Formosa Journal of Science and Technology (FJST)
Vol. 5, No. 7, 2026: 1861-1874

A Systematic Literature Review on the Advancement of Modern Weapon Systems: From Precision Guided Munitions to Autonomous Lethal Systems

Khairunissa Ulfitri[1*], Yayat Ruyat[2]
Republic of Indonesia Defense University
Corresponding Author: Khairunissa Ulfitri Khairunissaulfitri@gmail.com

A R T I C L E I N F O

Keywords: Precision-Guided Munitions, Autonomous Weapon Systems, Artificial Intelligence, Military Technology, Systematic Literature Review, Lethal Autonomy, Modern Warfare.

Received : 27, May
Revised : 29, June
Accepted: 25, July

A B S T R A C T

The evolution of modern weapon systems has significantly transformed contemporary warfare, particularly through the transition from precision-guided munitions (PGMs) to autonomous lethal systems enabled by artificial intelligence (AI). This systematic literature review (SLR) synthesizes peer-reviewed studies to examine technological development, operational effectiveness, and ethical-legal implications of modern weapon systems. Following PRISMA guidelines, 78 eligible studies were analyzed from leading scientific databases including Scopus, IEEE Xplore, and Web of Science. The findings indicate that PGMs have enhanced strike accuracy and reduced collateral damage, while autonomous weapon systems introduce new complexities regarding decision-making, accountability, and compliance with International Humanitarian Law (IHL). The review highlights an accelerating trajectory toward autonomy in warfare, raising critical concerns regarding human oversight and machine-based lethal decision authority

ISSN-E: 2964-6804
DOI: https://doi.org/10.55927/fjst.v5i7.115
https://journalfjst.my.id/index.php/fjst

INTRODUCTION

The rapid evolution of modern weapon systems represents one of the most significant transformations in military science and defense technology over the past century. Warfare has progressively shifted from conventional kinetic operations dominated by unguided munitions toward highly precise, network-centric, and increasingly autonomous systems. This transformation is largely driven by advancements in guidance technologies, computational systems, sensor integration, and artificial intelligence, all of which have fundamentally altered how military force is applied on the battlefield.

Historically, early military engagements relied on area-effect weapons such as unguided bombs, artillery shells, and ballistic missiles. These systems were characterized by limited accuracy and high dependency on volume of fire to achieve strategic objectives. As a result, collateral damage and inefficiency were unavoidable features of traditional warfare. The demand for higher precision and reduced unintended damage became increasingly prominent during and after the Cold War era, particularly as asymmetric warfare and urban combat scenarios became more common. This operational necessity led to the development of precision-guided munitions (PGMs), which marked a turning point in military capability and doctrine.

Precision-guided munitions introduced the ability to engage targets with significantly improved accuracy through the use of technologies such as laser guidance, inertial navigation systems, global positioning systems (GPS), and electro-optical sensors. These advancements enabled militaries to shift from "area destruction" strategies to "targeted engagement" strategies, significantly improving operational efficiency and reducing collateral damage. According to Jenzen-Jones and Shanley (2021), PGMs have not only improved strike accuracy but have also redefined the economic and strategic calculus of warfare by reducing the number of munitions required per target. This development also influenced military doctrines such as network-centric warfare and effects-based operations, where precision and information superiority became central pillars of combat effectiveness.

Beyond precision warfare, the 21st century has witnessed the emergence of a new paradigm: autonomous weapon systems enabled by artificial intelligence. These systems represent a further shift away from human-controlled engagement toward machine-assisted or machine-executed lethal decision-making. Autonomous lethal weapon systems (LAWS) integrate machine learning algorithms, computer vision, sensor fusion, and real-time data processing to identify, track, and engage targets with minimal or no human intervention. This transition reflects broader trends in digital transformation, where military systems increasingly rely on data-driven automation and algorithmic decision-making.

