

# Design and Implementation of a Heterogeneous Edge-AI Drone Swarm for Autonomous Logistics: Cloud Connected Hybrid Architecture

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**Abstract**—A heterogeneous unmanned aerial system (UAS) is developed for autonomous logistics and surveillance, integrating edge artificial intelligence with secure global connectivity. The system combines two complementary aerial platforms, a high agility ‘Scout’ quadcopter for rapid reconnaissance and real time visual tracking, and a heavy lift ‘Mule’ coaxial octocopter for reliable payload delivery. A major contribution of the proposed architecture lies in the unified onboard edge computing framework based on the NVIDIA Jetson Orin Nano Super, which enables real time computer vision, autonomous decision making, and closed loop control directly on each drone, removing dependence on centralized ground processing. Another distinctive contribution is the Beyond Line of Sight (BLoS) communication framework that leverages 4G LTE telemetry integrated with a Cloudflare Zero Trust Tunnel. This approach overcomes conventional radio range and network address translation limitations, providing secure, low latency command and control and high definition video streaming without a dedicated ground station. By combining heterogeneous airframes, decentralized edge AI intelligence, and cloud assisted global connectivity, the proposed system offers a scalable and cost effective solution for next generation autonomous aerial logistics and surveillance operations.

**Keywords**— *Heterogeneous Drone Swarm, Edge AI Computing, Autonomous Logistics, Beyond Visual Line of Sight (BVLOS), Cloud-Connected Robotics, Real-time Human Detection.*

## I. INTRODUCTION

The study [1] reviews how the integration of artificial intelligence with unmanned aerial vehicles has enhanced autonomous flight, decision making, and computer vision capabilities across many applications. It highlights the growing impact of AI-driven unmanned autonomous vehicles (UAV) in areas such as surveillance, smart cities,

agriculture, defence, and infrastructure by improving performance, efficiency, and real-time data analysis. The article [2] explores how artificial intelligence and drone technologies can support disaster relief by enabling rapid area assessment, survivor detection, and real time decision support for rescue teams. It also discusses future research directions, including multi agent systems, explainable AI, and ethical considerations, highlighting their potential to reduce the impact of natural disasters. The study [3] presents AgroVisionNet, an AI-driven drone and computer vision system that combines high resolution aerial images with IoT sensor data to enable early detection of crop diseases in large agricultural fields. The results show improved accuracy, real time edge deployment feasibility, and interpretable disease localization, making the approach practical for field level agricultural monitoring. The article [4] proposes the Bidirectional Fuzzy Brain Emotional Learning Prediction (BFBEL-P) model, a training free and adaptive AI-based trajectory prediction framework for cooperative UAV swarms operating in dynamic and cluttered environments. The approach combines fuzzy logic, neuro emotional learning, and decentralized multi-agent coordination to enable fast, accurate target tracking, robust obstacle avoidance, and real-time data fusion. Simulation results show that the Bidirectional Fuzzy Brain Emotional Learning Prediction model outperforms traditional methods in prediction accuracy, speed, and reliability by leveraging neuro-emotional learning to adaptively handle dynamic environmental uncertainties and obstacles, making it suitable for real world swarm UAV applications such as surveillance and search and rescue. In another study a design framework is presented for autonomous, cooperative drone swarms to inspect safety of critical infrastructure, moving beyond manual drone operations to leverage autonomy, coordination, and AI-driven capabilities [5]. Using a constructive approach

