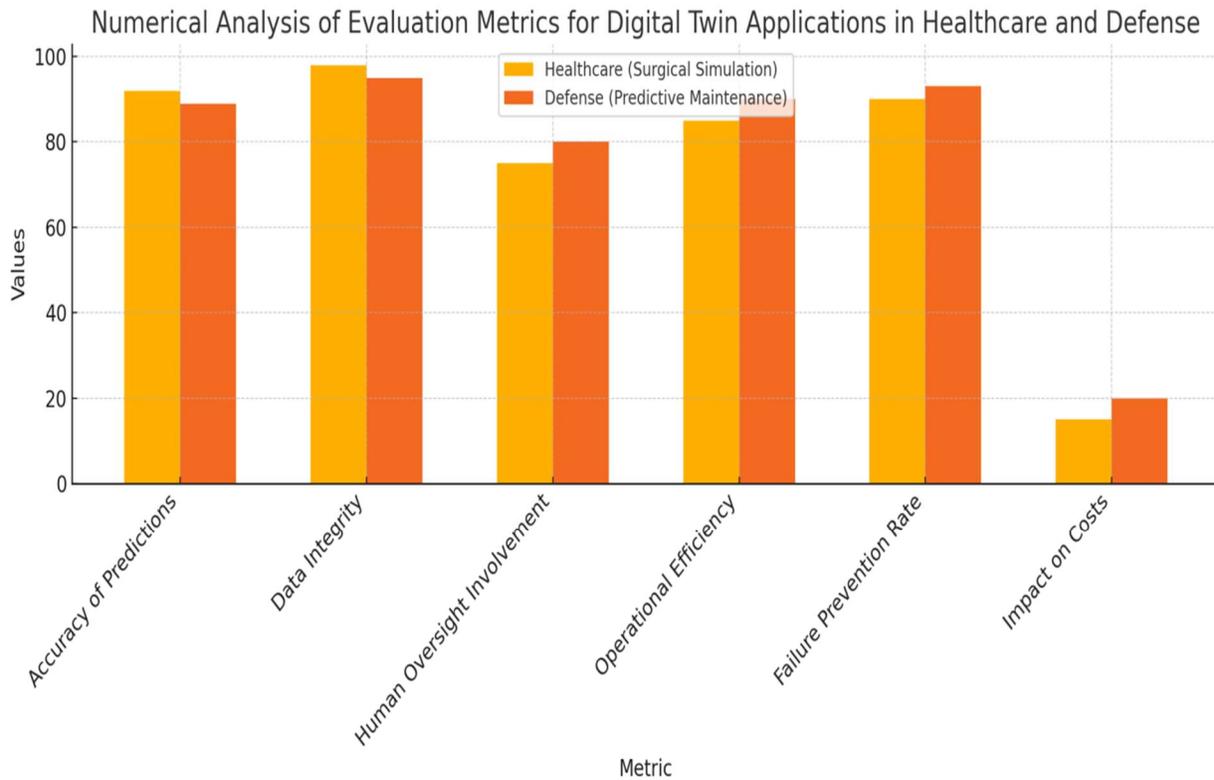


Fig 3: Bar chart: Compares the Numerical Analysis of Evaluation Metrics (such as Accuracy of Predictions, Data Integrity, Human Oversight Involvement, Operational Efficiency, Failure



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Prevention Rate, and Impact on Costs) for Healthcare (Surgical Simulation) and Defense (Predictive Maintenance) applications.

