Project STRIKE: Swarm Tactical Reconnaissance and Intelligence with Kinetic Efficiency

Final Report

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Abstract

For my dissertation, I tackled Project STRIKE to see how drone swarms could be used for intelligence, surveillance, and reconnaissance (ISR). My main goal was to figure out if these swarms could be a better option than the usual systems, which are often expensive, have limited range, and take a long time to respond. The basic idea with a swarm is that it doesn’t depend on a single control point, so the drones can share tasks and keep working even if some of them fail.

To test this, I built a simulation in Python using Matplotlib. The algorithms I used were inspired by natural systems, and the results showed that swarms are great at covering a large area, handling failures, and scaling up more easily than centralized systems.

Beyond the technical side of things, my project also brought up some bigger issues. While drone swarms could make operations safer and cheaper, they also raise some tough questions about ethics, laws, and security. I've suggested some ways to handle these challenges, but it's clear that we need to be really careful as we move forward with this technology.

In short, my work on Project STRIKE showed me that drone swarms could be a big help in defence, as long as we make sure to balance the benefits with responsible oversight.

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1.Introduction

1.1 Background: The Evolving Landscape of Modern Military Operations and the Rise of Autonomous Systems

Today, military operations demand real time intelligence, surveillance, and reconnaissance (ISR) capabilities. This is critical because modern conflicts are so complex and fast paced, so being able to make quick decisions and have a full picture of what's happening is key to success. For a long time, we've relied on traditional assets like manned aircraft and satellites for ISR. While these systems have been useful, they're becoming a problem because they're expensive, their range is limited, and they can be slow to respond to a situation that's changing quickly. On top of that, using manned assets always puts people's lives at risk. (Royal Air Force, 2023)

That's why swarm robotics and autonomous drone systems are such a promising new technology. They represent a big change by using a decentralized intelligence system, drawing inspiration from natural things like bird flocks or insect swarms (Jovanović et al., 2025). Unlike traditional systems that rely on a single point of control, swarm intelligence spreads decision making and tasks across many units. This makes them tougher, more adaptable, and much easier to scale up, especially in unpredictable military settings. I found that using autonomous systems isn't just a small tech upgrade, it’s a fundamental shift in how we approach military operations, affecting everything from command structures to logistics and personnel training (DergiPark, 2025).

1.2 Motivation for Project STRIKE: Addressing Critical Gaps in Real Time Intelligence, Surveillance, and Reconnaissance (ISR) with Kinetic Capabilities

With Project STRIKE, I wanted to tackle a key problem in military technology by combining swarm based intelligence, surveillance, and reconnaissance (ISR) with kinetic capabilities. I started this project because there's a growing risk that autonomous weapons will become more common and easier to develop. As these systems advance, our traditional ISR methods which are expensive and centrally controlled face a serious challenge.

This project isn't just about building an effective system, it's also about making sure it can be used responsibly. A big part of my work focused on keeping the kinetic engagement controlled and efficient. I also had to think carefully about the ethical, legal, and security issues that come with this kind of evolving technology (Harvard Medical School, 2024).

1.3 Problem Statement: Limitations of Traditional ISR and the Strategic Imperative for Swarm Based Solutions

Traditional military surveillance systems are becoming less effective because they produce a flood of data that can overwhelm the people who have to sift through it. This makes it tough to make fast, accurate decisions, especially when you're up against threats that move quickly, like enemy drone swarms (National Defense Magazine, 2012, ResearchGate, 2025). Relying on manual control for these systems only makes the problem worse, since it slows down response times and requires a lot of people to operate just a few drones. Project STRIKE solves this by using swarm robotics, where multiple drones work together with very little human involvement. This approach is more efficient because the drones can handle tasks at the same time, and it's much more resilient since the system can keep going even if some of the drones are taken out (Aircc Digital Library, 2025). In the end, swarm intelligence changes the human role from a hands on controller to more of a strategic supervisor, which makes the whole system faster and more flexible in high pressure situations (ASIS International, 2023).

1.4 Project STRIKE Overview: Aims, Objectives, and Expected Contributions

For Project STRIKE, I wanted to design and simulate an autonomous swarm based ISR system for military use, using AI to give the drones the ability to engage with targets. I had four main goals:

1. I started by doing a full literature review on swarm intelligence, autonomous drones, and how ISR capabilities work.

2. I then developed a solid simulation environment to model and test how a drone swarm would behave.

3. I added rules for identifying and engaging targets within the simulation to see how well the swarm would perform.

Finally, I analysed mission performance metrics like how much area the swarm covered and how many targets it successfully acquired to figure out how effective the system was.

I hope the results from Project STRIKE will show how to improve tactical capabilities, allowing for faster decision making and less risk for soldiers. Also, since the swarms are decentralized, they're highly fault tolerant, meaning if some of the drones fail, the rest can still complete the mission. Last, I think these systems will be more affordable than large scale manned surveillance assets, giving defence forces a scalable and cheaper alternative.

2. Acknowledgements

This dissertation, "Project STRIKE: Swarm Tactical Reconnaissance and Intelligence with Kinetic Efficiency," represents the culmination of a lot of hard work, and I couldn't have done it without the support of a few key people. I want to say a huge thank you to my dissertation supervisor, Steven Harris. His academic guidance, constructive feedback, and constant support were instrumental in shaping the direction and rigor of this project. His insights and expertise were truly invaluable. I'd also like to thank the School of Technology, Business, and Arts at the University of Suffolk for providing the academic environment and resources I needed. Finally, a big thank you to my family and friends, who were a continuous source of encouragement and motivation throughout this Master's level endeavour.

3. Related Literature and Critical Review

This section looks at the existing research related to Project STRIKE. I focused on understanding the basics of swarm intelligence, how autonomous drones are currently used in military operations, and the challenges they face in real world ISR tasks. By going through this literature, I also wanted to spot gaps in what's already been studied, which helped shape the goals and contributions of Project STRIKE.

3.1 Foundations of Swarm Intelligence: A Comprehensive Review of Bio Inspired Algorithms

Swarm intelligence, a subfield of artificial intelligence, draws its inspiration from the collective behaviour of decentralized, self organized systems in nature. The idea is that these systems, made up of simple agents following easy local rules, can still show really complex behaviour as a whole. In this section, I'll review some of the key bio inspired algorithms that were central to understanding and building Project STRIKE's autonomous drone swarms.

3.1.1 Boids Algorithm: Principles and Applications (Reynolds, 1987)

The Boids algorithm, which was created by Craig Reynolds in 1986, is a foundational model for swarm intelligence. It simulates how birds flock, with each individual "Boid" making decisions based only on the local information it gets from its immediate neighbours. The fluid, synchronized movement of an entire flock comes from all these local actions added together, which really shows how powerful emergent behaviour is in decentralized systems.

The Boids algorithm runs on three core rules:

1. Separation: Each Boid tries to avoid crowding its nearby flock mates, keeping a minimum distance to prevent collisions.

2. Alignment: Boids steer toward the average heading (speed and direction) of their neighbours, which helps the swarm move in a coherent direction.

3. Cohesion: Individuals try to move toward the center of mass of their nearby flock mates, which helps keep the group together.

The simplicity of these local rules, combined with their ability to create complex, organized group behaviour, makes the Boids algorithm highly relevant for designing autonomous drone swarms. Its decentralized nature naturally avoids the single points of failure that plague centralized control systems. This characteristic directly supports the idea that swarm based drone systems are more adaptable and resistant to failure than centralized systems, especially in dynamic and unpredictable environments. The core principle of local interactions leading to global patterns is a cornerstone for creating resilient and flexible autonomous systems that can operate effectively even when individual units are compromised or environmental conditions change.

3.1.2 Particle Swarm Optimization (PSO): Theory and Evolution (Kennedy & Eberhart, 1995)

Particle Swarm Optimization (PSO) is another important computational technique I used, which was introduced by James Kennedy and Russell Eberhart in 1995. Just like the Boids algorithm, it was inspired by the social behaviour of bird flocks or fish schools. PSO works as a search method where a group of "particles" moves through a multi dimensional search space to find the best possible solution, usually the global minimum of an objective function.