with simulations and demonstrations, the study shows that swarm enabled UAS (Unmanned Aerial System) integrating onboard perception, communication, and intelligent algorithms are feasible with current technologies. The study shows that using a group of autonomous drones to inspect critical infrastructure is practical with today's sensors, onboard computers, communication systems, and cloud support. While the proposed drone system works well in design, future work will focus on making it more robust, scalable, and compliant with aviation regulations. The survey [6] reviews how Distributed Edge Intelligence is transforming Intelligent Transportation Systems by bringing AI processing closer to vehicles, infrastructure, and communication networks. It discusses key applications, challenges, and future research directions, aiming to support the development of smarter and more sustainable transportation systems. The work reviews how Distributed Edge Intelligence is used in Intelligent Transportation Systems, focusing on its applications, integration, and key challenges. It also highlights future directions and aims to help researchers, practitioners, and policymakers make informed decisions for effective deployment and regulation. Further the article [7] proposes a UAV swarm system using an efficient network design and multi agent reinforcement learning to improve mission performance with limited information sharing. The approach significantly reduces communication delay and energy use, improves collision avoidance, and enables reliable, efficient operation of multiple drones. The study shows that combining an efficient UAV swarm network with multi agent reinforcement learning greatly improves communication efficiency, energy use, and collision avoidance in drone swarms. The results confirm that this approach enables reliable, scalable, and efficient operation of multiple drones for mission critical tasks such as surveillance and disaster response.

In another work [8] proposes the Swarm Allocation and Route Generation (SARG) framework, which jointly handles task assignment and safe, collision free path planning for autonomous drone swarms in complex environments. Experiments show that SARG maintains full collision avoidance while reducing computation time and improving efficiency, making it suitable for real world drone swarm missions. This work introduces the SARG framework, which jointly solves task assignment, collision free path planning, and real time trajectory generation for drone swarms, achieving faster computation while ensuring complete collision avoidance in complex environments. The framework offers a practical, adaptable solution for real world applications such as emergency response and infrastructure monitoring, with future work aimed at adding learning capabilities and supporting more diverse drone swarms. The paper [9] studies cooperative task planning for heterogeneous UAV swarms in edge environments using cooperative game theory and a hybrid centralized distributed framework. The proposed column generation and iterative approach improves computation efficiency and solution quality, especially for disaster response scenarios, while demonstrating the benefits of UAV swarm cooperation. An energy and resource aware cooperative framework is developed for heterogeneous UAV swarms that improves large scale 3D mapping and remote sensing using intelligent task assignment, priority handling, and reinforcement learning [10]. Simulation results show that the proposed method achieves higher mission completion, better handling of dynamic changes, and improved success for high priority tasks, making it effective for large scale and mission critical applications. The study [11] proposes a cooperative task assignment method using an extended contract net protocol to coordinate heterogeneous UAVs for simultaneous multi-directional attacks on a moving target. Simulation results

show that the proposed approach achieves better uniform resource allocation and mission success compared to traditional contract net and genetic algorithm methods.

This study demonstrates a novel heterogeneous drone swarm architecture that combines agile reconnaissance and heavy lift delivery platforms with edge AI processing on the NVIDIA Jetson Orin Nano Super for real time autonomous decision making and human tracking. Additionally, it introduces the innovative use of Cloudflare Zero Trust Tunnels over 4G-LTE networks to achieve secure, low latency, beyond line of sight command and control, enabling global connectivity without traditional ground station dependency.

## II. METHODOLOGY

The developed approach follows a system oriented design and implementation approach to develop a heterogeneous Edge AI enabled drone swarm capable of autonomous logistics and surveillance under Beyond Line of Sight (BLoS) operation. The approach integrates mechanical design, embedded edge computing, cloud assisted communication, autonomous perception, and safety mechanisms into a unified hybrid architecture.

### A. System Architecture Overview

The overall system is designed as a heterogeneous unmanned aerial system (UAS) consisting of two complementary aerial platforms, a high agility reconnaissance drone (Scout) and a heavy lift delivery drone (Mule). Both platforms share a common avionics and edge-computing framework to ensure interoperability, scalability, and ease of deployment. The architecture adopts decentralized edge intelligence, where onboard computing handles perception and decision making, while cloud connectivity supports global command and control.

### B. Platform Design and Hardware Configuration

The Scout platform employs a quad-rotor (Quad X) configuration optimized for maneuverability and rapid deployment, while the Mule platform uses a coaxial X8 configuration to support payload delivery with increased thrust redundancy. Each platform is equipped with a Pixhawk 6c flight controller for low level stabilization and a dedicated NVIDIA Jetson Orin Nano Super module for high level processing. Propulsion systems, structural materials, and payload components are selected based on mission requirements, ensuring agility for surveillance and robustness for logistics operations.