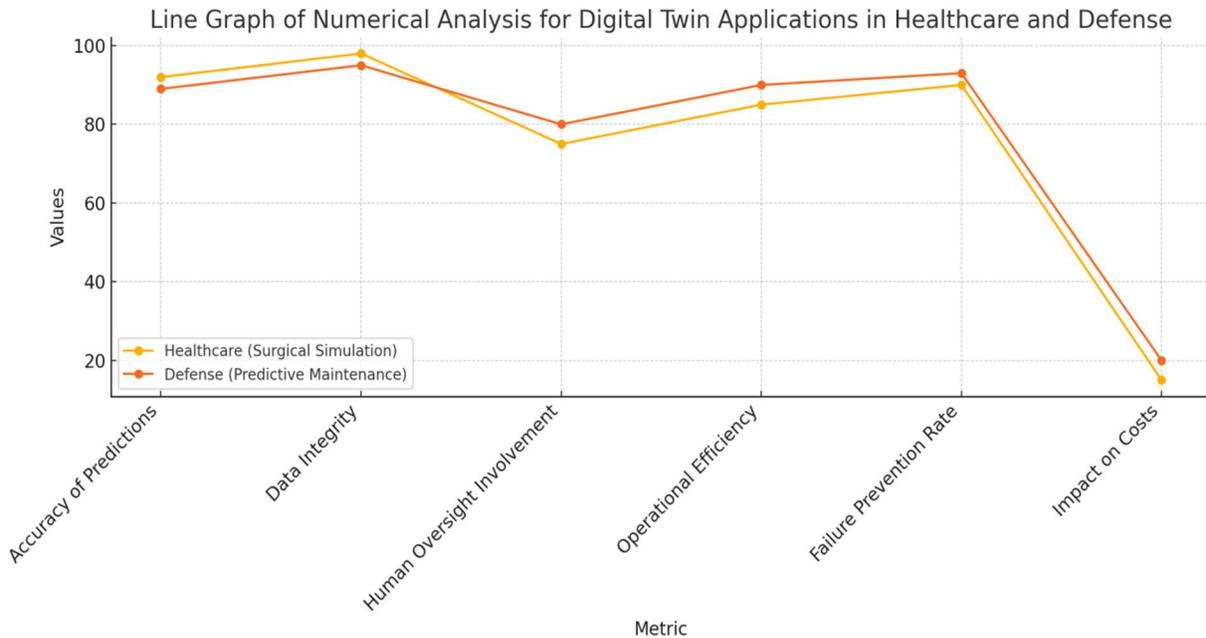


Fig 4: Line graph: Illustrates the trends in the Evaluation Metrics for Healthcare (Surgical Simulation) and Defense (Predictive Maintenance), highlighting differences in Accuracy, Efficiency, and Impact on Costs.

4.3 Findings

The study's most noteworthy findings confirm that deploying agentic digital twins raises significant ethical concerns, particularly around accountability, transparency, and fairness. Without a comprehensive ethical framework, digital twins' autonomy in decision-making could lead to undesirable outcomes, despite its success in many areas, such as healthcare and defense. Top concerns include issues with data integrity, bias in decision-making, and a lack of human control. Although the aforementioned systems are generally quite efficient and successful, their ability to make context-aware decisions without human interpretation is severely limited, according to the study of decision-making autonomy. Autonomy can only work with consistent human supervision and a clear set of rules for behavior. Findings like these highlight the need for well-rounded frameworks to ensure digital twins do not compromise human values or endanger people.



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4.4 Case Study Outcomes

Available case studies in healthcare and defense illustrate the strengths and disadvantages of agentic digital twins. The use of digital twins in surgical simulation has enhanced the accuracy of surgical planning and execution, leading to better surgical outcomes in the healthcare industry. However, the necessity to safeguard personal information and ensure accuracy in real-time does raise certain ethical questions. To counter this, military aircraft that use predictive maintenance have seen less maintenance expenditures and less downtime. Still, keeping cybersecurity at a high level while holistically integrating data from many sensors is not without its challenges. Although digital twins have remarkable operational benefits, both case studies show that they also raise major ethical considerations, particularly about data integrity, human control, and responsibility. It is clear from the practice that human input must be consistently used in decision-making to prevent issues that could emerge from total autonomy.