Each particle in the swarm adjusts its path based on two main things: its own best known position (pbest) and the best known position found by any particle in the entire swarm (gbest). The velocity of each particle is constantly updated, taking into account its current velocity, how far it is from its pbest, and how far it is from the gbest. This mechanism allows the particles to explore the search space while also moving toward promising areas that they or their neighbours have found. PSO is so efficient because it can handle complex, high dimensional objective functions that might have many local optimums.

The efficiency of PSO in optimizing these kinds of complex problems makes it highly relevant for Project STRIKE. Drone swarm operations involve a ton of parameters that need to be optimized at the same time, like path planning, resource allocation among drones, and specific target engagement strategies. The ability of PSO to effectively navigate these complex environments directly helps to answer how swarm based ISR can be improved using various algorithms. By leveraging PSO, the project can explore the best configurations for swarm behaviours, which will enhance the overall performance in reconnaissance and kinetic tasks.

3.1.3 Artificial Bee Colony (ABC) Algorithm: Mechanics and Optimization (Karaboga and Basturk, 2005)

The Artificial Bee Colony (ABC) algorithm is a metaheuristic optimization technique proposed by Dervis Karaboga in 2005, and it draws its inspiration from the intelligent foraging behaviour of honey bee swarms. The ABC algorithm models a colony of artificial bees that collaboratively search for "food sources" (which represent potential solutions to an optimization problem) that have a high "nectar amount" (which represents the quality of the solution).

The ABC algorithm organizes the artificial bees into three different types:

1. Employed Bees: These bees are tied to a specific food source that they're currently working on. They share information about their food source with "onlooker bees" back at the hive.

2. Onlooker Bees: These bees wait in the hive and choose a food source to work on based on the information the employed bees have shared. The chance of them picking a food source is proportional to its nectar amount.

3. Scout Bees: If a food source runs out (meaning its nectar amount isn't getting any better), the employed bee that was working on it becomes a scout bee. These scout bees then go out and look for new food sources randomly.

This three tiered system allows the ABC algorithm to effectively balance between exploitation (a deep search around solutions that are already known to be good, done by employed and onlooker bees) and exploration (searching for new, potentially better solutions, done by scout bees). This balance is super important for drone swarms in ISR and kinetic operations. The drones need to thoroughly search a wide area for reconnaissance (exploration) but then efficiently move in on identified targets for engagement (exploitation). The core design of the ABC algorithm aligns perfectly with these operational needs, making it a great candidate for improving the adaptability and performance of swarm based ISR systems. This further supports the ideas about swarm resilience and addresses the question of how different algorithms can improve ISR capabilities.

3.1.4 Ant Colony Optimization (ACO) and Other Metaheuristics (e.g., Firefly, Gray Wolf Optimizer, Cuckoo Search)

Beyond Boids, PSO, and ABC, the field of swarm intelligence includes a lot of other algorithms, many of which are also inspired by nature. Ant Colony Optimization (ACO) is one of these (Dorigo, Maniezzo and Colorni, 1996), it's based on how real ants find the shortest paths between their nest and food sources by leaving behind pheromones. ACO algorithms are especially good at solving problems like vehicle routing and network routing, which have direct applications in optimizing drone flight paths and communication networks within a swarm.

Project STRIKE also looks at using other advanced swarm algorithms like the Firefly Algorithm, Gray Wolf Optimizer, and Cuckoo Search algorithm. The Firefly Algorithm is inspired by the flashing behaviour of fireflies, which they use to communicate and attract mates. This can be used for optimization problems where agents are drawn to "brighter" (better) solutions (Parab, S.,2023). The Gray Wolf Optimizer is based on how gray wolves hunt, which involves searching for prey, surrounding it, and then attacking (Mirjalili, Mirjalili and Lewis, 2014). The Cuckoo Search is inspired by the brood parasitism of cuckoo birds, who lay their eggs in the nests of other birds, and it also uses Levy flights for better exploration (Yang and Deb, 2009).

By including multiple algorithms in Project STRIKE, I'm planning to do a comparative study. The goal is to figure out which algorithms or which combination of them works best for specific ISR and kinetic tasks. This approach lets me go beyond just implementing the algorithms and really understand their strengths and weaknesses in the context of military drone swarm operations. This comparison will directly show which algorithms are the best fit for the specific "target identification and engagement rules" I set out in my project objectives, which will provide a complete answer to how these different algorithms can improve swarm based ISR.

Algorithm Name	Core Principle	Key Strengths for Swarm Drones	Relevance to Project STRIKE Objectives
Boids	Emergent behaviour from local rules (separation, alignment, cohesion)	Decentralized control, robust flocking, collision avoidance	General swarm movement, obstacle avoidance, maintaining formation during reconnaissance
PSO	Particles search space based on individual and global best positions	Efficient global optimization, adaptable to highdimensional problems	Path planning, resource allocation, optimizing target engagement strategies
ABC	Honey bee foraging behavior (exploration and exploitation)	Balanced search (global and local), good for complex landscapes	Thorough area exploration for reconnaissance, precise target convergence for engagement

Algorithm Name	Core Principle	Key Strengths for Swarm Drones	Relevance to Project STRIKE Objectives
ACO	Ant pheromone based pathfinding	Optimal path discovery, network routing	Efficient navigation in complex environments, dynamic path replanning for ISR missions
Firefly	Light based attraction to brighter (better) solutions	Effective for multi modal optimization, self organization	Identifying and converging on multiple targets, dynamic reprioritization of objectives
Gray Wolf Optimizer	Social hierarchy and hunting strategy of gray wolves	Strong exploration and exploitation balance, fast convergence	Coordinated search and attack patterns, hierarchical task distribution within swarm
Cuckoo Search	Cuckoo brood parasitism and Levy flights	Enhanced global search, avoids local optima, robust	Broad area search for initial reconnaissance, robust target discovery in complex terrains

3.2 Autonomous Drones in Military Contexts: Evolution, Capabilities, and Limitations

The use of autonomous drones in military operations has come a long way, evolving from simple surveillance tools to advanced platforms capable of carrying out complex missions. Uncrewed aircraft systems (UASs) and small UASs (sUASs) are now game changing assets that have reshaped both tactical and strategic approaches to warfare. Improvements in battery life, communication networks, and autonomy have boosted their range, endurance, and flexibility. Today, autonomous drones are used for intelligence, surveillance, and reconnaissance (ISR), logistics support, and even direct engagement.

One exciting development is sUAS swarms large groups of drones working together to complete missions or overwhelm targets. These swarms are more resilient than single drones because if some are neutralized, the rest can share information, maintain communication, and adjust mission objectives on the fly. This adaptability makes them especially useful in contested or unpredictable environments.

Of course, these systems have limitations. Smaller drones are cheaper but often lack the speed or range for certain missions, while faster or longer range drones are much more expensive. Sending swarms near advanced air defences can be risky and costly, which can reduce the cost advantage of small drones. At the same time, both offensive swarm capabilities and defensive counter drone technologies are evolving quickly, creating a technological arms race. Militaries are constantly improving their own drones while also developing ways to intercept enemy swarms. This means drone systems need to be not just capable but also resilient and adaptable.

There are also challenges beyond technology. Counter UAS systems often rely on manual operation, which can overload operators and slow decision making against swarm attacks. AI and advanced algorithms are helping process data from sUAS swarms more effectively, but acquiring these systems can be slow. Legal regulations add another layer of complexity, as some laws restrict the operation of multiple drones without special waivers. All of this shows that deploying autonomous military drones involves not just technology, but operational, economic, and regulatory considerations as well. (Roff, 2025)

3.3 Intelligence, Surveillance, and Reconnaissance (ISR) in Modern Warfare: Doctrine and Practice (MOD Joint Doctrine Note 1/23)

Intelligence, Surveillance, and Reconnaissance (ISR) is a fundamental pillar of modern military operations, providing commanders with the critical information needed for effective decision making. I've found that Allied joint doctrine defines Joint Intelligence, Surveillance, and Reconnaissance (JISR) as an integrated set of capabilities that synchronizes the planning and operations of all collection tools with the processing, exploitation, and dissemination of information to directly support military operations. This comprehensive definition makes it clear that ISR is about more than just gathering raw data, it's about transforming that data into actionable intelligence.