### C. Edge Computing and Software Integration

A decentralized edge computing architecture is implemented, separating flight critical control from computationally intensive AI tasks. The Jetson Orin Nano Super serves as the primary mission computer, interfacing with the Pixhawk flight controller via MAVLink over a USB serial connection. Core mission logic is executed through lightweight MAVLink scripting to minimize latency, while MAVROS is maintained in standby mode to enable future ROS 2-based swarm coordination and extensibility.

### D. Autonomous Perception and Control

Autonomous perception is achieved using high resolution USB cameras processed directly on the Jetson platform. Deep learning based object detection models optimized with NVIDIA TensorRT are deployed for real time human detection. Detected object bounding boxes are converted into angular error signals, which are fed into a PID control loop running on the edge computer. Control

commands are transmitted to the flight controller to enable closed loop visual tracking without human intervention.

#### E. Cloud-Connected Communication Framework

To support global BLoS operation, each drone is equipped with a 4G-LTE modem providing continuous internet connectivity. A Cloudflare Zero Trust Tunnel is established from the onboard Linux system, enabling secure outbound communication that bypasses network address translation limitations. This approach exposes telemetry, video streams, and remote administration services through encrypted channels, allowing the ground control station to operate from any location without reliance on traditional radio links.

#### F. Power Distribution and Thermal Management

A multi rail power architecture is implemented to isolate high current propulsion loads from sensitive computing and control electronics. Independent voltage regulation ensures stable operation of the flight controller and edge computer under dynamic flight conditions. Thermal management strategies, including active cooling and airflow assisted heat dissipation, are employed to prevent performance degradation during sustained AI inference workloads.

#### G. Safety and Fail-Safe Mechanisms

A layered fail safe strategy is incorporated to ensure operational safety during non-line of sight missions. Communication latency and link integrity are continuously monitored, triggering autonomous hover or return to launch behaviors upon degradation or loss of connectivity. Additionally, firmware level geofencing is enforced to constrain flight within predefined operational boundaries, independent of high level AI control logic.

A compact block diagram of the proposed heterogeneous Edge AI drone swarm with cloud-connected hybrid architecture is given in figure 1.

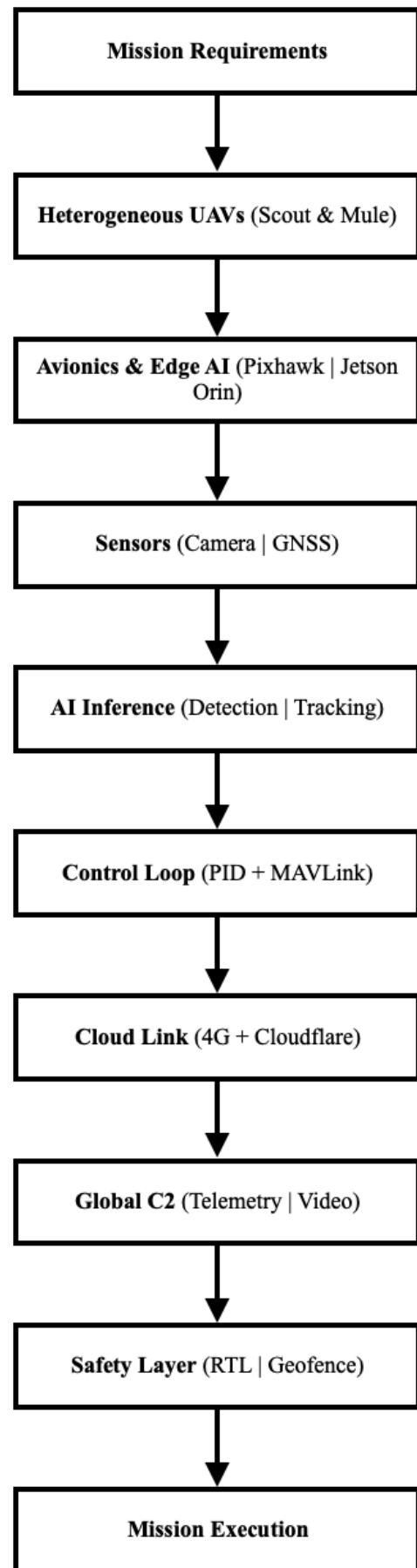


Fig. 1. Block diagram of Methodology

### III. OPERATIONAL WORKFLOW: AUTONOMOUS SEARCH AND RESCUE

The core of our proposed system relies on the synchronized operation of two distinct aerial units, a ‘Scout Drone’ for surveillance and a ‘Delivery Drone’ for relief. This dual drone architecture ensures that payload capacity is not compromised by surveillance equipment, and vice-versa. Figure 2 shows the delivery (big one) and scout (small one) drone system.

