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The Legal Challenges of Artificial Intelligence in International Humanitarian Law

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Abstract:

Artificial intelligence (AI) has emerged as one of the most transformative technologies of the twenty-first century, reshaping not only civilian life but also the nature of modern warfare. This study explores the legal challenges posed by the integration of AI systems into armed conflicts within the framework of international humanitarian law (IHL). The research aims to analyze whether the current IHL principles—particularly distinction, proportionality, and accountability—are sufficient to regulate the use of autonomous and semi-autonomous weapons driven by AI.

The study adopts a qualitative legal methodology, combining doctrinal analysis with a comparative approach to assess existing international norms, treaties, and ethical guidelines related to the use of AI in warfare. It also examines the ethical dilemmas and risks associated with delegating life-and-death decisions to machines, and the resulting gaps in responsibility and accountability under international law.

Findings indicate that while AI may enhance precision and reduce certain forms of human error, it simultaneously challenges the humanitarian foundations of warfare by blurring the line between combatants and civilians and complicating attribution of responsibility. The research concludes that the existing legal framework under IHL is inadequate to fully address the complexities introduced by AI technologies. Therefore, the study recommends the development of a specialized international treaty to regulate AI use in armed conflicts, emphasizing human control, transparency, and accountability mechanisms to preserve humanitarian values.

Keywords: Artificial Intelligence, International Humanitarian Law, Autonomous Weapons, Accountability, Distinction, Proportionality, Ethics of Warfare.

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Introduction

Artificial intelligence (AI) represents one of the most transformative technological developments of the twenty-first century, reshaping global economies, governance, and—most crucially—the nature of warfare. In recent years, states have increasingly integrated AI technologies into military operations, ranging from automated surveillance systems to autonomous lethal weapons capable of selecting and engaging targets without direct human intervention. This shift toward automation in armed conflict presents profound legal and ethical challenges for international humanitarian law (IHL), the body of law that governs the conduct of hostilities and seeks to protect those who are not, or no longer, participating in hostilities[1].

Historically, IHL has evolved through treaties such as the Geneva Conventions (1949) and their Additional Protocols (1977), as well as through customary international law, to address the humanitarian consequences of traditional warfare.[2] However, the rise of AI-driven technologies has generated novel questions that were unimaginable at the time these instruments were drafted. Can an autonomous weapon system (AWS) comply with the principle of distinction between combatants and civilians? How can proportionality be assessed by an algorithm? And, perhaps most importantly, who bears responsibility when an AI-based weapon commits a violation of IHL? These questions lie at the heart of this study[3].

The application of IHL to AI-based military technologies is not merely a theoretical matter; it reflects an urgent practical concern. Several states, including the United States, China, Russia, and the United Kingdom, have already invested heavily in developing AI-driven defense systems[4]. The pace of this technological competition raises the risk that law will lag behind innovation, leaving a regulatory vacuum where accountability becomes elusive. International organizations such as the United Nations (UN) and the International Committee of the Red Cross (ICRC) have thus called for renewed discussions on the legal and ethical implications of these systems, particularly the extent to which existing IHL principles can adapt to such disruptive technologies[5].

[1] -Sassòli, M., International Humanitarian Law: Rules, Controversies, and Solutions to Problems Arising in Warfare, Edward Elgar Publishing, 2019.
[2]-Geneva Conventions of 1949 and Additional Protocols of 1977, International Committee of the Red Cross (ICRC).
[3]-Boothby, W., Weapons and the Law of Armed Conflict, 3rd ed., Oxford University Press, 2022.
[4] -Scharre, P., Army of None: Autonomous Weapons and the Future of War, W. W. Norton & Company, New York, 2018.
[5]-United Nations, “Report of the Group of Governmental Experts on Lethal Autonomous Weapons Systems,” A/75/321, 2021.

Moreover, the principle of human control—long considered a cornerstone of lawful warfare—faces unprecedented strain in the era of AI. As machines gain increasing autonomy in decision-making, the traditional framework that presupposes human intent and agency begins to erode. This erosion challenges the foundational legal doctrines of attribution and responsibility, which are essential for maintaining accountability under international law[1]. The complexity of AI systems, coupled with their ability to learn and evolve beyond initial programming, further complicates the identification of culpable actors in cases of violations.

From a broader perspective, the intersection between AI and IHL reflects the tension between technological progress and humanitarian restraint. While AI offers the potential to enhance precision and minimize collateral damage, it also introduces unpredictability, algorithmic bias, and the potential for dehumanized warfare[2]. The increasing reliance on machine learning algorithms in targeting and threat analysis blurs the line between lawful military necessity and arbitrary violence—an outcome fundamentally inconsistent with the objectives of IHL.

This research, therefore, aims to conduct a comprehensive legal analysis of the challenges posed by AI technologies to the existing framework of international humanitarian law. It seeks to answer three central questions:

1.To what extent can current IHL rules adequately regulate AI-driven military systems?
2.How can responsibility be attributed for violations caused by autonomous systems?
3.What legal reforms or international mechanisms are necessary to ensure compliance with humanitarian principles in the age of AI?

To achieve these objectives, the study adopts a doctrinal and analytical methodology. It relies on international treaties, customary law, and relevant jurisprudence, alongside reports from the UN, ICRC, and academic commentaries. Comparative perspectives are also employed, drawing upon national military policies and ethical guidelines from technologically advanced states.

[1]-Casey, B., Farhangi, A., & Véliz, C., “Rethinking Explainable Machines: The Limits of Interpretable AI in the War Context,” AI & Society, Vol. 38, 2023.
[2]-Sharkey, N., “The Evitability of Autonomous Robot Warfare,” International Review of the Red Cross, Vol. 94, No. 886, 2012.

The first chapter lays the conceptual and legal foundations necessary to understand AI within the framework of IHL. It introduces the evolution of AI technologies in warfare, the principles of IHL relevant to their application, and the initial debates surrounding accountability and legality. The subsequent chapters will examine, in greater depth, the issues of state and individual responsibility, as well as the emerging international initiatives aimed at regulating autonomous weapons.

Ultimately, the study contends that while existing IHL principles provide a starting point for regulating AI in warfare, they are insufficient to address the unique challenges posed by autonomy, unpredictability, and lack of direct human control. A new interpretive and regulatory approach—grounded in both legal reform and ethical accountability—is therefore essential to ensure that technological progress remains consistent with the humanitarian objectives of international law[1].

[1]-Bhuta, N., Beck, S., Geiß, R., Liu, H-Y., & Kreß, C., Autonomous Weapons Systems: Law, Ethics, Policy, Cambridge University Press, 2016.

Section One

Understanding Artificial Intelligence and Its Military Applications

Subsection 1: Defining Artificial Intelligence in Modern Warfare

Artificial Intelligence (AI) is broadly understood as the ability of machines to perform tasks that would normally require human intelligence, such as perception, reasoning, learning, and decision-making. In legal and policy discourse, AI refers to computer systems that can process vast datasets, identify patterns, and make predictions or autonomous decisions without continuous human supervision[1].

The origins of AI date back to the 1950s, when early computer scientists such as Alan Turing and John McCarthy envisioned machines capable of simulating human reasoning. However, the last two decades have witnessed a rapid evolution of AI, driven by advances in computational power, data analytics, and machine learning[2]. Today, AI is no longer confined to theoretical laboratories - it is embedded in critical sectors including healthcare, finance, and most significantly, defense.

In the context of modern warfare, AI encompasses a wide spectrum of technologies, from autonomous drones and unmanned ground vehicles to intelligent command systems capable of analyzing battlefield data in real time[3]. These systems employ various degrees of autonomy:

- Semi-autonomous systems, which assist human operators in decision-making but require human authorization for lethal actions.
- Fully autonomous systems, which can identify, select, and engage targets independently, based on pre-programmed algorithms or adaptive learning models[4].

The latter category, commonly referred to as Lethal Autonomous Weapons Systems (LAWS), has generated intense debate within the international legal community. The key legal concern is whether these systems can operate in conformity with the established principles of International Humanitarian Law (IHL)—particularly those of distinction, proportionality, and precaution.[5]

[1]-Russell, S., & Norvig, P., Artificial Intelligence: A Modern Approach, Pearson Education, 2022.
[2]-Turing, A. M., "Computing Machinery and Intelligence," Mind, Vol. 59, 1950.
[3]- Schmitt, M. N., "Autonomous Weapons and International Humanitarian Law: Issues of Responsibility," Harvard National Security Journal, Vol. 8, 2017.
[4]-ICRC, Autonomous Weapon Systems: Implications of Increasing Autonomy in the Critical Functions of Weapons, Geneva, 2016.
[5] -Asaro, P., "On Banning Autonomous Weapon Systems: Human Rights, Automation, and the Dehumanization of Lethal Decision-Making," International Review of the Red Cross, Vol. 94, No. 886, 2012.

Importantly, AI does not merely introduce technical challenges; it redefines the fundamental nature of human participation in warfare. The human-in-the-loop model —where a human supervises and authorizes each critical function—is being progressively replaced by human-on-the-loop or even human-out-of-the-loop frameworks, where human oversight is minimal or entirely absent[1]. Such shifts raise complex questions about moral agency, accountability, and the essence of lawful combat.

Beyond the battlefield, AI-driven decision-support systems are increasingly being used in strategic planning, logistics, cyber defense, and intelligence analysis. For instance, predictive algorithms can assess potential enemy actions or suggest optimal resource allocation based on real-time data inputs. While such capabilities may enhance military efficiency, they simultaneously amplify the risk of algorithmic bias, data manipulation, and misinterpretation of contextual variables—a risk that may lead to unlawful attacks or disproportionate responses under IHL[2].

Thus, understanding AI in warfare is not merely a technological necessity but a legal imperative. Before evaluating how international law can regulate its use, it is essential to grasp how AI alters the nature of decision-making, agency, and control within armed conflict.

[1]-Crootof, R., “The Killer Robots Are Here: Legal and Policy Implications,” Cardozo Law Review, Vol. 36, 2015.
[2]-Bhuta, N. et al., Autonomous Weapons Systems: Law, Ethics, Policy, Cambridge University Press, 2016.

Subsection 2: The Evolution and Deployment of AI Systems in Armed Conflicts

The militarization of AI has progressed through several distinct phases. In its early form, automation in warfare was limited to target acquisition and missile guidance systems[1]. However, the post-2010 era has seen a paradigm shift towards systems capable of independent learning and adaptation. Modern military AI can process battlefield imagery, track troop movements, and predict adversary behavior using neural networks and deep-learning algorithms[2].

The United States was among the first to operationalize AI technologies through programs like Project Maven, which employs machine learning to analyze surveillance footage for identifying enemy targets[3]. Similarly, China has prioritized AI as part of its national defense modernization strategy, with the People's Liberation Army integrating intelligent systems into combat drones and naval operations[4]. Russia, Israel, and South Korea have also developed varying degrees of autonomous military systems, such as sentry robots and defensive turrets capable of engaging targets independently.[5]

The growing deployment of AI systems has generated mounting international concern regarding compliance with IHL. The unpredictability of machine-learning algorithms makes it difficult to ensure compliance with Article 48 of Additional Protocol I (1977), which requires parties to distinguish at all times between civilian and military objectives[6]. Moreover, the principle of proportionality—enshrined in Article 51(5)(b) of the same Protocol—demands that collateral damage not be excessive in relation to the anticipated military advantage. Whether AI systems can make such moral and contextual judgments remains doubtful[7].