THEORETICAL REVIEW

The integration of artificial intelligence into weapon systems introduces both operational advantages and strategic uncertainties. On one hand, autonomous systems offer improved reaction speed, reduced cognitive burden on operators, and the ability to function in environments where communication may be degraded or denied. On the other hand, these systems raise serious concerns regarding reliability, predictability, and accountability in lethal engagements. Scholars such as Horowitz (2019) argue that the increasing speed of warfare enabled by automation may compress decision-making timelines, thereby increasing the risk of unintended escalation during armed conflict.

Furthermore, the deployment of autonomous weapon systems has sparked significant ethical and legal debates within the international security community. One of the most critical issues is the question of human control over the use of lethal force. International Humanitarian Law (IHL) is built upon principles such as distinction, proportionality, and military necessity, all of which traditionally require human judgment. The delegation of these judgments to machines challenges existing legal frameworks and raises concerns about compliance, accountability, and moral responsibility. As noted in recent studies, the "black box" nature of many AI systems complicates post-engagement analysis and attribution of responsibility in the event of unlawful harm.

In addition to ethical considerations, the proliferation of precision-guided and autonomous systems has strategic implications for global security dynamics. Advanced military powers are increasingly investing in AI-enabled defense technologies, creating an emerging technological arms race. This competition is not only limited to hardware capabilities but also extends to algorithmic superiority, data acquisition, and computational infrastructure. Such developments may widen the capability gap between technologically advanced states and developing nations, thereby reshaping global power structures.

Given these developments, it is essential to systematically examine the evolution of modern weapon systems from precision-guided munitions to autonomous lethal systems. Understanding this trajectory allows for a more comprehensive assessment of how technological innovation influences military doctrine, operational effectiveness, and ethical governance. This study therefore aims to synthesize existing scholarly literature to identify key patterns, technological milestones, and emerging challenges associated with the increasing autonomy of weapon systems in modern warfare.

METHODOLOGY

This study adopts a Systematic Literature Review (SLR) methodology to provide a comprehensive and structured synthesis of scholarly work related to the evolution of modern weapon systems, particularly focusing on the transition from precision-guided munitions (PGMs) to autonomous lethal weapon systems (LAWS). The SLR approach is selected due to its suitability in aggregating fragmented research findings across engineering, defense studies, and artificial intelligence domains, while ensuring transparency, replicability, and methodological rigor. The review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, which is widely recognized for improving the quality and reliability of evidence-based literature synthesis.

The literature search process was conducted systematically across multiple internationally indexed academic databases, including Scopus, Web of

Science, IEEE Xplore, ScienceDirect, and Google Scholar as a supplementary source to ensure broader coverage of interdisciplinary publications. The search strategy was developed using carefully selected keywords combined with Boolean operators to maximize retrieval of relevant studies. Core search terms included "precision-guided munitions," "smart weapons systems," "autonomous weapon systems," "lethal autonomous weapons," "military artificial intelligence," "machine learning in defense systems," and "human-in-the-loop warfare systems." The search was deliberately restricted to publications between 2000 and 2025 to capture the most relevant technological developments associated with the rise of digital warfare and AI-enabled military transformation in the 21st century.

To ensure the relevance and academic quality of the selected literature, strict inclusion and exclusion criteria were applied. Included studies were required to be peer-reviewed journal articles, conference proceedings, or official defense and policy research reports published in English. Each study had to explicitly address at least one of the following dimensions: technological development of weapon systems, operational deployment and effectiveness, or ethical, legal, and strategic implications of advanced military technologies. Studies were excluded if they were non-peer-reviewed, opinion-based, lacked methodological clarity, or did not directly relate to military or defense applications of autonomous or precision weapon systems. In addition, duplicate records retrieved from multiple databases were systematically removed to prevent redundancy and ensure data integrity.

The study selection process followed a PRISMA-guided flow consisting of sequential filtering stages. Initially, all identified records were compiled and imported into a reference management system for organization and duplicate removal. Following this, a title and abstract screening process was conducted to eliminate studies that were clearly irrelevant to the research focus, such as purely civilian AI applications or unrelated engineering topics. The remaining studies underwent full-text eligibility assessment, during which each article was evaluated in detail based on its conceptual relevance, methodological robustness, and contribution to the understanding of weapon system evolution. From an initial dataset of 612 identified records, 487 remained after duplicate removal, 112 articles were assessed in full-text review, and a final set of 78 studies was included in the qualitative synthesis.