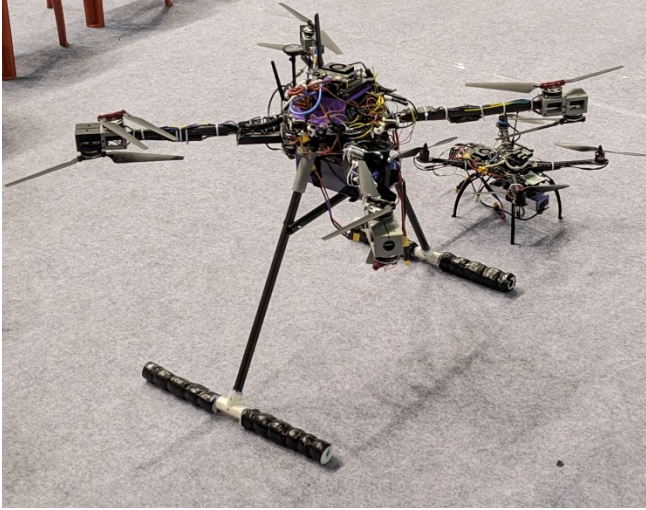


Fig. 2. Delivery and Scout Drone System

#### A. Detection and Geotagging

The operation commences with the Scout Drone scanning the affected area. Equipped with a high resolution Arducam, the drone captures real time visual data of the terrain. This input is processed locally on the onboard computer, a Jetson Orin Nano. We utilized a custom trained YOLOv8 model, refined over an extensive training period to maximize accuracy in identifying human forms in complex environments. Once a survivor is detected, the system immediately communicates with the flight controller (Pixhawk 6c) and the M10 GPS module. This integration allows us to instantaneously "lock" and record the precise GPS coordinates of the identified survivor. Figure 3 demonstrates the Scout Drone and figure 4 gives the Scout Drone flowchart.



Fig. 3. The Scout Drone

### Drone-Based Survivor Detection System

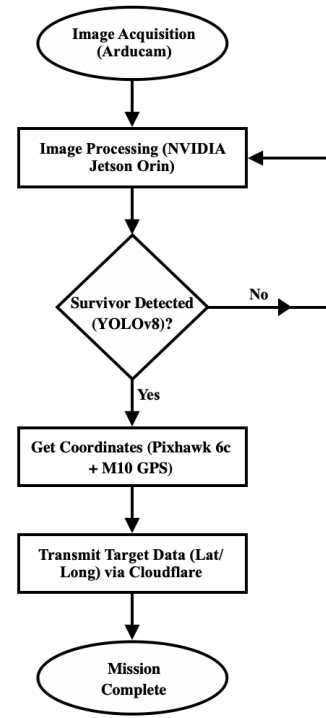


Fig. 4. Scout Drone Flowchart

#### B. Hybrid Communication Bridge

A critical component of our narrative is the seamless data transfer between the two units. We established a robust communication link to share the locked coordinates from the Scout to the Delivery Drone.

**Local Network:** When both drones are within a local range, coordinates are transferred via the SSH protocol for low latency communication.

**Global Network:** To ensure operational viability over vast distances or when local networks are unavailable, we implemented Cloudflare tunneling. This allows the Scout to securely transmit coordinate data over the internet to the Delivery Drone, regardless of physical separation.

#### C. Deployment and Dual Verification

Upon receiving the target coordinates via the hybrid network, the Delivery Drone’s onboard Jetson Orin Nano processes the location data. It commands the Pixhawk 6c mini flight controller to navigate autonomously to the specific waypoint.