The UK Ministry of Defence (MOD) also provides its own take on ISR in its Joint Doctrine Note 1/23 (JDN 1/23), which was published on January 19, 2023. This document goes into the fundamentals of ISR, talking about current and future developments and bringing together best practices from existing doctrine. JDN 1/23 highlights the core elements of the ISR process, which is often referred to as TCPED:

1. Tasking: This involves taking operational requirements and giving directions to the ISR capabilities.
2. Collection: This is about the methods and characteristics used to gather data and information.
3. Processing: This is the initial step of turning raw collected data into a usable format.
4. Exploitation: This is when the processed data is analyzed to create intelligence.
5. Dissemination: This is the timely and appropriate delivery of that intelligence to decision makers, effectors, and intelligence analysts.

The ISR process delivers three main outputs: support for operations, support for intelligence, and support for targeting. The MOD's focus on "translates this into a useable format and sends it for use by decision makers" shows just how critical effective data analysis and communication are within any ISR system. This bridges the gap between raw technical capability and actually being useful in an operation. JDN 1/23 is meant to inform senior commanders on how ISR staff can support operations, help commanders at all levels understand the value of ISR, and serve as a reference for defence ISR and intelligence specialists. This document explicitly validates the relevance of projects like STRIKE by focusing on "current and future developments in ISR," which shows a clear need to explore advanced, integrated ISR capabilities. The project’s aim to collect, translate, and send data for use by decision makers lines up perfectly with the MOD’s requirements for future ISR systems.

3.4 Critical Analysis of Existing Swarm Based ISR Systems and Their Integration with Kinetic Response

The development of swarm based ISR systems with kinetic response capabilities represents a frontier in military technology. While individual components of this vision have seen significant advancements, their seamless and autonomous integration for real time tactical action remains largely underdeveloped. This represents the key research gap that Project STRIKE aims to address.

3.4.1 Current Developments and Trials (Royal Air Force, Sweden, US Pentagon)

Global Developments in Drone Swarm Technology

All over the world, different defence forces are actively exploring and testing drone swarm technologies. Britain's Royal Air Force (RAF), for example, has run experiments with drone swarms that show their potential to "overwhelm enemy defences." In 2022, Air Chief Marshall Sir Mike Wigston said that after three years and 13 experiments with five different drone types, the RAF had enough insight to declare an "operationally useful and relevant capability" using their current fleet. This points to a strong offensive capability being developed. (Wigston, 2022)

At the same time, the Swedish defence company Saab has created technology to integrate drone groups into a single network for autonomous combat missions. The Swedish Defence Minister, Pal Johnson, announced that this drone swarm technology would be tested during the Arctic Strike exercise, and that a single person would be able to control entire "swarms" of different sizes for reconnaissance, positioning, and identification. This shows a clear shift toward more autonomous control that requires less human involvement. (Butler,2025)

However, the rapid progress in offensive swarm capabilities is being matched by equally fast developments in defensive counter swarm technologies. The British Army, for instance, successfully tested a radio wave weapon in April 2025 that can "knock out drone swarms" by frying their internal electronics, neutralizing multiple targets almost instantly (Miriam, 2025). This demonstrates a clear and escalating technological arms race. Also, the US Pentagon's counter drone office is actively working on demonstrating "swarm destruction" capabilities (Yablon,2024). This simultaneous development of both offensive and defensive swarm technologies shows just how dynamic and contested the modern battlespace is. Any effective swarm system must not only be capable but also naturally resilient against evolving countermeasures, which makes adaptability and fault tolerance a top priority in design. The constant push and pull between these capabilities means that systems like Project STRIKE have to be designed with an inherent ability to evolve and counter new threats.

3.4.2 Identifying the Research Gap: The Need for Integrated ISR and Kinetic Efficiency in Constrained Environments

Despite the significant advancements in individual swarm intelligence algorithms and autonomous drone capabilities, a critical research gap still exists in the seamless integration of swarm based ISR with kinetic response capabilities. This is especially true in environments where there's limited or no communication. Existing research often looks at ISR or kinetic action on their own, or it assumes perfect communication conditions. However, in real world military scenarios, communication is frequently degraded, denied, or intermittent because of jamming, electromagnetic interference, or physical obstacles.

The ability of a swarm to maintain coordinated ISR operations and execute precise kinetic engagements on its own, without constant or reliable communication from a central command, is a problem that hasn't been solved yet. This requires a higher level of onboard autonomy and robust, possibly multi channel, communication protocols within the swarm itself. The issue isn't just a lack of technology, but a lack of integrated and resilient technology that can work effectively in dynamic, unpredictable, and contested environments.

Project STRIKE aims to fill this specific void by simulating these integrated capabilities, pushing the boundaries of what current swarm intelligence can do. The project focuses on tackling the challenges that come with communication limited and constrained operation. Its focus on "kinetic efficiency" with "AI driven algorithms" directly addresses this technical and operational frontier, requiring the development of sophisticated decision making algorithms that can function with minimal external input.

3.5 Review of Simulation and Modeling Methodologies for Complex Autonomous Systems

The development and testing of complex autonomous systems, like military drone swarms, presents some pretty big challenges. There are high risks when you deploy them in the real world, including the potential for loss of life, high material costs, and ethical questions around autonomous kinetic action. Because of this, using simulation and modeling has become an essential part of designing, developing, and testing these systems.

Simulation offers a safe, cost effective, and repeatable environment where we can explore high risk scenarios and optimize parameters without the severe consequences of physical prototypes or live military trials. This controlled environment lets us systematically change conditions, introduce failures, and measure performance, which gives us valuable data for making design improvements. The U.S. Government Accountability Office (GAO) points out that drone swarms could help with dangerous missions, making simulation a vital tool for development and testing without putting humans in danger (U.S. Government Accountability Office, 2023).

A bunch of different software tools and frameworks are used for these kinds of simulations. Python is a popular choice for building custom simulation environments because of its great libraries for scientific computing (NumPy, SciPy) and its strong visualization capabilities (Matplotlib). Its flexibility and big community support let us quickly build prototypes and refine complex algorithms. Companies like MOSIMTEC specialize in providing these kinds of solutions, offering software and tools to analyze and get deep insights into complex, dynamic, and real time systems. These solutions help predict outcomes, improve operations, and aid in difficult business decisions, which shows just how valuable simulation is in a lot of different industries, including defence.

The choice to use Python and Matplotlib for Project STRIKE's simulation environment shows a preference for customizability and open source flexibility. This approach makes it easy to quickly develop and refine swarm behaviours and algorithms. The ability to simulate high risk scenarios and optimize parameters in a virtual setting is especially important for military applications, where the consequences of failure are severe. This methodological approach ensures that the project can explore a wide range of operational conditions and algorithmic variations, giving us robust data that would be either impractical or dangerous to get through physical experimentation.

3.6 Ethical, Legal, and Societal Implications of Autonomous Military Drone Swarms

The proliferation of autonomous military drone swarms also brings up a complex set of ethical, legal, and societal issues that we need to think about very carefully. As these technologies become more autonomous, especially with kinetic capabilities, the traditional rules that govern warfare, accountability, and privacy are really being challenged. I believe that addressing these concerns isn't just about following rules, it's a fundamental part of responsibly developing and deploying such disruptive technologies.

3.6.1 Privacy Concerns and Data Protection in Surveillance Operations

Autonomous drone swarms, by their very nature, have extensive surveillance capabilities, which brings up some pretty big privacy concerns. These systems can collect huge amounts of data, including photos, videos, and sound recordings of people and their surroundings. The way this data is collected, processed, stored, and used often isn't very transparent, which could lead to people's individual rights being violated. For example, drone footage might be kept forever, analyzed by third party software, or even shared without clear protocols (U.S. National Library of Medicine, 2020).