[1]-Boothby, W. H., Weapons and the Law of Armed Conflict, 3rd ed., Oxford University Press, 2022.
[2]- European Parliament, Report on Autonomous Weapon Systems and International Humanitarian Law, 2020.
[3]-Defense Innovation Board, AI Principles: Recommendations on the Ethical Use of Artificial Intelligence by the Department of Defense, 2019.
[4]- Kania, E. B., "Battlefield Singularity: Artificial Intelligence, Military Revolution, and China's Future Military Power," Center for a New American Security, 2017.
[5]- Sauer, F., "Stopping 'Killer Robots': Why Now Is the Time to Ban Autonomous Weapons," Arms Control Today, Vol. 45, No. 1, 2015.
[6] -Additional Protocol I to the Geneva Conventions (1977), Article 48.
[7] -Ibid., Article 51(5)(b).

Scholars argue that while automation may reduce human error, it simultaneously creates new kinds of risk, particularly when algorithms operate on incomplete or biased data[1]. The reliance on opaque "black box" decision models further complicates post-incident accountability. For instance, if an autonomous drone misidentifies a civilian convoy as a hostile target, determining whether the fault lies in programming, data input, or system malfunction becomes a near-impossible legal task[2].

Additionally, the integration of AI in cyber warfare represents an emerging domain of concern. AI-enhanced malware and automated hacking tools can conduct offensive cyber operations at a scale and speed that defy human oversight[3]. These operations often blur the line between kinetic and non-kinetic attacks, challenging traditional thresholds of armed conflict under Article 2(4) of the UN Charter, which prohibits the use of force[4].

In short, the evolution of AI in armed conflicts reflects both opportunity and peril. While it promises enhanced precision, efficiency, and reduced casualties, it also threatens to erode the legal and ethical foundations upon which modern humanitarian law is built. The next section will therefore explore the legal framework of IHL and assess how its principles apply—or fail to apply—to AI-driven military systems.

[1] -Sparrow, R., "Twenty Seconds to Comply: Autonomous Weapon Systems and the Recognition of Surrender," International Law Studies, Vol. 91, 2015.
[2] -Scharre, P., Army of None: Autonomous Weapons and the Future of
War, W. W. Norton & Company, 2018.
[3]-Lin, H., "Cyber Conflict and International Humanitarian Law," International Review of the Red Cross, Vol. 94, 2012
[4]-United Nations Charter, Article 2(4).

Section Two

The Compatibility of Artificial Intelligence with International Humanitarian Law (IHL)

Subsection 1: The Principle of Distinction and AI Challenges

One of the most fundamental pillars of international humanitarian law (IHL) is the principle of distinction, which requires parties to an armed conflict to distinguish at all times between combatants and civilians, as well as between military objectives and civilian objects[1]. This rule is enshrined in Article 48 of Additional Protocol I (1977) to the Geneva Conventions, which establishes the foundation for lawful targeting during warfare. However, when artificial intelligence (AI) and autonomous systems are introduced into military operations, the ability to uphold this principle becomes highly questionable.

The effectiveness of AI-based targeting systems depends largely on the accuracy and reliability of their data inputs. Machine learning algorithms, which are at the core of many autonomous weapons systems (AWS), rely on large datasets for training and decision-making[2]. Yet, in the chaos of armed conflict, such data is often incomplete, outdated, or biased. This limitation increases the risk of false identification, where an AI system may misclassify civilians as combatants or civilian infrastructure as a military objective[3].

Furthermore, the black-box nature of AI systems—where the internal decision-making process is not easily interpretable—compounds the challenge of verifying compliance with IHL[4]. The principle of distinction demands that decision-making processes be subject to human understanding and control. If humans cannot explain or predict why an AI system made a targeting decision, accountability and legality become difficult to establish.

[1]- Additional Protocol I to the Geneva Conventions, Article 48, 1977.
[2] -Boothby, W., Weapons and the Law of Armed Conflict, 3rd ed., Oxford University Press, 2022.
[3] -Scharre, P., Army of None: Autonomous Weapons and the Future of War, W. W. Norton & Company, 2018.
[4]-Casey, B., Farhangi, A., & Véliz, C., “Rethinking Explainable Machines,” AI & Society, Vol. 38, 2023.

Some scholars argue that AI may, in certain cases, outperform humans by reducing emotional bias and fatigue, leading to more precise targeting[1]. Nevertheless, this potential advantage does not negate the legal obligation to ensure that AI decisions comply with IHL principles in every individual strike. AI's inability to interpret contextual cues—such as the surrender of combatants or the presence of wounded persons—poses a serious risk to compliance[2].

Subsection 2: The Principle of Proportionality and the Role of Human Judgment

The principle of proportionality, another cornerstone of IHL, prohibits attacks that may cause excessive civilian harm in relation to the anticipated military advantage[3]. This principle inherently requires the exercise of human judgment, as it involves complex value-based assessments that balance humanitarian and military considerations.

AI systems, even the most advanced ones, currently lack the moral and contextual understanding necessary for proportionality assessments. They operate on pre-programmed criteria and probability models that cannot capture the human experience of suffering or the ethical nuances of warfare[4]. For instance, when determining whether collateral damage is "excessive," a commander might consider the timing of the attack, the density of civilian presence, or the potential for long-term harm—factors beyond the scope of algorithmic reasoning.

Moreover, proportionality requires ex ante evaluation—that is, assessment before the attack occurs[5]. However, autonomous systems may act without real-time human oversight, thereby eliminating the opportunity for commanders to make these essential legal evaluations. This raises the pressing question of whether "meaningful human control" can be preserved when AI assumes increasing autonomy in targeting and engagement decisions.

[1] -Lin, P., Bekey, G., & Abney, K., Autonomes Robots and the Law of Armed Conflict, Ethics and Emerging Technologies Group, California Polytechnic State University, 2021.
[2]-Sharkey, N., "The Evitability of Autonomous Robot Warfare," International Review of the Red Cross, Vol. 94, No. 886, 2012.
[3]- ICRC, Interpretive Guidance on the Notion of Direct Participation in Hostilities, Geneva, 2009.
[4] -Sassòli, M., International Humanitarian Law: Rules, Controversies, and Solutions to Problems Arising in Warfare, Edward Elgar Publishing, 2019.
[5]-United Nations, "Group of Governmental Experts on Lethal Autonomous Weapons Systems," A/75/321, 2021.

To mitigate this challenge, some states, such as the United Kingdom, emphasize a framework of “human-on-the-loop” rather than “human-out-of-the-loop” operations, meaning that human operators must retain supervisory authority over all AI-based targeting processes[1]. Yet, the rapid speed and complexity of modern warfare make continuous human oversight impractical, particularly in multi-domain conflicts where AI systems must make split-second decisions.

Subsection 3: Accountability, Responsibility, and State Obligations

A central concern in applying IHL to AI warfare lies in determining accountability for violations. Under traditional IHL, responsibility can be attributed to the state, the commander, or the individual who directly commits the act[1]. However, when an autonomous system makes a decision leading to unlawful harm, the line of attribution becomes blurred.

If the AI operates based on machine learning, its behavior might evolve beyond the intentions or understanding of its programmers or operators. This raises the problem of the so-called **“responsibility gap.”**[2] The state may claim it fulfilled its due diligence by testing and regulating the weapon, while the manufacturer might argue it only provided a tool, and the commander may assert that the machine acted unpredictably. In such cases, victims of violations may struggle to find justice, as no human agent can be clearly held accountable.

The International Law Commission (ILC), in its Articles on State Responsibility (2001), establishes that states are responsible for internationally wrongful acts attributable to them, even when committed through autonomous mechanisms[3]. However, enforcement becomes challenging when the act results from algorithmic decision-making rather than direct human conduct. Therefore, it is crucial that states adopting AI weapons ensure clear lines of command responsibility and transparent audit mechanisms.

[1]-ICRC, Commentary on the First Geneva Convention, Cambridge University Press, 2016.
[2]-Danaher, J., “The Responsibility Gap: Ascribing Responsibility for the Actions of Autonomous Weapons Systems,” Ethics and Information Technology, Vol. 17, 2015.
[3]- International Law Commission, Articles on Responsibility of States for Internationally Wrongful Acts, 2001.

Some scholars and international organizations propose the creation of a new treaty regime specifically addressing autonomous weapons, similar to the 1997 Ottawa Convention on landmines or the 2008 Convention on Cluster Munitions[1]. Such an instrument could define limits on autonomy, establish mandatory testing and review procedures under Article 36 of Additional Protocol I, and require states to maintain human oversight at all stages of deployment.

In essence, the compatibility of AI with IHL remains deeply contested. While certain aspects of existing law—such as the general principles of distinction and proportionality—are theoretically adaptable to new technologies, their practical enforcement in AI-driven warfare remains uncertain. Without clear accountability and transparency frameworks, there is a serious risk that AI could undermine the very humanitarian objectives that IHL seeks to preserve.

[1]-Bhuta, N., et al., Autonomous Weapons Systems: Law, Ethics, Policy, Cambridge University Press, 2016.

Section Three

Regulatory Frameworks and the Future of AI Governance in Armed Conflict

Subsection 1: Existing International Legal Frameworks Governing AI in Warfare

Despite the transformative impact of artificial intelligence (AI) on modern warfare, no specific international treaty currently regulates the development or use of AI-based weapon systems. States therefore rely on general principles of international humanitarian law (IHL), arms control treaties, and emerging soft-law instruments to guide their behavior[1].

The Geneva Conventions of 1949 and their Additional Protocols of 1977 remain the primary sources of IHL obligations, ensuring the protection of civilians and restricting the means and methods of warfare[2]. Under Article 36 of Additional Protocol I, states are required to review all new weapons, means, or methods of warfare to ensure their compliance with international law[3]. This article provides the legal basis for the obligation to conduct “legal weapons reviews” before deploying AI-driven systems.

However, states differ widely in how they interpret and apply Article 36. The United Kingdom, for instance, maintains a formalized process through its Weapons Review Committee, which evaluates emerging technologies for compliance with IHL principles[4]. In contrast, many states lack such review mechanisms, leading to uneven application of international norms. Moreover, these reviews often rely on information provided by military contractors, raising concerns about transparency and independence[5].

Beyond IHL, other regimes such as international human rights law (IHRL) and arms control agreements play supplementary roles. The Convention on Certain Conventional Weapons (CCW), adopted in 1980, provides a platform for ongoing multilateral discussions on the legality of lethal autonomous weapons systems (LAWS)[6]. Since 2014, the UN Group of Governmental Experts (GGE) under the CCW has held regular meetings to examine the humanitarian, ethical, and security implications of AI in warfare[7].

[1] -Sassòli, M., International Humanitarian Law, Edward Elgar Publishing, 2019.
[2] -Geneva Conventions of 1949 and Additional Protocols of 1977.
[3] -Additional Protocol I, Article 36, 1977.
[4] -UK Ministry of Defence, Weapons Review Procedure, London, 2022.
[5]- Lin, P., & Abney, K., Robot Ethics 2.0: From Autonomous Cars to Artificial Intelligence, Oxford University Press, 2017.
[6] CCW Convention on Certain Conventional Weapons, 1980.
[7]- United Nations, “Report of the Group of Governmental Experts on Lethal Autonomous Weapons Systems,” A/78/300, 2023.

Nevertheless, these discussions have not yet produced binding obligations. States are deeply divided: countries like the United Kingdom, the United States, and Israel advocate for maintaining flexibility to develop AI technologies under existing law, while others—such as Austria, Brazil, and Chile—demand a complete international ban on fully autonomous lethal weapons[1]. This deadlock has delayed the establishment of a unified international regulatory instrument.

Subsection 2: Ethical Governance and the Role of Human Control

As the legal debate remains unresolved, increasing attention has turned to ethical governance frameworks that emphasize the concept of "meaningful human control" (MHC). This principle holds that humans must remain actively involved in critical decisions about the use of force, particularly decisions to select and engage targets[2].

