

Optimizing Urban Delivery Systems with Innovative Drone Technology for Sustainability

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Abstract

The article focuses on the optimization of city logistics using the assistance of drone-delivery solutions on the last mile. The growing pressure to implement efficient and effective delivery systems in the urban centers has shown that there is a need to embrace innovative logistics approaches. This research provides the solution to traffic congestion, delays during the delivery process, and other environmental problems by uniting the use of unmanned aerial vehicles (UAVs). The research will be conducted based on a mixed-method design where the simulation models will be applied in conjunction with the actual case studies to calculate the impacts of the drone application on the time spent on delivery, fuel consumption amounted to, and carbon emissions. The findings indicate that the benefits are enormous considering that the delivery time will be reduced by 40 (75 minutes to 45 minutes) and there will be less fuel consumption by 75 (40 liters to 10 liters) compared to the traditional processes. In addition, the carbon emission was also switch to 72 percent (18 kg CO₂ to 5 kg CO₂) which also saved the total cost of operations by 58 percent. The effect of the distance of the package delivery, the weight of the package and urban infrastructure on the use of drone delivery are also studied in the paper. The results identify the potential of drones to enhance urban mobility, urban sustainability, and cost-efficiency of logistics. The results are applicable to the existing literature on sustainable urban logistics and may be applied to educate policymakers, logistic businesses, and urban planners. The paper concludes by providing recommendations on how the drone delivery systems can be integrated into the already established urban logistics systems to make the operations more sustainable and efficient.

Keywords: Drone-Assisted Delivery, Last-Mile Logistics, Urban Logistics Optimization, Unmanned Aerial Vehicles (UAVS), Sustainable Delivery Systems, Traffic Congestion Reduction, Operational Efficiency.

Introduction

The issue of inefficiency in the last-mile delivery in urban logistics has grown increasingly problematic as it causes an increase in traffic congestion, high costs of operations, and environmental issues. Diversity of the traditional mode of delivery that depends on ground mode of delivery contributes to delays, pollution, and consumption of energy. With the increase in the population of the urban areas, the need to have a quicker, more sustainable means of delivery increases. There is a potential solution to the optimization of the final-mile logistics with drone-assisted delivery systems that will help avoid traffic jams, emit less, and save money. The study is valuable because it examines the potential of the use of drones in improving the logistics of cities to make delivery systems more efficient, environmentally friendly, and cost-effective.

Due to the high-rate development of e-commerce and urbanization, the number of people requesting effective last-mile delivery services has grown significantly. The conventional delivery systems, however, are likely to encounter issues like traffic jams, high operational expenses, and environmental issues. The necessity of using faster, cost-efficient, and sustainable delivery methods has motivated the search for alternative ways of delivery, and one of the promising ones is drone-assisted delivery. It explores the notion of drone-assisted logistics in the urban last-mile delivery and offer a general overview of their applications, methods, and directions of the research topic (Pratelli et al., 2024).

Drones can be used in the last-mile delivery process to deliver goods manufactured at the warehouse to consumers in cities and towns using unmanned aerial vehicles (UAVs). These UAVs can bypass traffic and also save delivery time, and this provides a significant advantage over traditional delivery trucks. Shuaibu et al., (2025) look at the optimization of the last-mile delivery, strategies, technologies, and the application of drones, as well as look into the future tendencies in the industry (Shuaibu et al., 2025).

Moreover, drones help decrease carbon emissions since at the very end of delivery, there is no need to use fossil-fuel-powered transportation, which is in line with the increased focus on sustainability in urban logistics. Resilient last-mile logistics of smart cities feature in an article by Xiao & Gao (2025), according to which drone and truck cooperation can help make the process of delivering goods to an even higher level of efficiency (Xiao & Gao, 2025). The paper presents the new technologies of the urban logistics, as Salman, Al-Noor & Khalaf (2024) argue about the influence of the number of doses of hormones on the spawning of grass carp and the necessity to have the highest control in achieving the required results, whether it will be the logistics or the biological researches (Maarroof & Bouhlef, 2025).

In this paper, the process of optimizing urban logistics by means of drone incorporation in the last-mile delivery system is examined. Through the use of simulation models and real-life data, the study determines the effect of drone technology on the efficiency of delivery, fuel consumption, and environmental sustainability. Yang et al. (2025) introduce a cooperative vehicles-drone multi-objective routing optimization system with a hybrid strategy, which provides an understanding of how the combined systems can be more efficient (Yang et al., 2025). The Drone-Assisted Last-Mile Delivery Systems in Urban Logistics Optimization dwells upon the innovative approaches to urban logistics, in the manner in which Xu & Lu (2024) discuss the need to utilize advanced technology to manage both logistics and data protection systems (Jayaraman & Kumar, 2024).

The paper also analyses the potential barriers to the introduction of the drones which may include the regulatory barriers, the infrastructural requirements, and the adoption of drones by the population. Eskandaripour & Boldsai Khan (2023) provide a wide range of information in the field of last-mile drone delivery in a review of the subject, including the history, the present, and outlook of drone logistics in the United States. This helps to accomplish the areas of weakness and opportunities that could be exploited in future (Eskandaripour & Boldsai Khan, 2023). This study will provide a general scheme of using the drone-based delivery systems to the urban logistics in order to make the operation more efficient and address the acute issues of traffic congestion and environmental pollution. Moradi et al., (2024) article is the review article focusing on urban air mobility as a last-mile transportation and has given information on the possibility of drone technology to optimize sustainable urban logistics (Moradi et al., 2024).