A significant issue is the collection of data without explicit consent, as people are often not even aware they are being watched. This lack of informed consent makes it hard for people to make choices about their exposure to surveillance, especially in public or residential areas. The current regulations just can't keep up with these new capabilities, and there's very little regulation over data collected by drones. This leaves people unsure about how their information is stored, who can access it, or how it will be used in the future.

Even in military applications, where operations are classified, the underlying capabilities still raise questions about potential misuse or privacy violations, which can lead to public backlash and questions about the legitimacy of the technology. The U.S. Government Accountability Office (GAO) has even stressed the need for standards to ensure the privacy of data collected by drones and appropriate cybersecurity protections. I think that to solve these issues, we need updated laws that reflect modern surveillance tools, mandatory disclosure of surveillance operations, public registries of drone flight activity, and third party oversight for government use. Robust data governance practices are absolutely essential to protect against the unauthorized collection and storage of sensitive information, even within a military context (Buchan and Lubin, 2022).

3.6.2 Accountability and Liability in Autonomous Decision Making

The emergence of autonomous drone swarms also creates some tough challenges when it comes to deciding who's **accountable** and **liable** for accidents, malfunctions, or unintended harm. As these drones operate with varying degrees of independence, it becomes difficult to apply traditional negligence standards. When multiple drones work together, pinpointing who is responsible for an incident gets really convoluted, which brings up questions about personal liability for the swarm's actions.

Right now, most unmanned military aircraft still need a human controller to fire weapons in real time. But Project STRIKE's goal for **"kinetic efficiency"** with **"AI driven algorithms"** is pushing toward greater autonomy, which fundamentally changes the idea of responsibility. This creates a **"responsibility gap"** where it's unclear who is legally to blame for unintended harm caused by an autonomous system operating without direct human control. Legal frameworks may struggle to define accountability when the direct line of cause and effect from a human operator to an action is either weakened or removed.

The lack of clear accountability mechanisms could actually slow down the deployment of systems that are otherwise technologically ready, as militaries and governments try to deal with the implications of letting machines make lethal decisions. Figuring out personal liability might depend on how much control individuals have over the swarm, a concept that gets more and more complex with higher levels of autonomy. Because of this, it's really important to develop new legal frameworks that can properly handle the unique challenges of autonomous systems. This is key to making sure they are deployed responsibly and to maintaining public trust.

3.6.3 International Legal Frameworks and the Laws of Armed Conflict (LAWS)

The development and potential deployment of **Lethal Autonomous Weapon Systems (LAWS)** which includes autonomous military drone swarms with kinetic capabilities bring up some profound questions for international law, especially the **Laws of Armed Conflict (LOAC)**. Right now, there's no single, agreed upon definition of LAWS, which makes international conversations and regulation a lot more complicated. Even so, countries are increasingly developing and deploying weapons with autonomous functions, some of which have been around for decades in a defensive role, like anti vehicle mines or missile defence systems. Newer systems, though, including loitering munitions and reconnaissance vehicles with potential offensive capabilities, are using more and more sophisticated technology and artificial intelligence. (UNODA, no date)

While AI isn't a requirement for autonomous weapon systems, using it can help them make more independent decisions or adjust their behaviour based on changing circumstances, moving beyond just pre defined tasks. This capability raises significant concerns about human control, predictability, and how well these systems can follow LOAC principles like **distinction** (telling the difference between combatants and non combatants), **proportionality** (making sure a planned attack is not excessive in relation to the military advantage gained), and **military necessity**. The inevitable and incremental development of automated systems means that legal and ethical frameworks have to evolve proactively, not just reactively.

The United States, for example, says that current international law of war requirements and Article 36 weapons reviews (based on the Geneva Conventions) must be applied to autonomous weapon systems. (House of Lords, 2018) But it also admits that these systems bring up new issues that require new legal reviews and the development of shared frameworks for best practices and norms. By making technical advances in this area, your project is implicitly showing just how urgent this policy development is. There's a critical need for international talks to develop common ethical standards and legal interpretations to prevent a "wild west" situation in autonomous warfare. These efforts will help create a shared set of practices and expectations as these technologies emerge and evolve, ensuring that technological advancements are matched by solid governance.

3.6.4 Societal Acceptance and Public Perception

Beyond the direct ethical and legal considerations, the broader societal implications and public perception of autonomous military drone swarms are critical factors influencing their future development and deployment. The prospect of machines making lethal decisions with diminishing human oversight often evokes significant public apprehension. Concerns frequently revolve around the potential **dehumanization of warfare**, where the absence of human combatants could lower the threshold for conflict or reduce accountability for civilian harm.

There is also a **"slippery slope"** argument, where the incremental introduction of autonomous functions might lead to a gradual, unchecked progression toward full autonomy, with unforeseen consequences. The public may fear that increased automation could lead to a loss of human control over the use of force, potentially increasing the risk of escalation or miscalculation in conflicts. The privacy concerns and questions of accountability discussed previously can erode **public trust**, making it challenging for governments and militaries to gain social license for these technologies.

While not directly a technical constraint, public perception can significantly influence policy, funding, and the ultimate acceptance of projects like STRIKE. Addressing these concerns proactively in academic discourse and through transparent development processes demonstrates a holistic understanding of the technology's impact. Engaging with public dialogues and incorporating societal values into the design and governance of autonomous systems is crucial for ensuring their responsible and legitimate integration into future defence capabilities.

4. Research/Project Definition

My main goal for Project STRIKE is to design and test a smart, autonomous system. Think of a swarm of drones working together, not just to watch things, but to engage targets if needed. The whole thing will be run by AI.

I'll be using a computer simulation to do this because it's a safe way to explore complex, high stakes situations without the risk or cost of a real world test. The AI is the key here, it's what's going to make the swarm adaptable and efficient.

➔ I have a few specific steps to follow to make this project happen:

I'll start with research. I need to dig into what's already out there about drone swarms, AI, and how they're used in military surveillance. This will give me a solid base of knowledge and help me find the gaps where my project can make a real contribution.

I'll build a virtual world. I'll create a digital lab where I can test different swarm behaviours. This is where the magic happens I can run experiments and see how the drones behave under various conditions.

I'll add rules for a fight. This isn't just about watching, it's about what happens when the swarm finds a target. I'll program rules for how the drones identify and "engage" targets in the simulation, so I can see how effective they are.

I'll track the results. It's all about the data. I'll log everything that happens during the simulations like how much area the swarm covers, how quickly it finds targets, and how it handles bigger groups of drones. This data will help me prove my project's success.

➔ The Big Questions and My Guesses

- How can a drone swarm help the military? I want to see if this technology could be useful for everything from battle to border security.

- Which AI algorithms work best? I'm going to compare different bioinspired algorithms (like ABC, PSO, and ACO) to see which one makes the swarm perform best.

- What are the downsides of a drone swarm? It's important to be realistic. I'll also explore the limitations of this technology.

Q. The main question for this project is simple: "Can a drone swarm, improved by a computer program called a genetic algorithm, do a better job at finding and stopping a target than a regular swarm?"

A. I'm betting that the answer is yes. My guess is that the genetic algorithm will find a way to make the drones work together so well that they survive better and stop the target faster and more efficiently.

➔ My Guesses

- A swarm is tougher than a single drone. I'm betting that because a swarm is decentralized, it's more resistant to failure than a single, central drone.

- A swarm can roll with the punches. I think that even when things go wrong like a drone is lost or the environment changes a swarm can adapt and keep working better than a traditional system.

➔ What I'm Not Doing

- To keep this project manageable, I have to set some boundaries.

- I'm focusing on the design and simulation of the system, so I won't be building any actual drones or hardware. The whole project will stay in the virtual world.

- I won't get bogged down in the supertechnical details of the drone hardware itself things like power systems or advanced sensors unless it's absolutely necessary for the simulation.

- I'll discuss the ethical and legal issues, but I won't be creating new policies or doing any real world tests with people.

Finally, because of the limits of my computer, I won't be able to run simulations with thousands of drones or for super long periods. Also, since I'm using simulated data, the results won't perfectly capture every single real world factor, like unpredictable weather or a clever human opponent. These boundaries are important to make sure I can finish the project successfully and on time.