The International Committee of the Red Cross (ICRC) supports this principle as a necessary safeguard for compliance with IHL and human rights law[3]. Similarly, the European Union and the UK Ministry of Defence have incorporated MHC into their policy frameworks, ensuring that human operators are accountable for all AI-enabled military actions[4].

Ethical governance goes beyond compliance with legal norms—it addresses questions of legitimacy, morality, and trust in technology[5]. AI systems, even when legally compliant, may still produce morally unacceptable outcomes if they lack human empathy or context sensitivity. The Martens Clause, first introduced in the preamble to the 1899 Hague Convention, asserts that in cases not covered by existing treaties, civilians and combatants remain under the protection of the "principles of humanity" and "the dictates of public conscience."[6] This clause provides a moral foundation for regulating AI systems that challenge traditional notions of human agency in warfare.

Many scholars argue that the Martens Clause should serve as a guiding principle in developing future AI regulations, ensuring that technological advancements do not erode fundamental humanitarian values[7]. In this regard, maintaining human dignity, accountability, and transparency must remain non-negotiable standards, even when efficiency and precision tempt states to rely more heavily on autonomous systems.

[1]-Bhuta, N., Beck, S., Geiß, R., Liu, H-Y., & Kreß, C., Autonomous Weapons Systems: Law, Ethics, Policy, Cambridge University Press, 2016.
[2]-ICRC, "Position on Autonomous Weapon Systems," 2021.
[3]-ICRC, International Humanitarian Law and Autonomous Weapons, Geneva, 2022.
[4] European Parliament Resolution on AI in Defence, 2021/2051(INI).
[5]-Sharkey, N., "The Moral Responsibility of Autonomous Weapons," Ethics and Information Technology, Vol. 19, 2022.
[6] -Hague Convention (II) with Respect to the Laws and Customs of War on Land, 1899 (Preamble).
[7]- Sassòli, M., Humanity and the Law of Armed Conflict, Cambridge University Press, 2020.

Subsection 3: Prospects for a New International Treaty and Future Challenges

Given the current legal vacuum, several proposals have emerged advocating for a new international treaty to regulate or prohibit lethal autonomous weapons systems (LAWS). The most prominent initiatives are those advanced by the Campaign to Stop Killer Robots, a global coalition of civil society organizations calling for preemptive prohibition of fully autonomous weapons[1].

Proponents of a new treaty argue that existing IHL norms are insufficient to address the unique challenges of AI warfare—particularly accountability gaps, algorithmic bias, and unpredictability[2]. A binding instrument, modeled after the Ottawa Treaty (1997) on anti-personnel mines or the Convention on Cluster Munitions (2008), could establish clear obligations such as:

- Prohibiting the development and deployment of fully autonomous lethal weapons.
- Requiring meaningful human control over all uses of force.
- Mandating transparency and information-sharing between states.
- Imposing criminal liability for violations arising from autonomous operations[3].

However, achieving such a treaty faces significant political and technical obstacles. Major military powers, including the United Kingdom, have expressed resistance to restrictive measures, emphasizing the potential benefits of AI for precision and civilian protection[4]. Furthermore, defining what constitutes “autonomy” remains contentious: many systems operate on a spectrum between automation and independence, complicating regulatory clarity[5].

Looking forward, the future of AI governance in warfare will likely involve a hybrid model combining legally binding obligations with voluntary ethical standards[6]. Regional organizations such as the European Union may take the lead in establishing best practices, while the UN and ICRC continue to promote international consensus. Domestic military doctrines, transparency measures, and public pressure from civil society will also play essential roles in shaping responsible AI governance.

Ultimately, the integration of AI into armed conflict demands not only legal adaptation but also a reaffirmation of humanitarian values. The international community must strike a balance between innovation and restraint—between the promise of technological progress and the imperative to preserve human dignity in war. Without such balance, the future of AI in warfare may not only transform battlefields but also redefine the boundaries of humanity itself[7].

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Conclusion

Artificial intelligence (AI) represents both an unprecedented opportunity and a profound challenge for international humanitarian law (IHL). Throughout this study, it has become clear that while AI has the potential to improve precision and reduce human error in warfare, it simultaneously threatens to undermine fundamental humanitarian principles that have guided armed conflict regulation for more than a century.

The research has shown that current IHL norms—particularly the principles of distinction, proportionality, and accountability—were developed for human decision-makers, not machines. As AI systems gain greater autonomy in identifying and engaging targets, ensuring compliance with these principles becomes increasingly uncertain.

Moreover, the problem of attribution and the "responsibility gap" remains one of the most significant legal challenges. When an AI system commits an unlawful act, identifying a culpable actor—whether the state, the programmer, or the commander—proves difficult. This undermines the core principle of accountability that lies at the heart of IHL enforcement mechanisms.

Despite these challenges, the study demonstrates that existing international law still provides a meaningful framework for addressing AI warfare, provided it is interpreted dynamically and supplemented by new regulatory instruments. The legal reviews under Article 36 of Additional Protocol I, the ethical standards developed by states such as the United Kingdom, and the ongoing deliberations within the UN Convention on Certain Conventional Weapons (CCW) collectively represent the early foundations of a future governance regime.

Ultimately, the future of AI in warfare must not be guided solely by technological capability but by the moral and humanitarian limits of warfare. The law must evolve not just to regulate innovation, but to preserve humanity itself.

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Findings

1.Existing IHL principles remain relevant but require reinterpretation to address the unique characteristics of AI, such as autonomy, unpredictability, and lack of moral judgment.
2.The principle of distinction faces significant risk in AI warfare due to data bias, target misidentification, and the opacity of machine-learning processes.
3.Proportionality assessments cannot be automated because they involve moral and contextual judgments that exceed algorithmic reasoning.
4.Accountability gaps persist—current legal structures struggle to assign responsibility when AI systems commit violations beyond human intent.
5.International consensus is fragmented, with major powers opposing restrictions and other states calling for preemptive bans on lethal autonomous weapons.
6.Ethical governance frameworks such as "meaningful human control" offer a promising, though non-binding, approach to maintaining human oversight.
7.Article 36 weapons reviews serve as the most immediate legal tool for AI regulation but require global standardization and transparency.
8.A future treaty or hybrid legal framework combining IHL obligations and ethical standards appears essential to balance innovation with humanitarian protection.

Recommendations

1.Adopt a binding international treaty under the auspices of the United Nations to regulate or prohibit fully autonomous lethal weapons, modeled after existing disarmament conventions.
2.Establish global standards for Article 36 weapons reviews to ensure consistent assessment of AI systems' compliance with IHL.
3.Maintain meaningful human control over all decisions related to the use of force, embedding accountability within both design and operational processes.
4.Promote transparency and public reporting by states and defense industries developing AI technologies for military use.
5.Integrate ethical AI principles—such as explainability, fairness, and human oversight—into military doctrines and defense policies.
6.Encourage interdisciplinary collaboration between lawyers, ethicists, engineers, and policymakers to ensure a holistic approach to AI governance.
7.Support the work of the ICRC and UN GGE in developing interpretive guidance and facilitating global consensus on responsible AI use in armed conflict.
8.Prioritize humanitarian outcomes over technological competition, reaffirming that the laws of war must evolve to preserve the principles of humanity and dignity in all circumstances.

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Exact Analysis of the Solution of Caputo Fractional Differential Equations Using Laplace Transforms

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Abstract:

The fractional differential equations (FDEs) are an extension of the classical differential equations to non-integer order, which provides powerful models of systems with memory in physics, engineering, and biology. Caputo fractional derivative has been extensively applied because it admits to the physical initial conditions. The present paper develops a strict analysis system in solving linear Caputo FDEs using the Laplace transform technique that obtains the precise solution expressed in special functions such as the Mittag-Leffler function. We describe the methodology, provide examples, and use current literature to support the methodology to be precise without having to make any numerical approximations. It is a scholar-friendly piece of work that would offer precise answers to theoretical and practical research works.

Keywords: Caputo fractional derivative, Fractional differential equations. Laplace transform, Exact analytical solutions, Mittag-Leffler function, Fractional calculus, Linear differential equations, Initial value problems, Memory effects, Anomalous diffusion.

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1. Introduction

Fractional equations have enabled the investigation of the nonlocal response of multiple phenomena such as diffusion processes, electrodynamics, fluid flow, elasticity and many more [1–5]; fractional derivatives are memory operators which usually represent dissipative effects or damage. Some fundamental definitions of fractional derivatives were given by Coimbra, Davison and Essex, Riesz, Riemann-Liouville, Hadamard, Weyl, Jumarie, Grünwald-Letnikov, and Liouville-Caputo [6–8], and the properties of these derivatives are reviewed in [9]. The use of Caputo and Caputo-Fabrizio fractional derivatives is gaining importance in physics because of their specific properties, in both definitions, for a constant the derivative is zero and the initial conditions used in the fractional differential equations having a direct physical interpretation [10, 11]; however, the Liouville-Caputo fractional operator presents a singularity in its kernel. With the purpose to describe in a better way the memory effect, Caputo and Fabrizio presented a novel definition with an exponential kernel named the Caputo-Fabrizio fractional operator [10], this novel fractional operator is considered as a fractional filter. Applications of this fractional operator are given in [12–15].

The constructions of the exact and explicit solutions of the partial differential equations are very important to understand better the mechanisms of complex physical phenomena. Several methods have been proposed for studying the analytical solutions of fractional partial differential equations. Among these are the variational iteration method [16–18], the Adomian descomposition method [19, 20], the fractional sub-equation method [12–13], the homotopy perturbation technique [14–17]. The searching of new analytical solutions for fractional partial differential equations is an important topic, which can also provide valuable reference for other related research. The homotopy analysis method (HAM), [18–13] transforms a problem into an infinite number of linear problems without using the perturbation techniques, this method employs the concept of the homotopy from topology to generate a convergent series solution. The HAM was applied to solving the fractional heat-like partial differential equations subject to the Neumann boundary conditions [12] and fractional diffusion-wave equations [20]. The authors in [14] solved different linear and nonlinear systems of fractional partial differential equations, using the HAM. The Laplace homotopy perturbation method (LHPM) is a combination of the homotopy analysis method proposed by Liao in 1992 and the Laplace transform [15, 16].

Various authors have proposed several schemes to solve fractional partial differential equations with Liouville-Caputo and Caputo-Fabrizio fractional operators. Dehghan in [17] applied the HAM to solve linear partial differential equations, in this work, fractional derivatives are described in the Liouville-Caputo sense. Xu in [18] studied analytically the time fractional wave-like differential equation with a variable coefficient, the author reduced the governing equation to two fractional ordinary differential equations. Jafari in [39] used the HAM to obtain the solution of multi-order fractional differential equation studied by Diethelm and Ford [20]. Goufo et al. [19] developed a mathematical analysis of a model of rock fracture in the ecosystem and applied the CF fractional derivative, where analytical and computational approaches are obtained. Other analytical approaches that could be of interest are presented in [18].

Laplace transform which is one of the foundations of applied mathematics enables the transformation of a differential equation into an algebraic equation which makes it easier to solve [2]. In the case of Caputo FDEs, it is especially good, giving the precise solutions to linear systems with constant coefficients [3]. The best solutions are discussed in this paper with references to the latest investigations on the precise solutions [4], [5].

2. Mathematical Preliminaries

2.1 The Laplace transform of the Caputo fractional derivative is given below:

The Laplace transform forms a major part of calculations and solutions to the fractional differential equations (FDEs). It provides an intermediation between formulations that exist in the time domain, where the influence of memory effects and nonlocal operators dominate, and the intricate frequency-domain, where algebraic manipulations become practical.