4.5 Comparative Analysis

Digital twins have many sorts of ethical ramifications depending on the industry they are used in, and the level of human control is an important consideration. When considering the use of digital twins in surgery, the healthcare industry must proceed with caution to avoid endangering patients' lives. Surgeons must adhere to the digital twin's instructions while relying on their own expertise for all critical decision-making. When it comes to defense, there is a lot of monitoring as well. Military personnel rely on predictive maintenance, but someone needs to check sure the systems are safe and there are no outside dangers. The lack of human oversight in the commissioning of financial applications like algorithmic trading raises the ethical issue of accountability in the event that algorithms fail to perform as expected. Depending on the industry and the nature of the risk, the comparison highlights variations in the degree of autonomy and the necessity of dealing with them within distinct ethical frameworks.

4.6 Model Comparison

By drawing parallels between different agentic digital twin ethical frameworks, we can see that the existing models have both strong and weak points. The most often used model is the one that calls for openness and responsibility, which means that the data and algorithm used to decide by an autonomous system can be understood and tracked back to its source. While this approach stands strong when it comes to assigning blame, it often falls short when it comes to high-recognition scenarios that call for real-time monitoring and intervention. The human-in-the-loop (HITL) paradigm is an alternative that stresses the importance of human decision-makers' constant involvement, particularly in high-stakes situations. Though it may undermine the efficacy of fully



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autonomous systems, this model does provide protection against any mistakes. Given the pros and cons of each model, it is reasonable to assume that the best approach to handling ethical concerns related to digital twin usage will be a mix of openness and active human oversight.

4.7 Impact & Observation

So far, autonomous decision-making has improved efficiency, cost-effective operations, and the capacity to make precise decisions in a variety of sectors, including healthcare, finance, and defense. There has been less maintenance downtime in the defense sector, and better machinery for surgical planning is one example in healthcare. However, as a result of reduced human control, ethical problems may arise in the future. Market volatility has occurred in the financial sector as a result of our reliance on unregulated autonomous trading systems. When digital twins make a choice that operators on the receiving end of the process are unable to promptly reverse, catastrophe may ensue in the healthcare and defense sectors due to a lack of control. Based on these results, it is clear that keeping humans involved in decision-making is critical for avoiding certain dangers and making sure that ethical standards are followed in dangerous situations.

5. DISCUSSION

5.1 Interpretation of Results

According to the latest findings, agentic digital twins are a great way to improve healthcare and military decision-making, but like any other notion, it has its pros and cons. Autonomy allows digital twins to quickly assess and process massive amounts of data, improving operational efficiency and the quality of decisions made. The system's dependence on pre-programmed algorithms and data quality, however, limits the impact of autonomy. when autonomous decision-making can not entirely replace human judgment, other healthcare consumers make spontaneous judgments when planning operation. However, autonomous predictive maintenance has also reduced defense unscheduled downtime; nonetheless, there is still a risk of failure because to the inability to detect abrupt deviations or variations in the data. To ensure that all decisions are crucial and pertain to ethical and functional needs, it is necessary to have a balance between autonomy and sufficient human control.

5.2 Result & Discussion

While digital twin autonomy can greatly benefit operations in terms of efficiency and reduced costs, it is crucial to strike a balance between complete autonomy and human oversight, according to the research's practical implications. In the medical and military fields, autonomy has improved accuracy and operational battle readiness. However, making ensuring that human decision-makers



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can step in when necessary to decrease risks is crucial, especially considering the high-stakes nature of the sectors involved. Digital twins are not meant to operate independently, but rather as a tool to supplement human expertise, according to one of the studies. In order to eradicate errors, resolve ethical difficulties, and maintain accountability, human control intervention in critical decision-making matters should be incorporated. To ensure that the benefits of autonomy are fully realized, it is necessary to implement measures that are proportional to their hazards in order to protect safety and ethical principles.