Figure 4 demonstrates the Delivery Drone and figure 5 gives the Delivery Drone flowchart.



Fig. 4. The Delivery Drone

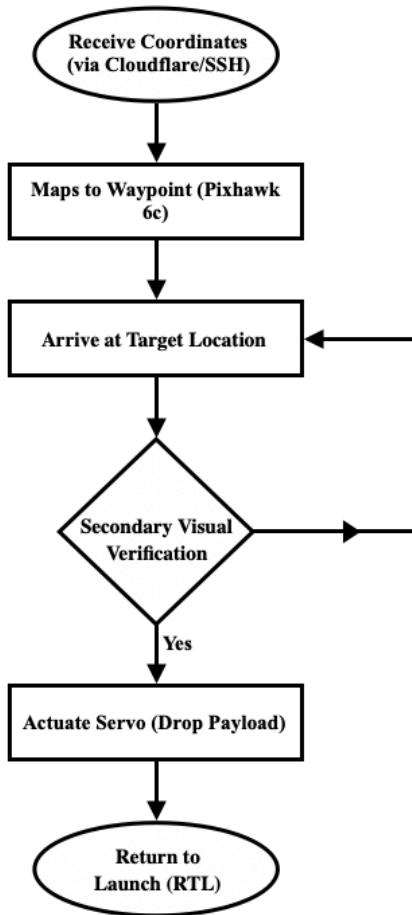


Fig. 5. Delivery Drone Flowchart

However, navigation is only part of the mission. To prevent wasted resources, we introduced a "Dual Verification" protocol. Once the Delivery Drone arrives at the target coordinates, it does not immediately drop the payload. Instead, it activates its own onboard camera to scan the area. The system must re-confirm the presence of the survivor. Only when this secondary positive identification is made does the Jetson trigger the pixhawk and then the pixhawk trigger servo mechanism. The servo actuates the release hook, deploying the medical supplies and food directly to the survivor. Figure 6 demonstrates the mechanism.

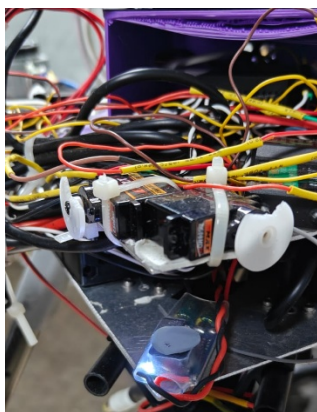
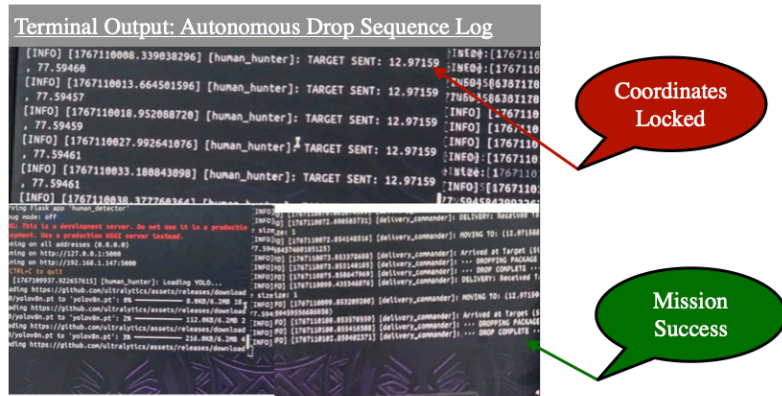


Fig. 6. Payload Drop Mechanism

#### D. Field Testing and System Validation

To validate the autonomous logic, we conducted field trials simulating disaster conditions. Figure 7 demonstrates the Scout Drone's successful identification of a survivor using the YOLOv8 algorithm.



enables real-time human detection, geotagging, and autonomous decision-making directly on the aircraft. The dual verification protocol and hybrid 4G-Cloudflare communication framework ensure precise payload delivery and secure global connectivity, overcoming conventional range limitations. Combined with robust power, thermal, and failsafe architectures, this approach establishes a scalable, fully autonomous aerial logistics platform, paving the way for future cooperative swarm behaviors and fully decentralized mission planning.