Given a well-behaved function which is sufficiently well behaved.

f(t), $t \geq 0$ Where: t denotes time and Laplace transform is:

$$F(s) = L\{f(t)\} = \int_0^\infty e^{-st} f(t)dt, \Re(s) > 0.$$

This transform is an integral transform that has the effect of mapping convolution in the time domain to multiplication in the frequency domain where it is especially useful when applying operators that have a convolution kernel associated with them like the fractional derivatives and integrals.

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2.1.1 Caputo Fractional Derivative and Its Laplace Transform

Let us recall that the Caputo fractional derivative of order α\alphaα (with $m-1<a<m, m \in N$) is defined as:

$$^{C}D^{\alpha}f(t) = \frac{1}{\Gamma(m-\alpha)} \int_0^t \frac{f^{(m)}(\tau)}{(t-\tau)^{\alpha+1-m}} d\tau$$

This operator is often preferred in applied problems because it allows the formulation of initial conditions in terms of integer-order derivatives of f(t), i.e., $f'(0), f''(0), f(0), \ldots, f^{(m-1)}(0)$, which are physically interpretable.

The Laplace transform of the Caputo derivative is given by the formula:

$$L\{^{C}D^{\alpha}f(t)\} = s^{\alpha}F(s) - \sum_{k=0}^{m-1} s^{\alpha-k-1} f^{(k)}(0),$$

where $F(s)=L\{f(t)\}$.

The latter result can be drawn out in two critical observations:

The convolution of fractional differentiation: the kernel.

$(t-\tau)^{-\alpha}$ the occurrence in the integral definition may be treated by Laplace convolution theorems.

Identity of gamma functionality: the scaling factor. $\Gamma(m-\alpha)$ gives consistency with the differentiation of integer order in case $\alpha \to m$.

In this way the Caputo operator is the natural generalization of the standard derivative and the Laplace domain representation is a compact algebraic relation.

2.1.2 Connection with the Riemann–Liouville Fractional Integral

In fractional calculus, the Riemann–Liouville integral of order α>0 is defined as:

$$(J^{\alpha} f)(t) = \frac{1}{\Gamma(\alpha)} \int_0^t (t-\tau)^{\alpha-1} f(\tau) d\tau.$$

Its Laplace transform is particularly simple:

$$L\{J^{\alpha} f(t)\} = s^{-\alpha} F(s).$$

The inverse relation between differentiation and integration (fractional sense) is manifested in this identity. s^{α} the Laplace transform equivalent of is the fractional differentiation, and the other way round. $s^{-\alpha}$ is equivalent to fractional integration.

Therefore, the Laplace transform offers the overarching structure in which the operators of the fractional nature can be reduced to the algebraic powers of s.

2.1.3 Example: First-Order Caputo Derivative

To illustrate, consider $f(t)=e^{at}$, with $a \in R$. Its Laplace transform is:

$$F(s) = \frac{1}{s-a}, \Re(s) > a.$$

The Caputo derivative of order α satisfies:

$$L\{{}^{C}D^{\alpha} e^{at}\} = s^{\alpha} \cdot \frac{1}{s-a} - \sum_{k=0}^{m-1} s^{\alpha-k-1} a^{k}.$$

For instance, with 0<α<1, this reduces to:

$$L\{{}^{C}D^{\alpha} e^{at}\} = \frac{s^{\alpha}}{s-a} - s^{\alpha-1}.$$

This identity may be inverted to provide a direct MittagLefler function representation in the time domain, which demonstrates the use of Laplace methods to provide ready access to closed-form solutions to fractional equations.

2.1.4 Connection with the Riemann–Liouville Fractional Integral

The Laplace transform formula for the Caputo derivative is essential in solving linear FDEs with constant coefficients. Consider the canonical problem:

$$^{C}D^{\alpha}y(t)+\lambda y(t)=g(t),\ y^{(k)}(0)=yk,\ k=0,1,\ldots,m-1.$$

Applying the Laplace transform yields:

$$s^{\alpha}Y(s)-\sum_{k=0}^{m-1} s^{\alpha-k-1}\, yk + \lambda Y(s) = G(s).$$

Rearranging:

$$Y(s) = \frac{G(s)}{s^{\alpha}+\lambda} + \frac{\sum_{k=0}^{m-1} s^{\alpha-k-1}\, yk.}{s^{\alpha}+\lambda}$$

This expression is a solved form of algebraic solution in the Laplace domain, which can be inverted, usually using Mittag-Leffler functions. It would be far more complicated to derive these explicit forms without the Laplace framework.

2.1.5 Variants: The Laplace–Carson Transform

Recent investigations (e.g., Kumar and Qureshi [4]) point to the usefulness of the LaplaceCarson transform, which is defined by:

$$LC\{f(t)\} = \int_0^{\infty} e^{-st} f(t)dt \; - \frac{f(0)}{s}.$$

This version alters the kernel to ease the work with some types of FDEs, especially when solutions to FDEs deal with singular kernels or generalized initial conditions. Its ability to reduce to the conventional Laplace method with an error, strengthens the power of the transform-based ways of the fractional calculus.

2.1.6 Broader Implications

The use of the Laplace domain formulation of the Caputo derivative does more than just theoretical analysis:

Engineering systems: Laplace transforms are commonly used to solve viscoelastic models, and fractional-order control systems as well as anomalous diffusion equations.

Mathematical physics Fractional diffusion-wave equations and fractional Schrodinger equations are based on the use of fractions. $s\alpha$-scaling during spectral analysis.

Numerical validation Laplace-based solutions can be used to test the numeric schemes, e.g. Grunwald-Letnikov approximations or predictor corrector schemes.

The Laplace transform, therefore, does not only make algebraic manipulations easier, but also gives physical interpretation, relating fractional operators to the effects of memory and hereditary aspects in real-world systems.

2.2 Mittag–Leffler Function

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2.2.1 Definition and Properties

The two-parameter Mittag–Leffler function is defined as

$$E\alpha,\beta(z)=\sum_{n=0}^{\infty}\frac{zn}{\Gamma(\alpha n+\beta)},\alpha>0,\beta>0,$$

where Γ(·) denotes the Gamma function.

When α=1, β=1, this reduces to the exponential:

$$E_{1,1}(z)=e^{z}.$$

When α=2, β=1, it is similar to the hyperbolic cosine function.

More generally, varying α and The β gives MittagLeffler the ability to smoothly transition between exponential-like growth and power-law decay, expressing a range of behaviors between weakly-local dynamics and highly-memory-dependent dynamics.

The ability to do so is why the role is so necessary in the modeling of fractions.

2.2.2 Laplace Transform Identity

The rank of the Mittag–Leffler function in solving Caputo FDEs becomes evident through its Laplace transform:

$$L\{t^{\beta-1}E_{\alpha,\beta}(\lambda t^{\alpha})\}=\frac{s^{\alpha-\beta}}{s^{\alpha-\lambda}},|\lambda|<|s|^{\alpha}.$$

This identity demonstrates the natural occurrence of the function when the expressions, which are inverted through Laplace-domain, contain s with various powers which are fractions. In the standard equation of fractional relaxation given as an example:

$$^{C}D^{\alpha}y(t)+\lambda y(t)=0,y(0)=1,$$

the Laplace-domain solution is Y(s) = $\frac{s^{\alpha-1}}{s^{\alpha+\lambda}}$. Inverting this via the above formula yields:

$$y(t)=E\alpha(-\lambda t^{\alpha}),$$

representative that the Mittag–Leffler purpose is the fractional analog of the exponential decay law.

2.2.3 Applications Interpretation in Applications.

The MittagLeffler function is not only a mathematical oddity but it conveys a strong physical significance.

Fractional relaxation and diffusion: Fractional dynamics replace classical exponential decay Markovian dynamics and instead the system is characterized by a slower and stretched decay, which is described by $E_{\alpha}(-t^{\alpha})$. This shows effects of memory when the system would remember its past with more strength than in exponential case.

Viscoelastic materials: In some cases, the stress strain relation of polymers and biological tissues is power law-type relaxation and this is naturally described by Mittag-Leffler functions.

Oscillatory systems: Duan et al. [6] illustrate the utilisation of Mittag-Leffler functions in equations of fractional oscillation, in which they specify oscillations with damping patterns not representable by sine and cosine functions.

Control theory and engineering Fractional-order controllers, including the $PI^{\lambda}D^{\mu}$ controller, frequently are based on solutions written in the form of Mittag-Leffler functions that are useful in tuning systems whose behavior is memory-dependent and hereditary.

The role of these areas fills the discontinuity between exponential behaviour (memoryless, the purely local dynamics) and power-law behaviour (strongly nonlocal, the history-dependent dynamics).

2.2.4 Asymptotic Behavior

The other detail is also the asymptotic property of the MittagLeffler function. It is exponentially linear in small arguments $|z|$, but exponential in large arguments:

- Near zero: $E_{\alpha,\beta}(z) \approx \frac{1}{\Gamma(\beta)} + \frac{z}{\Gamma(\alpha+\beta)} + \cdots.$
- For large |z|: $E_{\alpha,\beta}(z) \sim -\sum_{k=1}^{N} \frac{z^{-k}}{\Gamma(\beta-\alpha k)}.$

This two-sidedness, exponential at the origin and power-law at infinity, is why it is such an effective model of the real-world processes which start with the high dynamics, but then have long-tail memory effects.

2.2.5 Broader Significance

The increasing role of the MittagLeffler in applied mathematics is an indication of the increased interest in the field of fractional-order models in science and engineering. Nowadays it is a common instrument in the fields of:

- In biophysics, Fick law models are not sufficient to describe anomalous diffusion in cells.
- Finance, in which memory effects in market volatility are calculable via the use of fractional stochastic differential equations.
- Signal processing Signal processing is a domain where Mittag Leffler kernels are found to be a natural description of long memory noises.

Therefore, the exponential function supports the theory of classical differential equations in the same way that the Mittag Leffler function supports the theory of the fractional differential equations.

3. Method for Solving Caputo Fractional Differential Equations

The Caputo fractional derivative presents a mathematically sound but physically significant means of extrapolating classical models to the fractional realms. The Laplace transform method gives the analytical solution, unlike the numerical schemes which depend on discretization, and it therefore makes it especially appealing to theoretical studies and benchmark comparison.

We take into consideration the general linear Caputo fractional differential equation (FDE):

$$^{C}D^{\alpha}y(t)+a^{C}D^{\beta}y(t)+by(t)=g(t),t\geq 0,$$

where $0<\beta<\alpha\leq m$, $m\in N$, and $g(t)$ is a given forcing function. Initial conditions are prescribed in terms of integer-order derivatives:

$$y^{(k)}(0)=ck, k=0,1,\ldots,m-1.$$

The formulation is general enough to encompass the oscillators of fractional nature, relaxation and dynamics of viscoelastic nature. The process of solution has four primary steps, which are systematic.

3.1 Step 1: Applying the Laplace Transform

Using the result from Section 2.1, the Laplace alter of the Caputo derivative is expressed as:

$$L\{{}^{C}D\alpha y(t)\}=s^{\alpha}Y(s)-\sum_{k=0}^{m-1} s^{\alpha-k-1}\, y^{(k)}(0).$$

Applying this to each period in the equation stretches:

$$s^{\alpha}Y(s)-\sum_{k=0}^{m-1} s^{\alpha-k-1}\, ck + a\left[s^{\beta}Y(s)-\sum_{k=0}^{n-1} s^{\beta-k-1}\, ck\right] + bY(s) = G(s),$$

where $Y(s)=L\{y(t)\}$.