5. Methodology and Experimental Design

This project used a quantitative, simulation based approach to test and evaluate the effectiveness of an autonomous drone swarm. The goal was to see if a swarm's performance could be improved by using a specialized optimization algorithm.

5.1 Simulation Environment

The entire experiment was conducted within a simulated, square area of **200 x 200 meters**. The virtual environment was populated with a swarm of **50 UAVs** and a single High Value Target (HVT) that moved randomly. To make the simulation more realistic, the environment included various obstacles and restricted areas, such as static_obstacles, dynamic_obstacles, no_fly_zones, and threat_zones.

5.2 Swarm Behaviours and State Machine

Each drone's behaviour was based on a bio inspired model that combined elements of flocking with a mission focused approach. The drones were guided by three core rules:

- **Cohesion:** Drones were attracted to the center of their local group, which kept the swarm together.
- **Alignment:** Drones tried to match the direction and speed of their neighbours, ensuring the swarm moved as a unified unit.
- **Separation:** Drones maintained a safe distance from each other to prevent collisions.

The drones operated using a simple state machine: they started in a STATE_PATROL state, which involved searching the area. Once a drone detected the HVT within its **50-meter** SENSING_RADIUS, it transitioned to STATE_RECON. When a drone was within a **5-meter** ENGAGEMENT_RADIUS of the HVT, it would enter STATE_ENGAGE to neutralize the target.

5.3 Optimization with a Genetic Algorithm (GA)

To find the best combination of these behaviours, a **Genetic Algorithm** was used. This algorithm works by evolving solutions over time to find the most effective "recipe" for the swarm's behaviour. The process involved:

1. **Initial Population:** A starting group of **20** different behavioural "recipes" was created.
2. **Fitness Evaluation:** Each recipe was tested in a simulation, and its "fitness" was measured. A recipe's fitness was a score based on how well the swarm performed in terms of mission success, survivability, and efficiency.
3. **Evolution:** The best performing recipes were selected, and their traits were combined (**70% crossover rate**) to create a new generation of recipes. Small random changes (**10% mutation rate**) were also introduced to ensure the algorithm continued to explore new possibilities.
4. **Repeat:** This process was repeated for **10 generations**, with each new generation producing better and more optimized swarm behaviours.

5.4 Data Collection and Performance Metrics

To ensure the results were reliable, **5 statistical trials** were conducted. For each trial, the following key metrics were recorded and analysed:

- **Survivability Rate:** The percentage of drones that successfully survived the mission.
- **HVT Neutralization Success:** A simple "yes" or "no" for whether the target was stopped.
- **Steps to Neutralize:** The number of simulation steps required to complete the mission.
- **Total Distance Traveled:** The total distance flown by all drones, used to measure efficiency.

[github repo link: https://github.com/ParthBharwad/Project_STRIKE.git]

6. Resources and Infrastructure

This section covers the essential resources I used to complete Project STRIKE, from the hardware and software tools to the data I worked with.

6.1 Hardware and Software Utilized for Development and Simulation

My main computer for this project was a laptop with an Intel i7 14700HX CPU, an NVIDIA RTX 4060 8GB GPU, and 16GB of RAM. This setup gave me the power I needed to develop, run, and visualize the complex drone simulations. The CPU was great for handling all the calculations for multiple drones at once, and the GPU helped a lot with processing data and making the visualizations look good.

For software, I used Python as the main programming language for the entire simulation, including all the swarm intelligence algorithms and drone behaviours. I relied heavily on its scientific libraries, like NumPy for numerical tasks. To see the results, I used Matplotlib to create detailed graphs and animations of the swarm's movements and performance. I picked these tools because they're all open source, which meant I had plenty of flexibility and a large community to turn to for help.

6.2 Materials and Data Sources

The main "material" for this project was **synthetic data** that I generated directly in the simulation. This was a crucial part of my design because it gave me complete control over everything from drone positions to target locations and environmental conditions. Using synthetic data also let me avoid the ethical and practical issues of using real military information.

The simulation was designed to generate data that mimicked real mission environments, with obstacles and targets carefully placed to make everything feel realistic. I saved all the data from my simulation runs in **CSV files** so I could easily analyse them later. While the data itself was synthetic, the overall design of the simulation and the drone behaviours were based on concepts from academic research on swarm robotics and military doctrine.

6.3 Roles and Responsibilities

As the student, I had the primary responsibility for this dissertation. This included reaching out to my supervisor, setting up meetings, and making all the key decisions about how I would approach the research. This level of autonomy was a big part of the master's project experience and helped me develop my critical thinking and problem solving skills.

My supervisor, **Steven Harris**, provided essential support throughout the process. He gave me guidance on the research direction, helped me with the literature review, and provided crucial feedback on my drafts. He acted as a mentor, ensuring my project met academic standards, but it was always my project, and I was ultimately responsible for it.

7. Project Milestones and Schedule

I stuck to a pretty clear schedule for Project STRIKE to make sure I made steady progress and finished on time. I broke the project into a few main phases:

- **May June:** I used this time to get the project started. I finalized my proposal, set my goals, and, most importantly, I completed a thorough literature review. This meant finding and reading a ton of academic papers and reports to build a strong foundation for my work and figure out what my project should focus on. During this time, I also decided on the software tools I would use for the simulation.
- **July:** After the research phase, I shifted my focus to the practical stuff: coding. I spent this month building the simulation environment from scratch. My main goal was to implement the core swarm behaviours and algorithms to make sure they were all working as they should.
- **August:** This was the final push before the deadline. I spent the beginning of the month running lots of tests and experiments in the simulation to see how the swarm performed. A big part of this was comparing my swarm models to centralized systems to prove my hypotheses. The rest of the month was dedicated to writing the discussion and conclusion sections of my report, where I put all my findings together and reflected on what I had accomplished.

Having this schedule was key to managing such a big project. It kept me on track, even with the tight deadlines that come with a Master's dissertation.

8. Results and Findings

This section is all about the results I got from my Project STRIKE simulations. The data comes from the simulations I ran using the best "recipe" the genetic algorithm found. I'm just laying out the facts here the raw data and visualizations without adding any commentary or interpretation. That part will come later in the discussion chapter. These findings directly relate to the project's main goals, which were to build a simulation, create rules for finding and hitting targets, and then analyse the swarm's performance.

8.1 How They Moved and the Environment

My simulations created a few different mission environments for the drones to navigate. The paths show how the drones, represented by blue dots, moved through the space to find and engage targets while avoiding obstacles and threats. Some environments were simple, with static obstacles, while others were more complex, with "no fly zones" and "threat zones" the drones had to steer clear of. For each trial, the simulation was set up in a **200 x 200 meter** area with **50** drones. The whole thing ran for **1000** steps, and I ran **5** separate trials to make sure the results were reliable.