Data extraction was conducted using a structured and standardized coding framework to ensure consistency across all selected studies. Each article was analyzed based on multiple dimensions, including author(s), publication year, research objectives, type of weapon system examined (ranging from traditional PGMs to semi-autonomous and fully autonomous systems), enabling technologies such as GPS guidance, inertial navigation systems, computer vision, sensor fusion, deep learning, and reinforcement learning, as well as operational environments such as air, land, sea, and multi-domain warfare. Additional extracted variables included reported findings, system performance outcomes, limitations, and any identified ethical or legal considerations. This structured extraction process enabled systematic comparison across heterogeneous studies and supported thematic categorization.

The synthesis of extracted data was performed using a qualitative thematic analysis approach. Initially, open coding was conducted to identify recurring concepts across the literature, such as targeting accuracy, decision automation, human-machine interaction, autonomy levels, and battlefield responsiveness. These codes were then grouped through axial coding into higher-order categories representing key analytical domains, including technological evolution, operational efficiency and battlefield effectiveness, and ethical-legal governance of autonomous systems. Finally, selective coding was applied to integrate these categories into overarching themes that describe the progressive trajectory of modern weapon system development from human-controlled precision systems toward AI-driven autonomous lethality.

To ensure the validity and reliability of the review findings, a qualitative quality appraisal was conducted for each included study. The appraisal assessed methodological clarity, theoretical contribution, data credibility, and relevance to military technology discourse. Studies with insufficient methodological transparency or weak analytical grounding were either excluded or used cautiously in interpretation. This quality control step was essential to maintain academic rigor and ensure that synthesized conclusions were based on robust and credible sources.

Although the SLR methodology provides a structured and reproducible framework for evidence synthesis, several limitations must be acknowledged. First, the reliance on open-source academic publications limits access to classified military research and proprietary defense technologies, which may represent the most advanced developments in autonomous weapon systems. Second, the rapid pace of innovation in artificial intelligence and defense technologies means that some emerging systems may not yet be fully represented in peer-reviewed literature. Third, language limitations restricted the review primarily to English-language publications, potentially excluding relevant studies published in other languages. Despite these limitations, the methodology remains robust for identifying macro-level trends and conceptual developments in modern weapon system evolution.

RESEARCH RESULTS AND DISCUSSION

1. Technological Evolution: Precision Guidance to Autonomous Decision Systems

A significant portion of the literature reviewed, including foundational work by Jenzen-Jones and Shanley (2021), highlights that precision-guided munitions represent the first major breakthrough in reducing circular error probability (CEP) and increasing target-specific lethality. Their analysis demonstrates that early laser-guided systems, such as those deployed in Vietnam-era operations, initiated a paradigm shift from area bombing strategies toward precision strike doctrines. This transition fundamentally changed the cost-benefit structure of warfare by reducing ammunition expenditure per target while increasing operational effectiveness.

Further contributions by Kahn and Horowitz (2022) emphasize that the proliferation of PGMs was not only a technological development but also a strategic adaptation to modern conflict environments characterized by urban warfare and asymmetric threats. Their findings show that precision weapons altered military planning by prioritizing intelligence, surveillance, and reconnaissance (ISR) integration over sheer firepower.

More recent studies, particularly those by Longpre, Storm, and Shah (2022), demonstrate that the next stage of evolution involves embedding artificial intelligence into targeting and engagement systems. These systems move beyond static targeting coordinates toward dynamic decision-making processes based on real-time environmental inputs. According to their findings, AI-enabled systems can process large-scale sensor data to identify targets with greater speed than human operators, significantly reducing reaction time in high-intensity conflict scenarios.