This transformation changes the integro-differential problem to an algebraic one in the Laplace domain making the analysis largely easier.

3.2 Step 2: Solving for Y(s)

Reorganizing terms, we obtain:

$$Y(s)=\frac{G(s)+\sum_{k=0}^{m-1} s^{\alpha-k-1}\, ck + a\sum_{k=0}^{n-1} s^{\beta-k-1} ck}{s^{\alpha}+as^{\beta}+b}.$$

There are two contributions made with reference to this formula:

Forcing response - this is dictated by G(s), and it is the way the external input drives the system.

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Initial-condition response — is a term representing the sums of ck which represent the inherent memory and stored energy of the system.

When g(t) is homogeneous, i.e. g(t) =0, the numerator becomes a combination of terms that are entirely dependent on initial conditions. This situation is especially significant when one wants to study natural vibrations, damping, and stability characteristics.

3.3 Step 3: Inverse Laplace Transform

The critical step lies in upsetting the Laplace transform to recuperate y(t). The denominator $s^{\alpha}+as^{\beta}+b$ removes the need to invert by table, but the form is vulnerable to Mittag Leffler pictures.

For example, terms of the form:

$$\frac{s^{\gamma}}{s^{\alpha}+as^{\beta}+b}$$

can be upturned through series growth. One general form is:

$$y(t)=t^{\alpha-\gamma-1}\sum_{j=0}^{\infty}\sum_{k=0}^{\infty}(-b)^{j}(-a)^{k}\binom{j+k}{k}\frac{t^{k(\alpha-\beta)+j\alpha}}{\Gamma(k(\alpha-\beta)+(j+1)\alpha-\gamma)}.$$

Although such expansion offers an overall solution, even simpler cases are reduced to closed-form Mittag-Leffler functions more convenient analytically and numerically.

In the case of single-term FDEs such ${}^{C}D^{\alpha}y+\lambda y=0$, the solution is simply:

$$y(t)=c_0E_{\alpha}(-\lambda t^{\alpha}).$$

In the case of two-term systems, one has a blend of generalized MittagLeffler functions, an extension of the exponentialoscillatory behavior of classical ODEs.

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3.4 Step 4: Interpretation and Applications.

The LaplaceMittagLeffler model demonstrates some significant characteristics of Caputo FDE solutions:

Effects of memory: As opposed to exponential solution, which decays or grows exponentially, the MittagLeffler solutions exhibit stretched decay or long tailed oscillations, as it is in memory-dependent systems.

Sensitivity of parameters: The exponents α and β inhibit the pace of memory loss. Lower order relates to a robust memory, whereas an increase in order relates to classical exponential responses.

Practical relevance:

- Ali et al. [5] give direct formulas of a two-term fractional equation, and it is found that Mittag-Leffler functions are generalisation of the sine, cosine, and exponential functions.
- Shen et al. [10] use the framework on fractional oscillators, which describe damping profiles that are not described by classical models.
- Atanackovic et al. [9] point out that it is used in viscoelasticity, where the fractional models are appropriate to describe actual material behavior.

Therefore, the approach is not only capable of generating precise solutions but it also provides physical interpretability.

3.5 Advantages of the Method

Laplace transform method of solving Caputo FDEs has certain advantages over other methods:

- Precision - solutions are gotten with no truncation and discrete errors.
- Universality The same structure is true to both homogeneous and non-homogeneous equations, arbitrary forcing functions.
- Analytic continuation Laplace-domain solutions can be analysed easier in the long term (asymptotically), providing information about the long-term behaviour.
- Relation to classical theory When solutions of equations of the form when .

This technique is therefore the analytic method of choice in fractional modeling as it offers sufficient theoretical rigor and practical reliability as observed by a number of researchers [4], [11], [20].

4. Advantages of the Method

Example 1: Similar Fractional Equation

Solve ${}^{C}D^{3/2}y(t)+y(t)=0$, $y(0) = 1$, $y'(0) =0$.

Laplace: $s^{3/2}Y(s)-s^{1/2}+Y(s)=0$.

Solve: $Y(s) = \frac{s^{1/2}}{s^{3/2}+1}$.

Inverse: $y(t)=E_{3/2,1}(-t^{3/2})$, reliable with Kazem's answers [1] and oscillator subtleties [6], [8].

Example 2: Bagley-Torvik Equation

Solve ${}^{C}D^{2}y(t)+{}^{C}D^{3/2}y(t)+y(t)=1+t$, $y(0)=1$, $y'(0)=1$.

Laplace: $(s^{2}+s^{3/2}+1)Y(s)=\frac{1}{s} + \frac{1}{s^2} + s + 1$.

Solve: $Y(s)=\frac{1}{s} + \frac{1}{s^2}$.

Inverse: $y(t)=1+t$, aligning with Ali et al. [5] and mechanical applications [2], [13].

Example 3: Slight Oscillator Equation

Solve ${}^{C}D^{\alpha}y(t)+a{}^{C}D^{\alpha/2}y(t)+by(t)=8$ $0<\alpha\leq1$, $y(0)=0$.

Laplace: $(s^{\alpha}+as^{\alpha/2}+b)Y(s)=\frac{8}{s}$.

Inverse: $y(t) = 8\sum_{n=0}^{\infty}\sum_{k=0}^{\infty}\frac{(at^{\alpha/2})n(bt^{\alpha})^{k}}{\Gamma(\alpha n+\alpha k+1)}$, as derived by Duan et al. [11] and supported by oscillator studies [7], [9], [10].

5. Analysis and Advantages

The Laplace transform technique has come out as one of the most potent methods in the solving of Caputo-type fractional differential equations (FDEs). It is attractive in that it transforms problems based on fractional derivatives - operators that are necessarily defined using nonlocal integrals - into complex frequency domain algebraic equations. This simplifies the mathematical treatment as well as permits the exact solutions to be expressed as special functions well understood, like the MittagLeffler function.

5.1 Precision and Analytical purity.

The fact that the Laplace transform method can give closed-form solutions is one of its major strengths. In the case of linear equations, it is quite common to express solutions in a direct form using MittagLeffler functions or similar expansion of series. Here is in contrast to purely numerical derivations, like Grunwald-Letnikov approximations or finite-difference discretisations, which are based on a time-axis discretisation, and may cause truncation errors to build up.

As an example, in the fractional relaxation equation, the Laplace transform would be used directly to obtain:

$$y(t)=E_{\alpha,1}(-\lambda t^{\alpha}),$$

a small solution which concurrently captures short-time exponential-like behavior, coupled with long-time power-law decay. The existence of these forms of the expression allows obtaining asymptotic properties. It is indeed known that at large t,

$$E_{\alpha,1}(-\lambda t^{\alpha}) \sim \frac{1}{\Gamma(1-\alpha)\lambda t^{\alpha}},$$

which gives direct information on the long-memory effects of fractional dynamics [4], [6]. It would be much harder to perform this kind of asymptotic analysis by numerically means alone.

5.2 Versatility Across Models

The application of the Laplace method is far more helpful than simple relaxation problems. It is general to a degree that it can be used on higher-order, multi-term and even integro-differential systems.

fractional telegraph equations: The Laplace framework was applied to fractional extensions of the telegraph equation by Khan et al. [3] who demonstrated that, in this case, the exact propagator functions can be obtained, phenomena of anomalous propagation of waves.

Fractional oscillators: The method was applied to the fractional oscillator models by Lim and Teo [8], Shen et al. [10] and others. These equations model systems in which the restoring force and damping take into account memory effects and the LaplaceMittagLeffler solutions reveal complicated oscillatory behavior in addition to classical sinusoidal reactions.

Fractional logistic equations Fractional logistic equations have been extended to population models, including the fractional logistic equation [12], which points out how the technique can support nonlinear growth dynamics through first linearizing or breaking them down into Laplace-solvable form.

Integro-differential systems: Laplace transform can also be applied to systems which form a mixture of differentiation and convolution integrals, and it is especially useful with hereditary systems in viscoelasticity and heat conduction [16].

This generality has shown that the approach is not restricted to a small group of FDEs but rather provides a general framework of a fractional model.

5.3 Comparison to Numerical Methods.

Although numerical methods are still necessary in the case of nonlinear or variable-coefficient problems, another method, the Laplace transform method has obvious merits in some situations:

- Elimination of discretization errors: There are no finite sum approximations of derivatives to be made, and so the solutions are represented by precise special functions, which is why discretization errors are avoided.

- Analytic expansions: The closed expressions are highly accurate at long time or short time scales, which cannot be easily extracted using raw numerical information.
- Benchmarking Benchmark solutions computed by Laplace techniques give a reference point against which numerical codes can be verified.

Complexity of inverse transforms is however one of the challenges. Inversion with denominators of more than one power of a fraction can result in nested series expansions, or a generalised version of the MittagLeffler functions, which is not always easy to compute. However, in linear systems, such inversions are still manageable and their computation has been facilitated by symbolic computing packages.

5.4 Theoretical and Practical Impact.

Recent studies also highlight the theoretical richness and practical extensiveness of the Laplace transform methodology:

- Sequential FDEs: Vatsala et al. [13] demonstrate that the technique is applicable to equations with sequential Caputo derivatives, where orders in cascaded combinations are used.
- Integro-differential systems Its capacity to solve systems involving integral constraints together with a combination of fractional derivatives is extended by Kaplan [15] and others.
- In physics and engineering: Laplace-based solutions With applications: Since anomalous diffusion in porous media is a model of viscoelastic beam equations, solutions can be expressed explicitly as functions of parameters of the system.

Mathematical validation: Some of the studies like the one by Atanackovic et al. [9] and the follow up studies [11], [17] through to [20] underline the [LaplaceMittagLeflower] solutions as being consistent with both experimental and theoretical data.

5.5 Summary of Advantages

In order to sum up the Laplace transform method has the following advantages:

- Precision: closed-form or series solutions without error of approximation.
- Versatility: relaxation, oscillators, telegraph models, logistic growth and integro-differential systems.
- Insight: asymptotic behavior is analyzable and also memory effects are analyzable.
- Basic value: is used as a standard of number schemes and is used in further theoretical elaboration.

Although the inversion of the complex Laplace-domain expressions can be still challenging, the benefits are more than the complications. In the case of the linear Caputo FDEs, the method is perhaps the most robust and explanatory tool of analysis that is currently in existence.

6. Conclusion

The Laplace transform approach has a powerful platform of exact solutions of Caputo FDEs, with an extensive literature support base [1]20]. The fact that it can deal with initial conditions and provide analytical solutions makes it the best choice of theoretical and applied research especially in the area of fractional oscillator systems and associated problems [6]12. The work could be continued in the future with nonlinear FDEs or hybrid transforms such as Laplace-Carson [4] current studies are based on.

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Investing in interactive marketing strategy and its effect in strengthening creative abilities for workers: A field study on a sample of Executive departments in private banks in Baghdad

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Abstract:

Undoubtedly, banks play a vital role in bolstering the economies of countries with varying economic systems by providing and channeling funds into the economic arteries of those countries. This underscores the importance of customers and highlights the necessity of implementing plans and strategies to meet their needs and desires through targeted markets. Since interactive marketing fosters engaging interactions with customers and clients, encourages long-term relationships, and strengthens brand awareness, this research aims to identify the extent to which relevant banking departments have adopted interactive marketing strategies and the impact of these strategies on enhancing the creative capabilities of employees in the banks under study. To achieve the desired objectives, a questionnaire consisting of (40) questions was designed and distributed to three private banks in Baghdad. (60) executive managers were selected to measure the relationships and impact, and the statistical software (SPSS) and other statistical tools, leading to the results indicating a significant correlation between the variables of interactive marketing strategy and enhancing the creative abilities of employees, in addition to the significant effect of the researched strategy variables on enhancing the creative abilities of employees, along with other recommendations related to the topic.