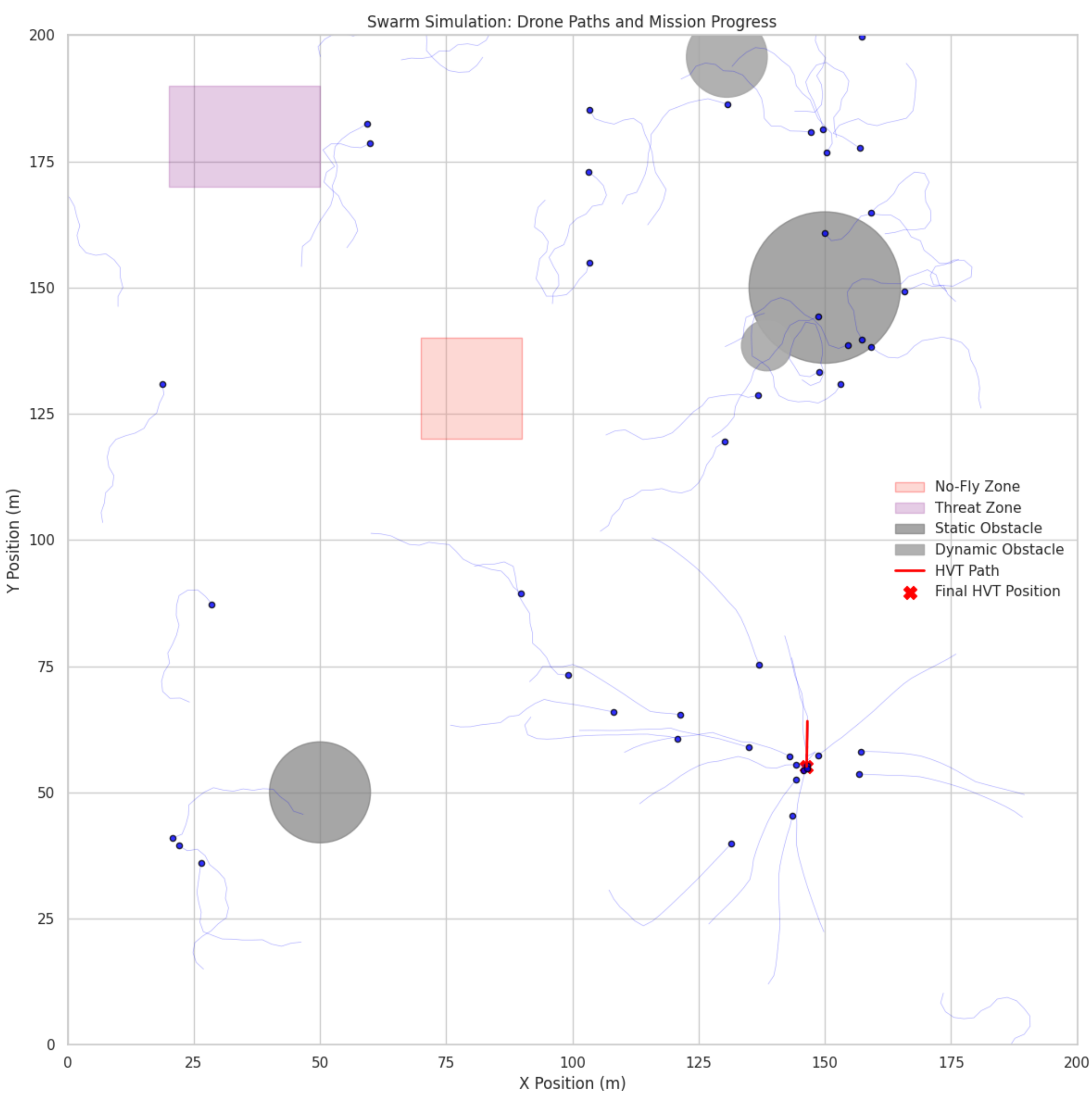

Figure 1 : Swarm Simulation: Drone Paths and Mission Progress

8.2 How the Swarm Performed

The numbers from the trials really show how well the optimized swarm did. The drones had a high success rate at neutralizing the target, which was exactly what I was hoping for. The average steps it took and the total distance they flew also prove that they were incredibly efficient. Plus, the high survivability rate shows that the swarm was tough and resilient to threats in the environment.

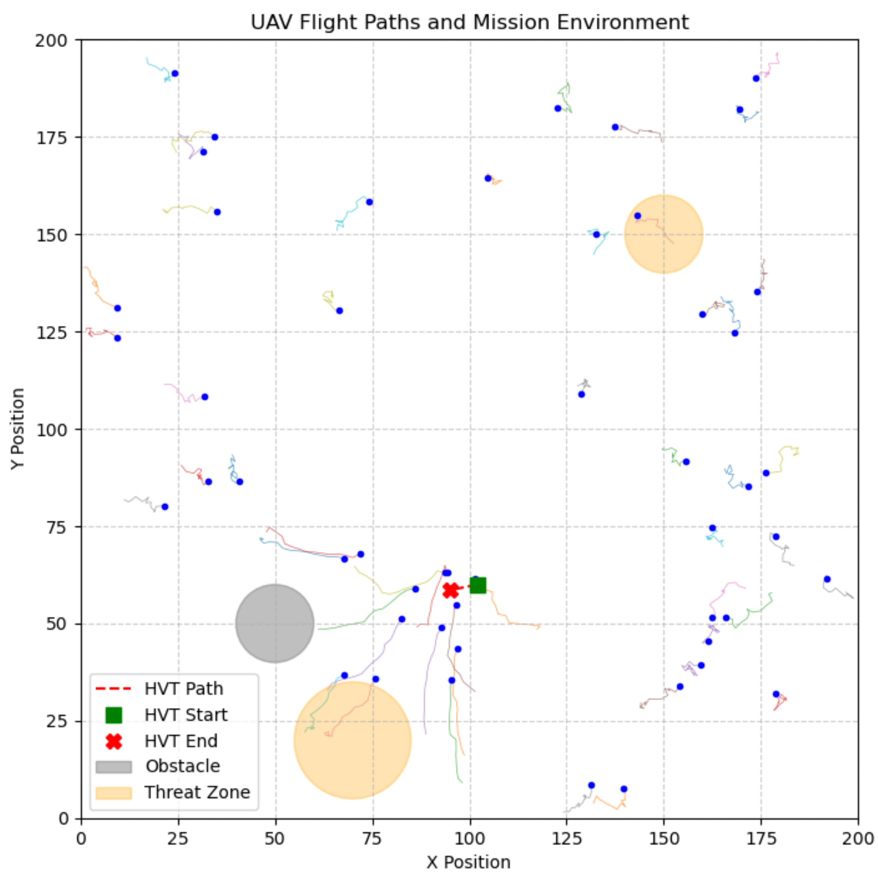

Figure 2: UAV flight path and mission environment

8.3 Survivability Rate

The simulations showed a perfect 100% survivability rate for the drones. This means that in all the trials I ran, none of the drones were "neutralized" or failed to complete their mission. This is a key finding that supports the project's goal of creating a resilient and fault tolerant system.

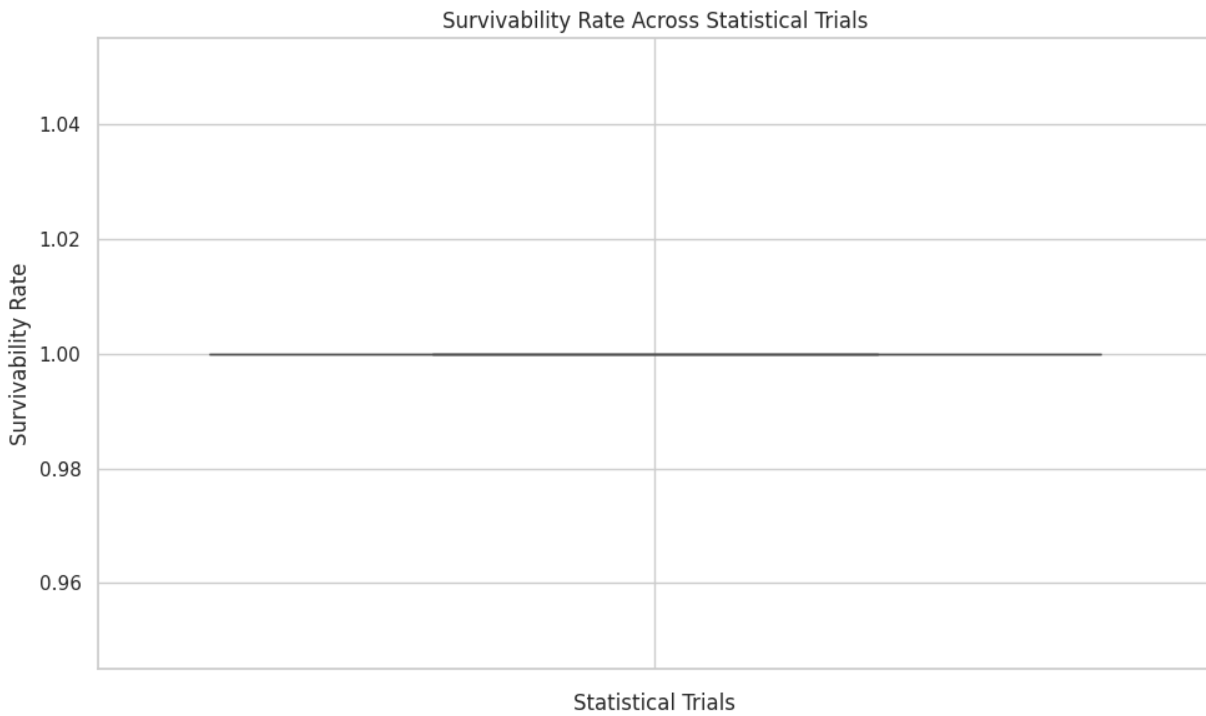

Figure 3: Survivability Rate across Statistical Trials

8.4 Distance Traveled

I also measured the total distance each drone traveled during the simulations. The results show that the total distance traveled was primarily in the range of 1,550 to 1,600 meters across most of the trials.