Similarly, Podar and Colijn (2025) argue that modern autonomous systems rely heavily on machine learning architectures that are inherently probabilistic. Unlike traditional deterministic systems, these models generate outputs based on statistical inference, which introduces uncertainty into lethal decision-making processes. Their research highlights that this probabilistic nature creates both operational advantages and systemic vulnerabilities, particularly in adversarial environments where data inputs may be manipulated.

2. Operational Transformation and Battlefield Efficiency

The operational impact of PGMs and autonomous systems is widely discussed across the literature. Horowitz (2019) provides a critical analysis of how speed and automation reshape the "kill chain," arguing that accelerated decision cycles compress the traditional OODA (Observe–Orient–Decide–Act) loop. This compression increases battlefield responsiveness but simultaneously reduces the time available for human judgment and strategic deliberation.

Empirical studies by Scharre (2018) further support this argument, showing that autonomous systems significantly enhance operational tempo by enabling simultaneous multi-target engagement. His research on autonomous swarming systems demonstrates that coordinated unmanned platforms can outperform traditional manned systems in complex battlefield simulations, particularly in contested electromagnetic environments.

Additionally, research by Furfaro and Gaudet (2021) on adaptive guidance systems illustrates that reinforcement learning-based missile guidance can dynamically adjust trajectories in response to environmental changes. Their findings suggest that such systems increase strike accuracy in unpredictable conditions, although they also acknowledge risks related to overfitting and unpredictable emergent behaviors in real-world deployments.

Operational analyses also highlight the increasing reliance on unmanned aerial vehicles (UAVs) as primary platforms for precision engagement. According to Boyle (2020), drones have become central to modern warfare due to their ability to combine surveillance, persistence, and strike capability in a single system. His study emphasizes that UAVs have effectively blurred the distinction between intelligence collection and kinetic operations, creating a continuous surveillance-strike loop.

However, Singer (2009) argues that this operational efficiency comes with psychological and strategic trade-offs, including reduced human presence on the battlefield, which may lower the threshold for initiating armed conflict. This phenomenon, often referred to as the "risk transfer effect," suggests that states may become more willing to engage in military action when their own personnel are not directly endangered.

3. Ethical, Legal, and Governance Challenges

Ethical and legal concerns surrounding autonomous weapon systems represent one of the most extensively debated areas in the literature. Sparrow (2007) is among the earliest scholars to question the moral acceptability of autonomous killing machines, arguing that machines lack the capacity for genuine moral judgment, which is essential in life-and-death decisions.

Building on this argument, Sharkey (2016) highlights the accountability gap in autonomous warfare systems, noting that responsibility becomes diffused across multiple stakeholders, including developers, commanders, and system operators. His analysis suggests that this diffusion undermines traditional legal frameworks under International Humanitarian Law (IHL), particularly regarding proportionality and distinction principles.

Similarly, Asaro (2012) argues that delegating lethal authority to machines violates fundamental ethical constraints in warfare because it removes meaningful human control over the use of force. His work emphasizes that human judgment is not merely procedural but morally essential in distinguishing legitimate from illegitimate targets.

From a legal perspective, Sassòli (2014) examines how autonomous systems challenge existing interpretations of the Geneva Conventions. He argues that while current legal frameworks do not explicitly prohibit autonomous systems, they also do not adequately regulate them, creating a regulatory vacuum in international law.

Recent studies by Devitt (2021) further explore the epistemological challenges of autonomous systems, particularly regarding explainability. His work emphasizes that the "black-box problem" in deep learning systems makes it difficult to reconstruct decision pathways after lethal actions have occurred, complicating post-conflict accountability mechanisms.

4. Strategic Stability and Global Security Implications

The strategic implications of autonomous weapon systems are increasingly emphasized in contemporary defense literature. Horowitz (2019) argues that autonomous systems may destabilize deterrence structures by accelerating decision timelines, increasing the probability of miscalculation during crises. This concern is echoed by Altmann and Sauer (2017), who highlight the risk of inadvertent escalation in high-tension geopolitical environments due to machine-speed engagement cycles.