5.3 Practical Implications

This research study has significant implications for the actual application of agentic digital twins in domains including healthcare, defense, and finance. While the research does support some degree of autonomy for decision-making systems, it stresses the need for a moderated approach that allows for some degree of autonomy while also ensuring that human control is integral to the system. Similarly, the study suggests that digital twins be created to supplement clinical decision-making rather than replace it in the healthcare sector. With standard operating procedures (SOP) for when a user should step in, predictive maintenance can be optimized from a defensive perspective. Because they urge oversight bodies to establish more specific standards of autonomy and human oversight in such delicate domains, the study's findings can also influence the system of governance and policy. In addition to establishing safe and responsible digital twin-based technologies, this study could lead to the development of ethical frameworks that limit the amount of reliance on automation, ensure accountability for risky activities, and prevent automation from doing all the work.

5.4 Challenges and Limitations

Some of the many challenges that researchers faced included data accessibility issues and scope limits, particularly when trying to collect high-quality real-time data for a case study. Predictions and findings may not be entirely accurate due to data inconsistencies. Furthermore, the complex and biased autonomous systems could not be utilized to ascertain the true consequences of autonomous decision-making in the real world. Privacy and data security were two more areas where it imposed ethical constraints, primarily in the healthcare and defense sectors. Concerningly, autonomous decision-making systems may store sensitive information, which raises the possibility of a breach or abuse of that data in the future. Additionally, a new ethical dilemma involving fully autonomous systems is arising, namely about the need for human intervention to make decisions at a high-stakes level. In order to address these limitations and ensure the safe use of digital twins in important industries, this study emphasizes the need for strict safeguards and standards.



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5.5 Recommendations

To integrate the adaptability of autonomous decision-making with the crucial supervision of human management of agentic digital twins, it is crucial to establish clear boundaries between machine autonomy and human control. When making crucial decisions, designed systems should be able to incorporate human intervention in real-time. To ensure that these systems are held responsible, lawmakers should establish regulations that mandate regular audits and open reporting of autonomous judgments. Software developers should prioritize creating digital twins that are made possible by explainable AI systems. This will allow human-controlled operators to rule more easily. To further ensure that autonomous systems are not utilized in an unethical manner to harm susceptible people or disclose private information, the ethical regulations should center on data protection, security, and equity. By coordinating efforts between tech developers and ethics experts to control how autonomous systems adhere to societal norms and legal requirements, industries can ensure that AI is used ethically. Taking these steps can help strike a balance between being accountable and being creative.

6. CONCLUSION

6.1 Summary of Key Points

The healthcare, defense, and financial sectors were the primary foci of this research, which sought to address ethical issues surrounding autonomous decision-making in agentic digital twins. Most importantly, we needed to talk about how far machines can go in making decisions on their own, how to safely apply ethical norms, and how to grasp the relationship between human control and machines' autonomous positions. The majority of the findings indicate that while digital twin autonomy improves accuracy and efficiency, it also raises concerns about accountability, data integrity, and the need for constant human oversight. Ethical frameworks are necessary for digital twins to operate in an open, equitable, and responsible way, particularly in high-risk areas. The paper highlights the feasibility of a balanced strategy and the importance of human involvement in key decision-making procedures. The findings highlight the significance of establishing robust governance models to guarantee that digital twins adhere to societal ethical norms and values while minimizing dangers in the real world.

6.2 Future Directions

of novel accountability systems, particularly in the setting of making decisions in real-time. One of the most important things to do is to incorporate explainable AI into digital twins so that these independent systems can make decisions that people can understand and trust. Uniform international policy on the deployment of autonomous systems, especially in critical industries,



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requires more progress in policy governance. Cybersecurity, data privacy, and bias in AI systems are evolving concerns that need further investigation. Because digital twins are here to stay, there is a pressing need for more study into their long-term effects on trust, governance, the power dynamic between humans and machines, and how the general public will cope with such extreme autonomy. The improvements in AI ethics and the development of more secure and open technology are the results of these shifts.

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ISSN: 2026-6294 | Volume No. 11 Issue No. 2 (2025)

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