## V. CONCLUSIONS

This study demonstrates the design and implementation of a heterogeneous, 4G connected drone swarm capable of autonomous logistics and surveillance under ‘Beyond Line of Sight’ operation. By combining the agile Scout quadcopter for rapid reconnaissance with the heavy lift Mule coaxial X8 for payload delivery, the system effectively addresses diverse mechanical and operational requirements. Onboard Edge AI processing using the NVIDIA Jetson Orin Nano Super enables real time human detection, geotagging, and autonomous decision making, eliminating dependence on centralized ground stations. The dual verification protocol ensures accurate payload deployment by combining GPS coordinates with secondary visual confirmation. On the other hand the hybrid communication framework leveraging local SSH links and Cloudflare Zero Trust Tunnels over 4G-LTE provides secure, low latency global connectivity. Rigorous power distribution, thermal management, and multi layered failsafe mechanisms further enhance operational reliability. Overall, this work establishes a scalable, cost effective, and fully autonomous aerial logistics framework, with future directions aimed at enabling cooperative swarm behaviors and fully decentralized mission planning.

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## REFERENCES

1. K. L. Prakash, S. K. Ravva, M. V. Rathnamma, and G. Suryanarayana, "AI Applications of Drones," in **Scenarios and Solutions for the Future of Drones**, Wiley, 2024, pp. 153-182. <https://doi.org/10.1002/9781394168002.ch7>
2. M. Krichen and M. S. Abdalzaher, "Advances in AI and Drone-based Natural Disaster Management: A Survey," 2023 20th ACS/IEEE International Conference on Computer Systems and Applications (AICCSA), Giza, Egypt, 2023, pp. 1-6, doi: 10.1109/AICCSA59173.2023.10479345.
3. H. M. Manoj, D. L. Shanthi, B. N. Lakshmi, K. J. Archana, and K. Archana, "AI-driven drone technology and computer vision for early detection of crop disease in large agricultural areas," 2025, Scientific Reports, 16(1), 2479. <https://doi.org/10.1038/s41598-025-32384-1>
4. L. W. Page, V. P. Tran, and D. L. Nguyen, "Real-time cooperative target tracking in cluttered environments using multiple drone swarms with adaptive fuzzy emotional learning," 2025, Engineering Applications of Artificial Intelligence, 161, 112125. <https://doi.org/10.1016/j.engappai.2025.112125>
5. R. H. Jacobsen et al, "Design of an Autonomous Cooperative Drone Swarm for Inspections of Safety Critical Infrastructure," 2023, Applied Sciences, 13(3). <https://doi.org/10.3390/app13031256>
6. A. Ghasemi et al, "Edge Intelligence for Intelligent Transport Systems: Approaches, challenges, and future directions," 2025, Expert Systems With Applications, 280, 127273. <https://doi.org/10.1016/j.eswa.2025.127273>
7. W. Jung et al, "Enhancing UAV Swarm Tactics with Edge AI: Adaptive Decision Making in Changing Environments," 2024, Drones, 8(10). <https://doi.org/10.3390/drones8100582>
8. Y. Alqudsi, and M. Makaraci, "Towards Optimal Guidance of Autonomous Swarm Drones in Dynamic Constrained Environments," 2025, Expert Systems, 42(6), e70067. <https://doi.org/10.1111/exsy.70067>
9. J. Gao et al, "Cooperative game based heterogeneous tasks planning for UAV swarms in edge environments," 2025, Transportation Research Part E: Logistics and Transportation Review, 197, 104065. <https://doi.org/10.1016/j.tre.2025.104065>
10. J. Zhang, "Learning enhanced scheduling and resource allocation for heterogeneous UAV swarms in edge assisted remote sensing," 2026, Scientific Reports. <https://doi.org/10.1038/s41598-025-34497-z>
11. S. Shahid, Z. Zhen, and U. Javaid, "Cooperative task assignment of heterogeneous unmanned aerial vehicles for simultaneous multi-directional attack on a moving target," 2024, Engineering Applications of Artificial Intelligence, 139, 109595. <https://doi.org/10.1016/j.engappai.2024.109595>