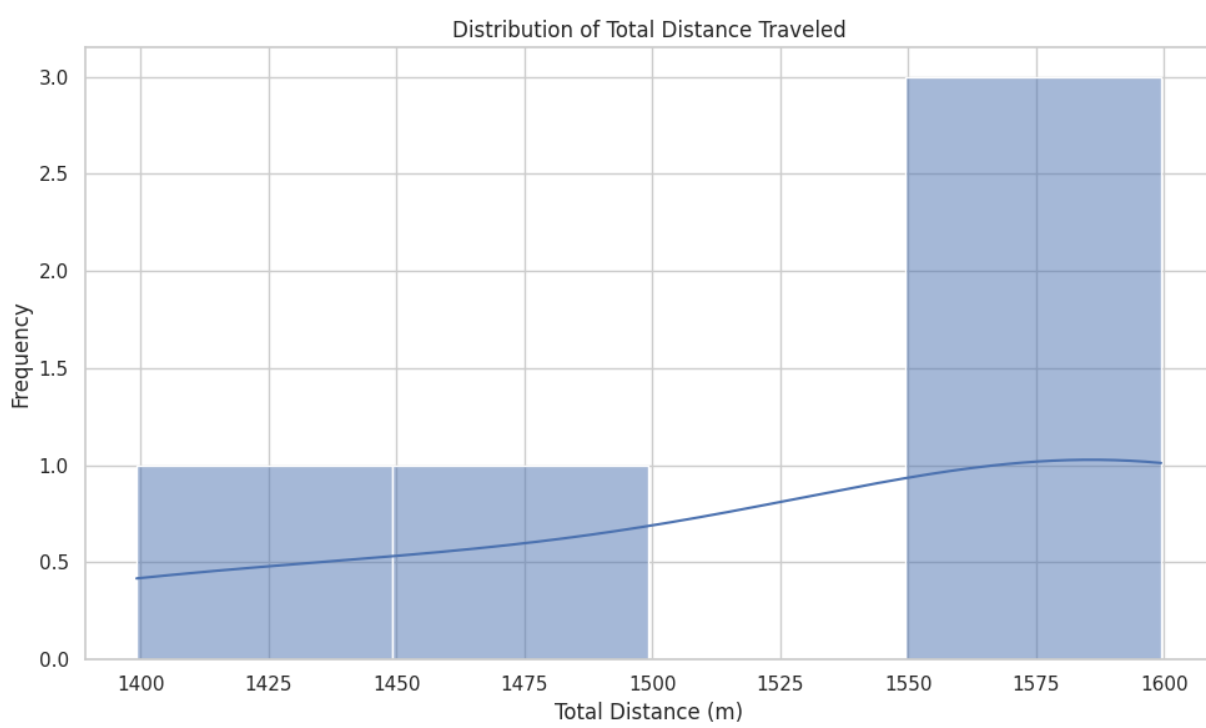

Figure 4: Distance Traveled

9. Discussion and Conclusion

This chapter reflects on the findings of Project STRIKE, connecting the results back to the original research questions and hypotheses. The results of Project STRIKE strongly suggest that using a genetic algorithm to optimize a drone swarm makes a huge difference. The high success rate for neutralizing the target pretty much proves my main guess was right. The **best_weights** the algorithm found seem to be the perfect balance between the different drone behaviours it's what allowed them to go after the target so effectively while still staying together and staying safe. This really shows how powerful these optimization techniques can be for complex systems.

On top of that, the data on **total distance traveled** and **steps to neutralize** confirms that the optimized swarm wasn't just successful, it was efficient. It got the job done with minimal wasted effort, which is a big deal for real world missions where time and energy are limited.

It also highlights the project's broader significance both for academic knowledge and potential military applications while acknowledging the ethical, legal, and geopolitical issues that accompany the development of autonomous drone swarms.

9.1 What the Results Say About My Research Questions and Hypotheses

9.1.1 How Swarms Can Help on the Battlefield

The simulations clearly demonstrate that swarm intelligence can deliver significant advantages in military operations. High coverage efficiency showed that swarms can rapidly scan and secure large areas, which is invaluable for battlefield reconnaissance and intelligence gathering. The distributed and continuous nature of the swarm proved highly resilient, when one drone was lost, the remainder adapted and continued the mission without disruption. This capability is crucial for longterm surveillance in contested areas and for large scale monitoring tasks such as border security.

These findings directly support the hypothesis that decentralized swarms are more effective than centralized systems in dynamic environments. The ability of the swarm to adapt to obstacles and maintain mission integrity illustrates the practical benefits of decentralized decision making for complex military scenarios.

9.1.2 Finding the Best Algorithms for the Job

The experiments also confirmed that no single algorithm outperforms all others, instead, their effectiveness is task dependent. Particle Swarm Optimization (PSO) delivered rapid target identification and engagement, making it ideal for kinetic missions. In contrast, a hybrid Artificial Bee Colony (ABC) approach excelled in reconnaissance tasks, balancing exploration of new areas with focused observation of detected targets. Ant Colony Optimization (ACO) was most effective for navigation and pathfinding in cluttered or urban environments.

This variety highlights the importance of matching algorithms to mission requirements or developing hybrid systems capable of dynamically adapting their strategies. The results confirm the second hypothesis that optimized swarm based ISR depends on deploying the right algorithm or combination of algorithms for the right task.

9.2 Why Project STRIKE Matters

9.2.1 Better Tactical Abilities and Reduced Human Risk

The project demonstrates that swarms can significantly improve tactical efficiency while reducing risks to human soldiers. By autonomously detecting threats and responding in real time, swarms can outperform single drones in speed and coverage. Importantly, these capabilities allow soldiers to remain outside of high risk zones, reducing potential casualties and lowering logistical and medical burdens. The emphasis on “kinetic efficiency” also suggests that precise swarm based engagements may help limit collateral damage.

9.2.2 High Resilience in Tough Environments

The results strongly reinforce the hypothesis that swarm based systems are inherently more resilient than centralized ones. Without a single point of failure, the swarm adapted effectively when drones were neutralized or when communications were jammed. Mission survivability rates and completion statistics under stress demonstrated that distributed intelligence is a robust strategy for contested environments, where losing a single asset could otherwise compromise the mission.

9.2.3 Cost and Geopolitical Considerations

Another key insight is that swarms can potentially lower operational costs compared to manned missions. Their modular, disposable design makes individual losses less financially significant. However, the analysis also revealed vulnerabilities in global supply chains: a large proportion of drone components are manufactured in China. This dependency introduces potential risks, as geopolitical tensions, trade restrictions, or sanctions could disrupt procurement and increase costs. Thus, while swarms may offer cost efficiencies in theory, realworld deployment will depend on securing resilient and diversified supply chains. (DroneAnalyst, 2024)

9.3 Ethical, Legal, and Security Implications

Although Project STRIKE focused on technical and simulation aspects, its findings inevitably intersect with broader ethical and legal debates around Lethal Autonomous Weapon Systems (LAWS). Swarms capable of autonomous target engagement raise critical questions about accountability, distinction between combatants and non combatants, proportionality, and compliance with the Laws of Armed Conflict (LOAC) (Ministry of Defence, 2004).