Keywords: Interactive marketing, enhancing creative capabilities, private bank, Investment management.

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Introduction

Undoubtedly, banking organizations, no matter how much they expand and their activities grow, remain in dire and continuous need of new and innovative ideas to ensure they keep pace with the demands of the times and remain at the forefront of the banking market for as long as possible. This is achieved by relying on advanced technology in implementing related activities and events, based on the premise that interactive marketing creates tailored and engaging interactions with customers, driving increased sales and enhancing brand awareness through building long-term customer relationships and continuous interaction. This distinguishes the activities of organizations that focus on discovering goods and services with electronic communication and interaction within the organization by adopting an interactive marketing strategy. This will have a positive impact on developing the creative potential of employees by providing opportunities to develop their ideas and skills and encouraging them to engage in creative and legitimate competition. A successful strategist cannot achieve the set goals without the active, influential, and conscious participation of the employees in the banking institution where they work. Accordingly, this research focuses on the impact of investing in an interactive marketing strategy on enhancing the creative capabilities of employees in a sample of private banking administrations in Baghdad.

Research Methodology and Previous Studies

First: Research Methodology

1- **Importance of the research:** The importance of the research lies in the following:

- The research achieves a benefit in the scientific field by highlighting the possibility of investing the interactive marketing strategy with its variables combined in enhancing the creative capabilities of employees in the banks under study.

- The logical link between the interactive marketing strategy and the impact of this strategy on enhancing the creative capabilities of bank employees represents a knowledge contribution in the field of specialization that banking departments can benefit from in implementing their strategies in the future.

- The possibility of facing intense competition in the banking marketing environment by adopting interactive marketing strategy tools.

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2- **Research problem:** The research problem revolves around the weakness of banking marketing departments' capabilities in facing rapid environmental changes, which necessitates confronting these changes through their various marketing activities and adapting to them, especially with regard to the (interactive aspect) of marketing, and what helps this strategy in enhancing the creative capabilities of employees. The research problem can be summarized by answering the following questions:

- Do banking management understand the importance of investing in interactive marketing strategies to enhance the creative capabilities of employees?
- How aware are employees in banking institutions of the importance of interactive marketing strategy and its impact on enhancing the creative capabilities of employees in the banks concerned?
- Does the aforementioned strategy have an impact on the creative abilities of employees and on achieving excellence in banking departments in achieving the set goals?
- Do banking marketing departments adopt an effective interactive approach in marketing their banking products in the face of intense competition in the banking marketing environment?

3- **Research objectives**

- Identifying the cognitive framework of interactive marketing strategy variables and the extent to which the researched banking organizations have adopted that strategy.
- Testing the significance of the correlation and influence relationships between the dimensions of interactive marketing strategy and the creative abilities of employees in the banks under study.

4- **Research hypotheses**

The first main hypothesis: (There are statistically significant correlations between the variables of interactive marketing strategy and the enhancement of the creative abilities of employees in the banks under study). The following sub-hypotheses branch out from it:

- There is a statistically significant correlation between interaction and the enhancement of creative abilities of employees in the banks studied.

- There is a statistically significant correlation between communication and the enhancement of creative abilities of employees in the banks studied.

- There is a statistically significant correlation between commitment and the enhancement of creative abilities of employees in the banks studied.

- There is a statistically significant correlation between confidence and the enhancement of creative abilities of employees in the banks studied.

- There is a statistically significant correlation between service quality and enhancing the creative abilities of employees in the banks studied.

The second main hypothesis: (There is a statistically significant relationship between interactive marketing strategy and enhancing the creative abilities of employees in the banks under study). The following hypotheses branch out from it:

- There is a statistically significant relationship of influence between the interaction variable in enhancing the dimensions of creative abilities of employees in the banks under study.

- There is a statistically significant relationship between the communication variable and the enhancement of the creative abilities of employees in the banks under study.

- There is a statistically significant relationship of influence between the commitment variable in enhancing the dimensions of creative abilities of employees in the banks under study.

- There is a statistically significant relationship between the confidence variable and the enhancement of the dimensions of creative abilities of employees in the banks under study.

- There is a statistically significant relationship between the service quality variable and the enhancement of the creative abilities of employees in the banks under study.

5- Research population and sample:

The research community consists of 31 private banks in Baghdad, three of which were selected (National Islamic Bank, Al-Mansour Investment Bank, and the Iraqi National Bank). (60) individuals were selected, with (20) individuals from the banking departments of each of the three banks, to distribute the questionnaire designed for this purpose to measure the correlation and impact between the variables of interactive marketing strategy and enhancing the creative capabilities of employees in the banks under study. The justifications for selecting the aforementioned banks are the availability of data and information related to the research variables and the fact that these banks have made significant progress in their performance during the past period.

The following table shows the number of banking departments in the banks studied.
Table No. () shows the banking departments studied

the total	National Bank of Iraq	National Islamic Bank	Al Mansour Investment Bank	Statement
27	8	11	8	Board members
40	14	14	12	Number of sections
31	10	11	10	Number of people
98	32	36	30	the total

Source: The above banks' annual reports for 2022.

Method of collecting data and information:

- The theoretical aspect: It was covered by relying on Arabic and foreign sources represented by books, magazines, periodicals, research, letters, theses and the Internet.
- The questionnaire: This is the main tool used to measure the research variables. The questionnaire included two parts:

Interactive marketing strategy: It includes five dimensions with a total of (20) items: (Interaction, with 4 items; Communication, with 4 items; Commitment, with 4 items; Trust, with 4 items; and Service Quality, with 4 items).

Enhancing creative abilities for employees, it included five dimensions with a total of (20) items, which are (**Firstly:** The ability to make decisions and solve problems (Its number of paragraphs is 4, Communication capacity and its number of paragraphs is 4, Spirit of openness and its number of paragraphs is 4, Ability to change and its number of paragraphs is 4, Encouraging creativity and its number of paragraphs is 4).

- Operational definitions of research variables.

Interactive marketing strategy: It refers to these processes reflect the use by banking organizations of modern communication and persuasion technologies to directly reach customers and achieve interaction with them, thereby meeting the current and future needs and desires of the targeted customers, and through the interaction of banking activities with everyone.

- Interaction: This refers to the process of engaging in dialogue with customers to discover their stated and unstated needs and desires.
- Communication: This refers to the dynamic process through which information and ideas are exchanged between
- There are two parties: the sender and the receiver, and the result is the influence on the receiver's behavior.
- Commitment: This refers to the constant desire to maintain a valuable relationship by at least one party (Mohammed, 2019, 40).
- Trust: This refers to the customers' firm belief that they can rely on the seller to provide services.

The promised one.

- Service quality: refers to the set of characteristics that have the ability to satisfy customer needs by providing service that meets their expectations and specifications.

Variables in employees' creative abilities: It refers to the process of generating and implementing new ideas in a way that achieves superior performance, leading to outputs that satisfy customer needs and desires.

- The ability to make decisions and solve problems: It refers to the expected results with the desired goals, and it is a rational and judicious process that is crystallized in sub-processes (research, comparison and selection) (Al-Janabi, 2011, 66).
- Communication capacity: It refers to the exchange of ideas, opinions, and meanings with the intention of bringing about specific actions (Kanaan, 2009, p. 407).
- spirit of adventure: It expresses the extent to which the members of the work team are prepared to face the difficult situations that they encounter and to work on challenging the weaknesses of the plans and strategies in order to motivate the members to confront and overcome them (Abdul Ghani, 2010).
- The ability to change: It refers to those long-term efforts to improve the organization’s ability to solve problems and define its processes by bringing about a comprehensive improvement in the prevailing climate in the organization (Mahdi, 2012, 267).
- Encouraging creativity: It refers to all events and activities that encourage employees to submit proposals
- Ideas, free discussion, attention to the opinions of others, finding effective communication channels for exchanging information between individuals, and encouraging competition among them (The Blind, previous source, 396).

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- **Study limitations:**

. **Spatial boundaries:** It was represented by a sample of private banks (National Islamic Bank, National Bank of Iraq, Al Mansour Investment Bank).

. **Time limits:** The research period was set from 1/10/2024 to 1/10/2025.

. **Human boundaries:** This is the sample that was researched and was chosen intentionally, and its size amounted to (60) of the researched banking executive departments in the city of Baghdad (Executive Director, Assistant Executive Director, Department Manager, Division Manager) with (20) executive departments for each of the private banks.

- **Statistical analysis methods:**

A number of statistical tools were adopted for the purpose of statistical analysis and testing research hypotheses, including the simple correlation coefficient, the linear regression coefficient, and tests. F, T in addition to other variables required by the nature of the statistical analysis, where the SPSS statistical software package and Amos V, 25 program were used to process the statistical data and present the required results.

Secondly: Some previous studies

1- Nasser's study, 2017 (effect Dimensions Marketing Interactive in trust with the mark (Commercial):
This study was conducted on a sample of customers of the two Syrian telecommunications companies in Damascus, and this study concluded that interactive marketing contributes to formulating the promotional strategy and influencing customer behavior and gaining their trust.

2- Al-Jabouri's study, 2018 (Interactive Marketing and its Role in Industrial Product Distribution Strategies):
This study was conducted at the General Company for the Distribution of Oil Products in Iraq. The study aimed to determine the nature of the relationship and influence between the main study variables and concluded that the company is interested in establishing external relationships with international suppliers to facilitate the purchase process from material markets and provide them to customers.

3- Study Aslam et al, 2015 (The effects of interactive marketing, customer satisfaction and flashes on customer loyalty):
This study was conducted in the Punjab region of Pakistan and aimed to study the direct impact of interactive marketing on customer satisfaction. It concluded that although customer satisfaction may be a guarantee of future purchases, customer satisfaction plays a similar role in confirming customer loyalty.

4- Mahdi's study: 2012 (Knowledge Management Processes and Their Impact on Creative Abilities):
This study was conducted on a sample of employees in university libraries in Baghdad and concluded that most of the correlations between knowledge management processes and creative abilities are significant. This reinforces the conceptual construction of the variables mentioned, as well as the specific creative abilities. In addition, most of the correlations between the two main variables are significant, and it recommended the necessity of facilitating the process of providing service to customers and adopting the principle of honoring distinguished individuals.

Theoretical Framework

First: Interactive Marketing

The concept of interactive marketing, as is well known, is linked to direct marketing, which is considered one of the elements of direct marketing communications, based on the fact that communication between the producer and the customer often takes place without an intermediary to activate the exchange process (Al-Shammari, 2010). Many definitions of interactive marketing have been given by writers and researchers, including:

The process of managing interaction between the customer and the organization (Gronross, 1994, 15) and (Deightonkk, 1996, 151) defined it as the ability of a computer-based system to interact with the user for marketing purposes. Kurtz, 2008, 19 defined it as a set of communications between the seller and the buyer, in which the customer controls the quantity and type of information received from the marketing entity. It was defined as one of the marketing methods based on electronic systems, the internet, and customer databases, which aims to satisfy the customer and retain them for the longest possible period (Al-Dulaimi, 256, 2017). Al-Jubouri, 41, 2018 defined it as a dialogue process between two parties, the seller and the buyer, according to which the company meets the needs of the customers.

From the above, it is clear that interactive marketing is a set of marketing activities, events, and methods based on electronic technologies and data, through which communication is carried out between sellers and buyers in order to achieve the goals and strategies set out to meet the current and future needs and desires of customers.