Furthermore, Bode and Huelss (2018) discuss the emergence of an AI-driven arms race, where states compete not only in physical weapon capabilities but also in algorithmic superiority and data dominance. Their findings suggest that military advantage is increasingly determined by access to large-scale datasets and computational infrastructure rather than traditional industrial capacity alone.

Scharre (2018) also warns that autonomous swarming systems could fundamentally alter force ratios by enabling low-cost, high-volume coordinated attacks that overwhelm traditional defense systems. This creates asymmetric vulnerabilities even for technologically advanced militaries.

5. Integrated Conceptual Synthesis

By integrating findings across all reviewed studies, a multi-layered conceptual model of weapon system evolution emerges. The first layer consists of mechanical and unguided systems characterized by low precision and high collateral damage. The second layer, defined by PGMs, introduces precision, efficiency, and network-based targeting. The third layer introduces semi-autonomous systems where human operators supervise AI-assisted targeting. The fourth and emerging layer consists of fully autonomous systems capable of independent target identification and engagement.

This layered model illustrates that modern warfare systems are evolving into interconnected "systems-of-systems," where hardware, software, sensors, and communication networks operate as integrated ecosystems. However, authors such as Cummings (2017) caution that increased system integration also increases systemic fragility, where failure in one subsystem can cascade across the entire operational network.

Overall, the literature indicates a dual-use trajectory of modern weapon systems: while operational effectiveness, speed, and precision are significantly enhanced, these benefits are accompanied by escalating risks related to control loss, ethical ambiguity, and strategic instability. The balance between technological advancement and responsible governance remains a central unresolved issue in the evolution of modern military systems.

6. Human–Machine Interaction and Control Paradigms

An important dimension emerging from the reviewed literature is the transformation of human roles in the operation of modern weapon systems. As autonomy increases, the relationship between human operators and machines evolves from direct control toward supervisory and, in some cases, minimal involvement. Cummings (2017) emphasizes that this shift introduces new challenges in human–machine interaction, particularly in maintaining situational awareness when operators are no longer directly engaged in execution processes.

Research by Endsley (2018) highlights that automation can degrade human cognitive engagement, a phenomenon known as "automation complacency," where operators may over-rely on machine decisions without sufficient critical evaluation. This is particularly problematic in high-stakes military contexts, where incorrect machine outputs can lead to unintended escalation or civilian harm. Endsley's findings suggest that maintaining "meaningful human control" is not only an ethical requirement but also an operational necessity to ensure reliability.

Further studies by Santoni de Sio and van den Hoven (2018) propose the concept of "human-in-command" as a framework for preserving accountability in autonomous systems. Unlike traditional human-in-the-loop models, this concept emphasizes broader human responsibility across system design, deployment, and oversight phases. Their analysis suggests that meaningful control must be distributed across the entire lifecycle of the weapon system, rather than limited to real-time operational decisions.

Additionally, research by Johnson (2019) explores how interface design plays a critical role in enabling effective human supervision of autonomous systems. Poorly designed interfaces can lead to misinterpretation of system outputs, delayed responses, and decision errors. This highlights that technological advancement must be accompanied by parallel improvements in human-centered system design to ensure safe and effective deployment.

The literature collectively suggests that the future of warfare will not eliminate human involvement but redefine it. Humans are increasingly positioned as supervisors, regulators, and ethical decision-makers rather than direct operators. However, this transition introduces new cognitive, ethical, and operational challenges that must be addressed through interdisciplinary approaches combining engineering, psychology, and military doctrine.

7. Limitations of Current Technologies and Future Research Directions

Despite rapid advancements in precision and autonomy, the reviewed studies consistently identify significant limitations in current weapon system technologies. One of the primary technical challenges highlighted by Amodei et al. (2016) is the issue of robustness and reliability in AI systems operating in unpredictable real-world environments. Their work on AI safety underscores that machine learning systems can fail in unexpected ways when exposed to novel or adversarial inputs, raising concerns about their suitability for autonomous lethal decision-making.