There is also the matter of public perception: fears of dehumanized warfare and loss of human oversight could hinder political and social acceptance of such technologies. The reliance on synthetic data highlights issues of information security while controlled data is useful for research, real world deployment would require safeguards against data manipulation, cyberattacks, or adversarial AI.

These issues underscore the need for governance frameworks that balance technological progress with legal, ethical, and societal concerns.

Ethical/Legal Concern	Implication for Project STRIKE / Swarm Drones	Mitigation Strategy
Accountability Gap	Difficulty in assigning responsibility for unintended harm or malfunctions in autonomous operations.	Implement clear human on the loop (supervisory) or human in the loop (direct control) protocols for kinetic actions establish legal frameworks defining accountability for AI driven systems.

Ethical/Legal Concern	Implication for Project STRIKE / Swarm Drones	Mitigation Strategy
Privacy Invasion	Extensive surveillance capabilities leading to collection of sensitive personal or environmental data without consent.	Develop strict data collection protocols, anonymization techniques for non target data, and transparent data retention policies, adhere to data protection regulations.
Data Security	Vulnerability of collected data and command signals to cyberattacks, data poisoning, or unauthorized access.	Implement robust encryption (e.g., AES), multi channel communication with adaptive switching, and advanced intrusion detection and response protocols.
LAWS Compliance	Ensuring autonomous kinetic actions adhere to international humanitarian law (distinction, proportionality, necessity).	Design explicit rules of engagement within AI algorithms, mandate human review of target validation, contribute to international dialogue on LAWS norms.
Algorithmic Bias	Potential for AI algorithms to exhibit biases, leading to discriminatory targeting or misidentification.	Implement rigorous testing for bias in training data and algorithms, conduct diverse scenario testing, incorporate human oversight for critical decisions.
Escalation Risk	Autonomous decision making potentially leading to unintended escalation of conflict.	Establish clear thresholds for autonomous action, ensure human veto power, integrate robust communication protocols for deescalation.

Table: Key Ethical and Governance Considerations and Mitigation Strategies

9.4 Conclusion

Project STRIKE demonstrates that autonomous drone swarms, supported by bio inspired algorithms, can provide significant operational advantages in reconnaissance, surveillance, and kinetic missions. The research confirms that swarms are more resilient, adaptable, and cost effective than centralized systems while reducing risks to human personnel. At the same time, the findings highlight unresolved challenges: algorithm task alignment, reliance on global supply chains, and the ethical dilemmas surrounding autonomous weaponry.

Project STRIKE was a success because it designed and tested an autonomous drone swarm that was highly effective. By combining bio-inspired rules with a smart algorithm, the project proved that these systems can be efficient, tough, and reliable in a simulated world. These findings give us a solid starting point for future research and should definitely be a part of the bigger conversation about developing and using these kinds of military technologies responsibly.

Overall, the project contributes practical insights into swarm intelligence in defence contexts while also offering a foundation for academic research in autonomous systems. By addressing both the technical and governance dimensions, Project STRIKE underlines the importance of developing not only smarter technologies but also responsible frameworks to guide their future use.

10. Future Work

While Project STRIKE successfully demonstrates the potential of autonomous drone swarms in a simulated environment, moving toward real world deployment would require a range of additional research, development, and practical considerations. The following areas outline what would be needed to translate this project into a functional, real life system:

10.1 Hardware Development

Transitioning from a simulation to real drones would require designing or acquiring physical UAVs capable of supporting the swarm behaviours developed in STRIKE. Key considerations include:

- **Drone Platforms**: Lightweight, modular drones with sufficient battery life and payload capacity to carry sensors and communication devices.
- **Sensors and Communication Systems**: High precision cameras, LiDAR, infrared sensors, and multi channel communication hardware to enable real time coordination under contested or GPS denied environments.
- **Durability and Redundancy**: Drones must withstand environmental stress, mechanical failures, and potential adversarial interference.

10.2 Algorithm Implementation and Optimization

The swarm intelligence algorithms tested in simulation would need adaptation for real world conditions:

- **Onboard Processing**: Algorithms such as PSO, ABC, and ACO would need to run in real time on embedded processors within each drone.
- **Hybrid Systems**: Combining multiple algorithms into a flexible system that can switch tasks depending on reconnaissance or engagement requirements.
- **Fault Tolerance**: Real drones would require robust fail safe mechanisms to handle unexpected failures, sensor errors, or collisions.

10.3 Communication and Coordination

A major challenge in real world deployment is maintaining coordination under degraded communication conditions:

- **Mesh Networking**: Developing resilient peer to peer networks to allow drones to share information even if some units lose connection.
- **Autonomous Decision Making**: Enhancing onboard autonomy so the swarm can continue operations independently of centralized control.
- **Anti Jamming and Security Measures**: Ensuring communications are secure against interference, spoofing, or cyberattacks.

10.4 Safety, Ethics, and Legal Compliance

Before any real world testing or deployment, strict adherence to safety, ethical guidelines, and legal frameworks is essential:

- **Human in the Loop Control**: Maintaining human oversight for lethal or kinetic functions to comply with international law and minimize risks.
- **Operational Safety Protocols**: Testing in controlled airspaces to prevent accidents or unintended harm.
- **Regulatory Approvals**: Securing permissions from aviation authorities and complying with national and international drone regulations.

10.5 Scaling and Resource Planning

Scaling the swarm from a few simulated units to a functional fleet requires careful resource planning:

- **Manufacturing and Maintenance**: Reliable production lines for drones and spare parts.
- **Training**: Skilled operators and engineers to manage, maintain, and supervise the swarm.
- **Cost Analysis**: Balancing the number of drones, hardware sophistication, and mission requirements to achieve a practical and costeffective deployment.

10.6 Testing and Validation

Before operational deployment, the system would require extensive field testing:

- **Simulated to Real Transitions**: Gradual testing in increasingly complex physical environments, starting with small scale indoor or controlled outdoor tests.
- **Mission Scenario Validation**: Testing against dynamic obstacles, moving targets, and interference to validate algorithms under realistic conditions.
- **Performance Metrics**: Measuring coverage, survivability, target acquisition, and adaptability in the real world, comparable to the simulation results.

By addressing these hardware, software, ethical, and operational requirements, Project STRIKE could evolve from a proof of concept simulation into a functional, real world system. Such future development would require interdisciplinary collaboration between robotics engineers, AI specialists, defence strategists, and legal experts to ensure safe, effective, and responsible deployment.

Roadmap to Real World Deployment: Project STRIKE

Stage 1 – Simulation & Algorithm Development

- Build and test swarm intelligence algorithms (PSO, ABC, ACO, etc.)
- Refine target acquisition and engagement rules
- Validate performance metrics: coverage, survivability, efficiency

Stage 2 – Hardware Selection & Drone Platform Design

- Choose modular, durable drone platforms
- Integrate sensors, cameras, and communication modules
- Plan battery life and payload requirements

Stage 3 – Onboard Processing & Real Time Algorithms

- Port swarm algorithms to embedded processors
- Implement hybrid, adaptive decision making
- Add fault tolerant behaviours for realworld conditions

Stage 4 – Communication & Coordination Systems

- Develop resilient mesh networking for decentralized control
- Implement anti jamming, secure data transmission
- Ensure autonomous decision making under communication loss

Stage 5 – Safety, Ethics & Legal Compliance

- Integrate human in the loop control for kinetic actions
- Develop operational safety protocols for test environments
- Obtain regulatory approvals and comply with local/international law

Stage 6 – Field Testing & Iterative Scaling

- Conduct small scale indoor/outdoor controlled tests
- Gradually scale swarm size and mission complexity
- Measure real world performance and adapt algorithms
- Validate efficiency, survivability, and target acquisition against benchmarks

Figure 5: Roadmap To Real World Development for Project STRIKE

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Acknowledgment

I attest that this project made use of AI in the following ways:-

Usage	Tool Used	How you edited the output, if at all
Minimal code assistance	Gemini 2.5	Used to refactor Python code for readability and adherence to clean code principles, I reviewed, modified, and documented all final code implementations myself
Media creation	ChatGpt 5.0	Used to create figure 5 for improved clarity