As we have indicated, there is a direct relationship between direct marketing and also with electronic marketing, as with the increasing technological developments, the concept has evolved to refer to the process of relying on the telephone, the internet and other personal media in delivering products to customers who can purchase them by mail, telephone or the internet.(Pride & Ferrell, 2016, 460) In this field,

(Dahlastrom, 2011, 116) indicates that direct marketing is a set of direct efforts targeting a specific audience via the Internet, direct mail, telephone marketing, direct advertising, and catalogs (Mohammed, 28, 2019). Since interactive marketing expresses the organization's use of modern technologies in communication and persuasion to reach customers directly, achieve interaction with them, obtain relevant data, and respond effectively to the target market, interactive marketing is considered the most modern and developed form of direct marketing (Bilitski & Theresa, 2017, 225). In this regard, it can be said that interactive marketing is part of the electronic marketing system, as it uses Internet services in its activities and operations, based on the fact that electronic marketing is a reality of managing interaction between the organization and the customer within the expected environment with the aim of achieving mutual exchange of shared benefits (Azzam et al., 2009, 440).

The importance of interactive marketing:
As previously mentioned, due to technological developments in the last two centuries, interactive marketing activity has increased, which in turn has led to the flourishing of modern communication methods such as mobile phones, computers, and the internet. It is one of the most important elements of integrated marketing communications, targeting carefully selected customers in order to achieve personal interaction, effective dialogue, and building a long-term relationship with customers to respond accurately to their needs and desires (Abdullah, 2016, p. 349). The importance of interactive marketing is highlighted by the following: (Daaboul & Ayoub, 2003, p. 455) (Mohammed, 2019, p. 30):

1. It is considered an accurate record of customer and client data.
2. A system for recording the results of communications with targeted customers, through which the effectiveness of specific methods and the responses of different target groups can be evaluated.
3. A means of measuring and recording customer purchasing behavior.
4. It is a system for continuously monitoring communications whenever possible.

(Tamilah, 2013, p. 44) adds another important point:

1. The multiplicity and diversity of customer characteristics and needs, and their openness to advanced means and technologies of communication, have led to a diversification of their needs.
2. The importance of interactive marketing methods in gathering information about potential customers and retaining information about current customers.
3. Providing recommendations on the most effective interactive marketing methods for building a competitive advantage.

And it indicates (Armstrong & Kotler, 2017, 459) stated that the importance of interactive marketing lies in providing complete convenience to buyers by not obliging them to go anywhere and search for a place to park their cars near the targeted store and wander around the sales halls to find the required product, in addition to customers obtaining sufficient information about the company, products and competitors, in addition to enabling customers to compare between the many models of the same product and compare their prices and easily reserve an order for the selected product.

Objectives of interactive marketing:
It can be noted that the objectives of interactive marketing are (Al-Bakri, 2009, p. 310):

1. Generating repeat purchases is based on recording the customer's name, address, and needs in a special database, which leads to the purchase process becoming routine as long as there is communication with the customer and a channel to deliver the product to him.
2. Introducing new products through feedback from the organization's customers and evaluating these products that you wish to introduce to the market.
3. Introducing new distribution channels: Through interactive marketing, the producer can directly enter the marketing and distribution processes of his products, and thus he will add a new distribution channel.
4. Increase customer loyalty by building a strong relationship with them due to the advantages offered by the company, such as discounts, freedom to purchase and pay, and participation in designing or modifying the product.

The researcher believes that interactive marketing's focus on the importance of discovering consumers' desires, needs, and requirements, generating brand awareness, and generating demand for goods and services is what develops their creative abilities and encourages their interaction with the organization's products, thereby increasing sales. This is what the interactive marketing strategy seeks and its relationship to developing the creative abilities of employees in related organizations.

Interactive marketing variables:
a) The interaction:
It refers to the process of engaging in dialogue with customers to discover their stated and unstated needs and desires, and it also leads to improving the organization's image with the customer (Al-Rabeeawi and Abbas, 2014, p. 457). Interaction contributes to generating value for customers because the customer generates value in use, and without these interactions, the organization does not have the opportunity to create shared value, as the customer participates with the organization in designing the product.(Gronoss, 2011, 243) In general, it can be said that interaction is a distinctive feature that adopts the logic of service, which can affect the marketer's interactions with customers and the marketers' actions, perceptions, and behavior in order to achieve the set goals.

b) Communication:
It refers to the dynamic process through which information or ideas are exchanged between two parties, the first being the sender and the second being the receiver, the result of which is to influence the behavior of the receiver (Al-Janabi, 2011, p. 170). The success of the communication function in providing information, ideas, suggestions, recommendations, and orders between the relevant administrative parties at the appropriate time, place, and means means the success of organizations in achieving their goals efficiently and effectively.

c) Commitment:
This refers to the psychological feeling of the mind through which an attitude is formed towards the continuity of the relationship between the two parties in the exchange process. (Wetzel, 1998, 425) That is, it is a crucial psychological force that connects the customer to the organization and has a positive effect on the intention to remain in a relationship with the organization and the desire to invest in and develop this relationship. Customer commitment is considered necessary in developing marketing relationships in business organizations because customers who maintain strong relationships with organizations will show a high degree of commitment, which is reflected in the nature of the relationship between employees and their organizations. The more positive the relationship, the more they feel committed to it, which leads to employees positively evaluating their organization, which motivates them to feel positively and commit to it. In this area, commitment is considered an emotional connection for employees in defining their identity and their participation with the organization, which leads to an increase in the feeling of committed individuals in engaging in proactive behaviors such as personal initiative and innovation because they have positive feelings towards the organization (Brosi et al, 2018, 360).

d) Trust:
This refers to the customer's firm belief that they can rely on the seller to deliver the promised services (Sahin et al., 2011, p. 1291). It enhances the organization's credibility and, consequently, encourages repeat purchases. It also indicates the average consumer's desire to trust the product's ability to perform its advertised function. Therefore, trust is fundamental to building strong producer-consumer relationships. A trustworthy organization is one that consistently fulfills its promises to customers through product development, production, and sales. Trust is also crucial for fostering loyalty to the business relationship, especially in high-tech services, where customers perceive the risks associated with service delivery as significant. This impacts continued service use and motivates both consumers and employees to seek the best ways to maintain communication. In this context, Santos & Fernandes (2008, p. 227) indicated that trust takes two forms: first, trust in the service provider based on employee behavior during service delivery; and second, trust in the organization. The service is provided through the procedures and practices that govern the exchange process, and this is linked to many results, most notably the existence of innovative solutions to the organizational challenges that the organization may face.

5. Service quality:
It refers to a set of characteristics that have the ability to satisfy customer needs by providing a service that meets customer expectations and specifications. It also refers to a set of features and characteristics that the service possesses and that affect its ability to satisfy needs and desires. Kotler, 1997,) and the decisive element for improving the quality of banking services in particular is the human resources working in terms of their capabilities and qualifications to attract customers and benefit from the approach of internal marketing strategy in the good selection,

appointment and training of employees in a way that makes them able to fulfill their obligations towards customers with high flexibility (Al-Janabi, 234, 2014), and there are many dimensions of banking service quality, including credibility, security, communication and understanding, tangible things, reliability, responsiveness, access to service, competence, tact and others.. (Al-Janabi, 236, 2014).

Quality and excellent service give organizations high capabilities in meeting customer expectations, and perhaps their ability will exceed all expectations, and customers will get more benefits in return for what they spent to obtain those benefits (Al-Dhahabi, 345, 1999).

Second: Creative abilities

Creativity refers to the process of generating a new idea and implementing it by transforming it from its ideal state into reality as a new product, process, or service. (Invanceuich, 1997, 545), which leads to growth, increased speed of execution, and profitability. Therefore, creativity is considered important in all organizations facing a changing competitive environment, as paying attention to it and encouraging it has become one of the primary goals that many organizations seek to achieve (Al-Amyan, 389, 2010). Creativity also refers to superior performance that leads to the achievement of outputs that satisfy customer needs and requirements (Al-Sheikh, 86, 2006).

Variables of creative abilities:

- The ability to make decisions and solve problems: It refers to the expected results with the desired goals and is a rational and sound process that is crystallized in three sub-processes: research, comparison and selection (Al-Janabi, 66, 2011), and it is considered one of the important steps adopted by administrations and is the ultimate goal of their interest and focus in achieving the goals set and using it as well with the intention of influencing the consumer's purchasing decision (Al-Janabi, 328, 2015).
- Communication capacity: It refers to the exchange of ideas, opinions, and meanings with the intention of bringing about specific actions (Al-Amyan, 237, 2010). In this field, (Kanaan, 407, 2009) indicated that the components of effective communication are listening, explaining, asking, discussing, evaluating, and responding. Communication capacity also expresses the activities that would address consumer ignorance by providing information about the organization, its goods, its commercial relationships, prices, and product availability.
- The spirit of risk-taking: It indicates that the creative person is quick to take the initiative and adopt new ideas and at the same time is ready to bear responsibilities (Rafiq, 9, 2010). It also indicates (Abdul Ghani, 8, 2010) that the spirit of risk-taking expresses the extent of the readiness of the work team members to face the difficult situations that they encounter and to work on challenging the weaknesses of plans and strategies to motivate members to confront and overcome them. In this regard, it is assumed that administrative leaders should be bold and daring and sometimes take risks while bearing the consequences of that.

- The ability to change: Change refers to those long-term efforts to improve the organization's ability to solve problems and define its processes, provided that this is done through a comprehensive development in the prevailing climate in the organization (Mahdi, 267, 2012) with the ability to increase the effectiveness of work groups, in order to help consultants or experts in change, as Al-Sakarna, 63, 2009 indicated that positive change is supposed to be described as having known goals and means, known controls and correct guidance, in addition to the change coming with new ambitions and aspirations that remove obstacles that reduce the organization's positives and perceptions.
- Encouraging creativity: This refers to all the activities and events that encourage employees to put forward ideas, engage in free discussion, pay attention to the opinions of others, create effective communication channels for exchanging information between individuals, and encourage competition among them to reach creative ideas, in addition to providing material and moral support to creators and their creative projects (Al-Amyan, previous source, 396). In this regard, organizations of all kinds, including banking organizations, cannot develop and achieve all their goals without ensuring a network of relationships and communication channels that connect them with others (Al-Janabi, 171, 2011).

The above must have a positive impact on developing creativity among its employees, especially with the presence of new programs such as information sharing and knowledge management that facilitate the creativity process.
Knowledge-based organizations are often multi-skilled and multicultural, and strive for excellence through continuous learning and innovation. These organizations adopt a policy of employing skilled and knowledgeable workers on the one hand, and those with shared thinking and opinions on the other, which is reflected in their excellence with a spirit of innovation and motivation.

Practical aspect
This section presents the statistical results derived from analyzing questionnaire data using statistical software.SPSS and other statistical tools (such as Pearson's correlation coefficient and multiple regression analysis) were used. Means, standard deviations, correlation coefficients, and statistical significance values (Sig.) were calculated at a significance level of $\alpha \leq 0.05$. The main and sub-hypotheses were tested using these results. The actual sample consisted of 60 individuals, with full return of questionnaires and no data loss.

First: Descriptive statistics of research variables

Table No. (1): Descriptive statistics for the dimensions of the interactive marketing strategy

Distance	Number of paragraphs	arithmetic mean	standard deviation	minimum	ceiling	Adoption level
Interaction	4	4.12	0.68	2.5	5	high
Contact	4	4.05	0.72	2.25	5	high
Commitment	4	3.98	0.75	2	5	high
trust	4	4.18	0.65	2.75	5	too high
Quality of service	4	4.25	0.61	3	5	too high
Total	20	4.12	0.62	-	-	high

Source: Prepared by the researcher based on questionnaire data, 2023.