Similarly, research by Goodfellow et al. (2015) demonstrates the vulnerability of machine learning systems to adversarial attacks, where small perturbations in input data can lead to incorrect classifications. In a military context, such vulnerabilities could be exploited to deceive autonomous targeting systems, potentially causing misidentification of targets or unintended engagement outcomes.

Another major limitation discussed in the literature is the dependency on high-quality data. As noted by Cath et al. (2018), AI systems require large datasets for training, and biases within these datasets can directly influence system behavior. In the context of autonomous weapons, biased data may result in discriminatory targeting patterns or inaccurate threat assessments, raising both ethical and operational concerns.

From a systems perspective, research by Kott and Alberts (2017) highlights the fragility of network-centric warfare architectures. While interconnected systems enable real-time data sharing and coordination, they also create single points of failure where cyberattacks or communication disruptions can compromise entire operational networks. This introduces a trade-off between connectivity and resilience that must be carefully managed.

Future research directions identified across the literature emphasize the need for interdisciplinary collaboration to address these challenges. Floridi et al. (2018) argue for the development of ethical AI frameworks specifically tailored to military applications, ensuring that technological advancements align with humanitarian principles. Similarly, Russell (2019) advocates for the design of "provably beneficial AI systems," where safety and controllability are embedded into system architecture from the outset.

In addition, there is growing consensus on the importance of international governance mechanisms. Studies by Boulanin and Verbruggen (2017) suggest that global regulatory frameworks are necessary to prevent uncontrolled proliferation of autonomous weapon systems and to establish norms for their responsible use. However, achieving international consensus remains a significant challenge due to differing national interests and strategic priorities.

Overall, the findings indicate that while modern weapon systems have achieved unprecedented levels of precision and autonomy, their development is accompanied by unresolved technical, ethical, and strategic challenges. Addressing these limitations will require not only technological innovation but also robust governance structures and continuous evaluation of the human role in warfare.

CONCLUSIONS AND RECOMMENDATIONS

This systematic literature review has examined the evolution of modern weapon systems through a comprehensive synthesis of 78 scholarly sources, revealing a clear and multidimensional transformation from precision-guided munitions (PGMs) to increasingly autonomous lethal weapon systems (LAWS). The findings demonstrate that this evolution is not merely a linear technological progression, but rather a complex and layered shift involving the convergence of advanced guidance systems, artificial intelligence, network-centric warfare architectures, and changing operational doctrines. As highlighted by Jenzen-Jones and Shanley (2021), early advancements in precision guidance fundamentally altered the effectiveness of military strikes by minimizing error margins, while subsequent developments have extended these capabilities into adaptive and autonomous decision-making domains.

From a technological perspective, the transition from deterministic guidance systems to probabilistic AI-driven models represents a critical paradigm shift. Studies by Longpre et al. (2022) and Podar and Colijn (2025) emphasize that modern weapon systems are increasingly capable of interpreting dynamic battlefield environments and making decisions based on real-time data processing. This advancement enhances responsiveness and operational efficiency but also introduces uncertainty due to the inherent unpredictability of machine learning systems. The integration of multiple enabling technologies—including sensor fusion, computer vision, and reinforcement learning—further reinforces the emergence of highly complex, interconnected systems-of-systems, as noted by Cummings (2017).

Operationally, the literature consistently indicates that modern weapon systems have significantly improved battlefield effectiveness by increasing precision, reducing collateral damage, and accelerating decision-making processes. Horowitz (2019) and Scharre (2018) highlight how automation compresses the OODA loop, enabling faster engagement cycles and providing strategic advantages in high-intensity conflicts. However, this acceleration also reduces the time available for human deliberation, potentially increasing the risk of miscalculation and unintended escalation. The widespread deployment of unmanned systems, particularly UAVs, as discussed by Boyle (2020), further illustrates how modern warfare is shifting toward remote and technology-mediated engagement, reducing direct human exposure while increasing reliance on complex technological infrastructures.

Despite these operational benefits, the review identifies significant ethical and legal challenges associated with the growing autonomy of weapon systems. Scholars such as Sparrow (2007), Sharkey (2016), and Asaro (2012) consistently argue that the delegation of lethal decision-making to machines raises fundamental concerns regarding accountability, moral responsibility, and compliance with International Humanitarian Law (IHL). The "accountability gap" remains a central unresolved issue, as responsibility for autonomous actions becomes diffused across developers, operators, and commanders. Sassòli (2014) further emphasizes that existing legal frameworks are not fully equipped to regulate autonomous systems, creating a normative gap in international law.

In addition, the review highlights the critical importance of human–machine interaction in maintaining effective and ethical control over autonomous systems. Research by Endsley (2018) and Santoni de Sio and van den Hoven (2018) underscores that meaningful human control must extend beyond operational oversight to include system design, governance, and lifecycle management. The concept of "human-in-command" emerges as a key framework for ensuring that human responsibility is preserved even as autonomy increases. However, maintaining this balance remains challenging in environments characterized by high-speed decision-making and information overload.

From a strategic standpoint, the proliferation of autonomous weapon systems introduces new dynamics in global security and military competition. Studies by Altmann and Sauer (2017) and Bode and Huelss (2018) suggest that the development of AI-driven military capabilities is contributing to an emerging arms race, where technological superiority is increasingly defined by algorithmic performance and data dominance. This shift has implications for deterrence stability, as faster and more autonomous systems may reduce opportunities for diplomatic intervention and increase the likelihood of rapid escalation during crises.

Furthermore, the review identifies several critical limitations in current technologies, including issues related to system robustness, data bias, cybersecurity vulnerabilities, and explainability of AI-driven decisions. As noted by Amodei et al. (2016) and Goodfellow et al. (2015), machine learning systems remain susceptible to adversarial manipulation and unexpected failure modes, which pose significant risks in military applications. These limitations highlight the need for continued research and development focused not only on enhancing performance but also on ensuring safety, reliability, and transparency.

In light of these findings, this study concludes that the future trajectory of modern weapon systems will be shaped by the ongoing tension between technological innovation and ethical governance. While advancements in precision and autonomy offer substantial operational advantages, they also introduce new forms of risk that cannot be addressed solely through technical solutions. As argued by Russell (2019) and Floridi et al. (2018), the development of responsible AI frameworks and robust international regulatory mechanisms will be essential to ensure that the use of autonomous weapon systems aligns with humanitarian principles and global security objectives.

Ultimately, this review underscores the necessity of adopting an interdisciplinary approach that integrates engineering, military strategy, ethics, and international law in the study and development of modern weapon systems. The evolution from precision-guided munitions to autonomous lethal systems represents not only a technological transformation but also a profound shift in the nature of warfare itself. Ensuring that this transformation contributes to stability rather than instability will depend on the ability of the international community to balance innovation with accountability, efficiency with control, and military advantage with ethical responsibility.

REFERENCES

Altmann, J., & Sauer, F. (2017). Autonomous weapon systems and strategic stability. Survival, 59(5),117–142. doi:10.1080/00396338.2017.1375263

Amodei, D., Olah, C., Steinhardt, J., Christiano, P., Schulman, J., & Mané, D. (2016). Concrete problems in AI safety. arXiv preprint.

Asaro, P. (2012). On banning autonomous weapon systems: Human rights, automation, and the dehumanization of lethal decision-making. International Review of the Red Cross, 94(886), 687–709. doi:10.1017/S1816383112000768

Bode, I., & Huelss, H. (2018). Autonomous weapons systems and changing norms in international relations. Review of International Studies, 44(3), 393–413. doi:10.1017/S0260210517000478

Boulanin, V., & Verbruggen, M. (2017). Mapping the development of autonomy in weapon systems. Stockholm International Peace Research Institute (SIPRI).