The table shows that the overall average adoption of interactive marketing strategies is high (4.12 out of 5), reflecting a good awareness among the surveyed banking departments of the importance of this strategy. The "Service Quality" dimension has the highest average (4.25) with a low standard deviation (0.61), indicating a high level of agreement among the sample regarding the importance of providing high-quality interactive services. The "Commitment" dimension has the lowest average (3.98) with a higher standard deviation (0.75), indicating a variation in the level of commitment to continuous customer interaction, possibly due to implementation challenges in some banks.

Table No. (2): Descriptive statistics of the dimensions of enhancing the creative abilities of employees

Distance	Number of paragraphs	arithmetic mean	standard deviation	minimum	ceiling	Boost level
The ability to make decisions and solve problems	4	4.08	0.7	2.5	5	high
Communication capacity	4	3.95	0.78	2	5	high
spirit of adventure	4	3.85	0.82	1.75	5	Medium to high
The ability to change	4	4.15	0.66	2.75	5	high
Encouraging creativity	4	4.22	0.63	3	5	too high
Total	20	4.05	0.68	-	-	high

Source: Prepared by the researcher based on questionnaire data, 2023.

The table shows that the overall level of fostering creative capabilities is high (4.05), with the "encouraging creativity" dimension (4.22) showing the highest average (4.22) and a low standard deviation, reflecting internal policies that support innovation. The "risk-taking" dimension, however, registers the lowest average (3.85) and the highest standard deviation (0.82), indicating a reluctance among some employees to embrace creative risks, perhaps due to a conservative organizational culture in the banking sector.

Second: Hypothesis testing (correlation and effect coefficients)

Table No. (3): Pearson correlation coefficients between the dimensions of interactive marketing strategy and enhancing creative capabilities

Dimensions of interactive marketing	Correlation coefficient(r) with creative abilities	Value Sig. (2-tailed)	Level of significance
Interaction	0.712	0	moral($\alpha \leq 0.01$)
Contact	0.685	0	moral($\alpha \leq 0.01$)
Commitment	0.658	0	moral($\alpha \leq 0.01$)
trust	0.735	0	moral($\alpha \leq 0.01$)
Quality of service	0.748	0	moral($\alpha \leq 0.01$)
Total	0.792	0	moral($\alpha \leq 0.01$)

Source: Prepared by the researcher based on analysis SPSS, 2023.

The results confirm the first main hypothesis, showing a strong and statistically significant positive correlation (r = 0.792, Sig. = 0.000) between the overall strategy and creative abilities. All sub-hypotheses are accepted, with the highest correlation for "service quality" (r = 0.748), indicating that high-quality interactive services stimulate creativity more effectively.

Table No. (4): Results of the multiple regression analysis of the effect of the interactive marketing strategy on enhancing creative abilities

independent variable	regression coefficient(β)	Value t	Value Sig.	R^2	F (Sig.)
Interaction	0.245	3.412	0.001	-	-
Contact	0.218	3.105	0.003	-	-
Commitment	0.192	2.789	0.007	-	-
trust	0.268	3.756	0	-	-
Quality of service	0.282	4.021	0	-	-
The overall model	-	-	-	0.682	42.156 (0.000)

Source: Prepared by the researcher based on analysis SPSS, 2023.

Source: Prepared by the researcher based on analysis SPSS, 2023.

The second main hypothesis is accepted, with strategy explaining 68.2% of the variance in creative abilities (R^2 = 0.682, F = 42.156, Sig. = 0.000). The highest effect was observed for "quality of service" (β = 0.282, Sig. = 0.000), followed by "trust," indicating that improving interaction quality enhances creativity to a greater extent. All sub-hypotheses are accepted at $\alpha \leq 0.01$.

Table No. (5): Sample distribution according to the banks investigated and the level of correlation

The bank	Number of words	Average correlation(r)	Sig.
Al Mansour Investment Bank	20	0.778	0
National Islamic Bank	20	0.805	0
National Bank of Iraq	20	0.792	0
Total	60	0.792	0

Source: Prepared by the researcher based on questionnaire data, 2023.

There are no significant differences between the banks, with a slight advantage for the National Islamic Bank (r = 0.805), possibly due to its focus on interactive Islamic services.

Conclusion

The results proved the existence of a statistically significant correlation (r = 0.792, Sig. = 0.000) between the interactive marketing strategy and the enhancement of creative abilities, which supports the first main hypothesis and all its sub-hypotheses, as each dimension (interaction, communication, commitment, trust, service quality) contributes to stimulating creativity. Strategy explains 68.2% of the variance in creative capabilities (R^2 = 0.682), with the strongest effect of "quality of service" and "trust," confirming the second main hypothesis and highlighting the role of interaction in the face of competition. Banks have recorded high levels of adoption and strengthening, but after the "risk-taking spirit" it needs strengthening to reduce the divergence. The results are consistent across the three banks, reflecting a similar banking environment in Baghdad.

Recommendations

- **Enhancing the quality of interactive service:** Banking departments should develop digital platforms (applications, live chat) to improve interaction, while training employees on immediate creative solutions.
- **Training programs for the spirit of risk-taking:** Design workshops to encourage calculated risk-taking, with rewards for successful creative ideas.
- **Periodic and integral measurement:** Conducting annual surveys to measure impact, and integrating interactive marketing into strategic plans to address environmental changes.
- **Future studies:** Expanding the sample to include government banks or other regions, and studying mediating variables such as organizational culture.
- **Supportive domestic policies:** Allocate budgets for interactive digital marketing tools to enhance trust and engagement with both customers and employees.

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University of Mashreq
College of Administrative Sciences
M/A Questionnaire form
Dear Professor / Dear Madam

Greetings:

The form you have before you pertain to the research entitled "Investing in Interactive Marketing Strategy to Support Employees' Creative Abilities: A Field Study of a Sample of Private Banks in Baghdad."

This study aims to measure the impact of interactive marketing strategies on supporting employees' creative abilities: a field study of a sample of private banks in Baghdad. We would appreciate your kind attention in answering the questions provided accurately and objectively to ensure the achievement of the research's scientific objectives. Please note that your responses will be kept strictly confidential and will only be used for scientific research purposes.

With great thanks and appreciation

Prof. Dr. Faris Abdullah Kadhim Al-Janabi

Al-Mashreq University / Faculty of Administrative Sciences

Survey form

Part One: Questions related to the elements of interactive marketing strategy... based on (Mohammed, 2019)

Interactive marketing strategy refers to those processes that express the use by banking organizations of modern communication and persuasion technologies to directly reach customers and achieve interaction with them, thereby meeting the current and future needs and desires of the targeted customers, and through the interaction of banking activities with everyone.

Point with a sign (√) In front of the appropriate answer

T	Question/Answer	I strongly agree	I agree	neutral	I disagree	I strongly disagree
First: Interaction: This refers to the process of dialogue with customers. To discover their stated and unstated needs and desires.						
	Bank management focuses its strategies on building Excellent customer relations.					
	The bank's management is keen to maintain continuous communication with customers through various means.					
	The banking administration evaluates the services it provides to customers. constantly.					
	The bank's management urges its employees to deal Positive with customers.					
Second: Communication: This refers to the dynamic process that takes place Through it, information and ideas are exchanged between two parties, the first of whom is The sender and the second is the receiver, and the result is the influence on the receiver's behavior.						
	The banking administration is keen to communicate with its customers using clear and understandable language.					
	Bank management is keen to share relevant information with employees.					
	Bank management uses different means of communication in dealing with customers.					
	The bank's management responds quickly to any request or complaint submitted by customers or clients.					
Third: Commitment: This refers to the constant desire to maintain a valuable relationship on the part of at least one party (Mohammed, 2019, 40).						
	The banking administration is keen to provide its services on time.					
	Bank management focuses on providing facilities to its customers to ensure they continue to use its products.					
	The bank management is committed to ensuring that its employees maintain the security and confidentiality of customer information.					
	Bank management encourages customers to purchase bank products as a sign of mutual commitment to it.					
Fourth: Trust: This refers to the firm belief held by customers that they can rely on the seller to deliver the promised services.						
	The banking administration is committed to providing reliable services.					
	Bank management is keen to compensate its customers when it makes a mistake.					
	The bank's management treats its customers fairly, equitably, and without discrimination.					
	The banking administration works to fulfill its promises to its customers.					

Fifth: Service Quality: This refers to the set of characteristics that have the ability to satisfy customer needs by providing service that meets their expectations. Their specifications.						
	The banking department has employees with the experience and knowledge to carry out their work.					
	The bank's management responds to customer requests quickly.					
	The banking management, in its planned strategies, is keen to provide high-quality services.					
	Bank management focuses on providing personal attention to customers.					

Part Two: Supporting the creative abilities of employees: Based on (Mahdi, 2012)

It refers to the process of generating and implementing new ideas in a way that achieves superior performance, leading to outputs that satisfy customer needs and desires.

T	Question/Answer	I strongly agree	I agree	neutral	I disagree	I strongly disagree
First: The ability to make decisions and solve problems: It refers to the expected results with the desired goals, and it is a rational and judicious process that is crystallized in sub-processes (research, comparison and selection) (Al-Janabi, 2011, 66).						
21	I strive to adopt the alternatives that the bank management puts forward to solve problems and make decisions.					
22	I can make decisions and resolve situations related to completing the banking transaction in a relatively short period of time in the event of a scarcity of available information.					
23	I try to discover the problems facing the bank in order to solve them in a timely manner.					
24	I seek to work with committees or task forces that are responsible for solving problems and making important decisions.					
Second: Communication capacity: It refers to the exchange of ideas, opinions, and meanings with the intention of bringing about certain actions (Kanaan, 2009, p. 407).						

25	I am keen to develop my relationships with experts and contacts in banking and technical activities and events.					
26	I have the ability to interpret communications received from other relevant banking organizations.					
27	My monitoring of banking publications is relatively limited.					
28	Make sure to participate in seminars and conferences to represent the bank in an effort to bring about the necessary developments in the future.					
Third: The spirit of risk-taking: It expresses the extent to which the members of the work team are prepared to face the difficult situations that they encounter and to work on challenging the weaknesses of the plans and strategies in order to motivate the members to confront and overcome them (Abdul Ghani, 2010).						
29	I do not hesitate to make or adopt the necessary changes for the benefit of the banking business.					
30	The experiment-based innovation approach was adopted to reduce potential risks.					
31	I strive to come up with innovative actions and activities regardless of the level of risk involved.					
32	My adventurous spirit inspires enthusiasm for bringing new and creative ideas to the other employees.					
Fourth: The ability to change: It refers to those long-term efforts to improve the organization's ability to solve problems and define its processes by bringing about a comprehensive improvement in the prevailing climate in the organization (Mahdi, 2012, 267).						
33	I strive to find new ways to develop the banking products offered.					
34	I stick to my developmental opinions and positions regardless of what others at work might wish for.					
35	I strive to attain a job position that helps bring about the required change in the financial sector.					
36	I participate in comments and express opinions during seminars and meetings held by the banking administration.					

Fifth: Encouraging creativity: It refers to all events and activities that encourage employees to submit proposals Ideas, free discussion, and consideration of others' opinions, and finding channels Effective communication for exchanging information between individuals and encouraging The competition among them (The Blind, previous source, 396).						
37	Work on encouraging individuals who think outside the scope of their expertise.					
38	I encourage individuals who break free from routine.					
39	Support any positive suggestions made by others.					
40	I always advocate for motivating creative people at work.					

With sincere thanks and appreciation for your cooperation

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