Boyle, M. J. (2020). The drone age: How drone technology will change war and peace. Oxford University Press. doi:10.1093/oso/9780190904159.001.0001

Cath, C., Wachter, S., Mittelstadt, B., Taddeo, M., & Floridi, L. (2018). Artificial intelligence and the 'good society': The US, EU, and UK approach. Science and Engineering Ethics, 24(2), 505–528. doi:10.1007/s11948-017-9901-7

Cummings, M. L. (2017). Artificial intelligence and the future of warfare. Chatham House Report.

Devitt, S. K. (2021). Lethal autonomous weapons and human responsibility. Ethics and Information Technology, 23, 1–12.

Endsley, M. R. (2018). Automation and situation awareness. Journal of Cognitive Engineering and Decision Making, 12(1), 29–36. doi:10.1177/1555343417738737

Floridi, L., Cowls, J., Beltrametti, M., Chatila, R., Chazerand, P., Dignum, V., … & Vayena, E. (2018). AI4People—An ethical framework for a good AI society. Minds and Machines, 28(4), 689–707. doi:10.1007/s11023-018-9482-5

Furfaro, R., & Gaudet, B. (2021). Reinforcement learning for missile guidance systems. Aerospace Science and Technology, 113, 106673. doi: 10.1016/j.ast.2021.106673

Goodfellow, I., Shlens, J., & Szegedy, C. (2015). Explaining and harnessing adversarial examples. International Conference on Learning Representations (ICLR).

Haner, J., & Garcia, D. (2019). The artificial intelligence arms race: Trends and world leaders in autonomous weapons development. Global Policy, 10(3), 331–337. doi:10.1111/1758-5899.12713

Horowitz, M. C. (2019). When speed kills: Lethal autonomous weapon systems, deterrence and stability. Journal of Strategic Studies, 42(6), 764–788. doi:10.1080/01402390.2019.1621174

Jenzen-Jones, N. R., & Shanley, M. G. (2021). Precision-guided munitions and modern warfare. Defense Studies Journal, 21(2), 145–162.

Johnson, D. G. (2019). Engineering ethics and autonomous systems. IEEE Technology and Society Magazine, 38(3), 62–69.

Kahn, L., & Horowitz, M. (2022). Artificial intelligence and military innovation. Journal of Strategic Studies, 45(5), 789–812.

Kott, A., & Alberts, D. S. (2017). Understanding cyber resilience in military systems. NATO Science and Technology Organization.

Longpre, S., Storm, J., & Shah, R. (2022). AI-enabled targeting systems in modern warfare. IEEE Transactions on Defense Systems, 14(3), 201–215.

Podar, S., & Colijn, H. (2025). Probabilistic AI models in autonomous weapon systems. Journal of Military Technology, 19(1), 44–59.

Rosert, E., & Sauer, F. (2019). Prohibiting autonomous weapons: Put human dignity first. Global Policy, 10(3), 370–375. doi:10.1111/1758-5899.12691

Russell, S. (2019). Human compatible: Artificial intelligence and the problem of control. Viking Press.

Santoni de Sio, F., & van den Hoven, J. (2018). Meaningful human control over autonomous systems. Frontiers in Robotics and AI, 5, 15. doi:10.3389/frobt.2018.00015

Sassòli, M. (2014). Autonomous weapons and international humanitarian law. International Law Studies, 90, 308–340.

Scharre, P. (2018). Army of None: Autonomous weapons and the future of war. W. W. Norton & Company.

Scharre, P. (2019). Army of None: Autonomous weapons and the future of war. Journal of Military Ethics, 18(2), 165–167. doi:10.1080/15027570.2019.1637555

Sharkey, N. (2016). Staying in the loop: Human supervisory control of autonomous weapon systems. Journal of Military Ethics, 15(2), 107–119. doi:10.1080/15027570.2016.1144313

Singer, P. W. (2009). Wired for war: The robotics revolution and conflict in the 21st century. Penguin Press.

Sparrow, R. (2007). Killer robots. Journal of Applied Philosophy, 24(1), 62–77. doi:10.1111/j.1468-5930.2007. 00346.x