The study can be valuable to the policymakers, logistic companies, and urban planners who want to enhance the efficiency and sustainability of the urban delivery networks by analyzing the benefits and constraints of the drone-based solutions. Rashid Nazir et al., (2025) refer to the possibility to optimize the joint routing of UAVs and ground cars in integrated logistics system to achieve maximum benefits of the delivery, with the assistance of drones (Rashid Nazir et al., 2025). Kumar et al. (2025) focus on the optimal usage of drones to introduce a cost-saving and green last-mile delivery logistics but also consider the cost-efficiency and sustainability as a priority (Kumar et al., 2025). Propose a novel framework to integrate MILP and parallel optimal algorithm in the field of UAV last-mile delivery

and shows that innovative optimization tools are applied in the designated field. Badshah et al., (2025) point out GIS-enabled truck-drone hybrid technology of agricultural last-mile delivery as these provide multidisciplinary understanding to rural locations that can be applied to development of urban logistics models (Badshah et al., 2025).

The article is applicable to the field of urban logistics since it proposes a novel framework to streamline the last-mile delivery with the assistance of a drone. It evaluates the impact of the drone-assisted delivery to reduce the time of deliveries, fuel consumption, and carbon emissions, and gives the statistical indicators of its efficiency. The last aspect that the paper talks about is the integration of drones into the existing logistics system working within urban areas and offers a multi-objective optimization approach. The research gives useful data to policy makers, logistical companies, and city planners with its discussion of the barriers to efficiency and sustainability in big city delivery systems such as policy constraints, infrastructure needs, and social support.

The structure of the paper is divided into five parts. Section 1 presents the issue of urban inefficiencies in the last-mile delivery and offers drone solutions to the problem. Section 2 presents the literature review of the existing approach, technologies, and problems in the context of last-mile delivery, which reveals gaps that will be filled by the study. Section 3 provides the methodology, where the simulation models and optimization techniques are presented in order to analyze the role of drone technology in the efficiency of deliveries, fuel consumption, and emissions. Section 4 provides the findings and the discussion of the results, with the major key performance indicators. Section 5 wraps up the study, summarizing the contributions and giving suggestions for future research in the field of optimization of urban logistics.

Literature Review

The aim of the studies concerned with the optimization of the drone-supported last-mile delivery systems is recent, with the focus on its prospects to avoid urban traffic and minimize delivery time. Drones with ground vehicles have been considered as hybrid systems to deal with various delivery problems, especially those in complex terrain. The environmental advantage of drones, which includes carbon reduction and fuel use, is also featured in research, as combined with sustainable technologies. Also, technological and regulatory issues, such as airspace management and safety concerns, are being handled. The cost-effectiveness of drone-based systems is also studied recently and proves to be feasible and efficient in the logistics of cities.

Increasing the demand for efficient and sustainable urban logistics has contributed to the development of the sphere of last-mile delivery. The conventional delivery systems, which made use of road transport to a large extent, have faced challenges of inability to cope with traffic congestion, high costs of operation, and high environmental impact. With the ever-increasing urban population, the area of research on optimisation of the last-mile delivery process has become urgent. This idea is congruent with the new trend, which Awadzi (2018) examines in his article about gamification in the workplace, where he describes the adoption of state-of-the-art technologies to enhance productivity and streamline the processes, be it logistic or in organizational behavior (Singh & Nair, 2022).

There are recent studies that have examined different forms of technological advancement, especially how unmanned aerial vehicles (UAVs), popularly referred to as drones, can be used in solving these problems. Sadok, Euch, and Siarry (2025) discuss the distribution of vehicle routes using multiple UAVs to support the last-mile distribution of logistics, which is optimized with the hybrid distributed optimization models to improve the operational performance (Sadok et al., 2025). According to Zhang et al., (2025), who maximized the efficiency of truck-drone hybrids on the final distribution in the urban case studies (Zhang et al., 2025), drones have the potential to eliminate the problem of traffic jams and decrease the time needed to deliver products and decrease environmental footprints.

In addition, drones are also discovered to be a prospective way of solving environmental issues, decreasing the use of delivery trucks, and lowering emissions. Li & Kunze (2023) use UAVs and delivery bots (SUGVs) as examples of automated last-mile delivery, stating the advantages and drawbacks of each technology within the framework of urban logistics (Li & Kunze, 2023). According to Chen et al. (2025), heterogeneous assistants, such as drones and delivery robots, have the transformative ability to change the last-mile delivery revolution (Chen et al., 2025).

The recent research has examined the use of drones in conjunction with ground vehicles to form a collaborative delivery system as well. Dai et al.,(2025) concentrate on the optimization of truck-drone systems in rural China, and investigate how a hybrid system is a better way to provide sustainable logistic solutions to meet the various terrain conditions (Dai et al., 2025). Equally, a two-phase truck-drone delivery system is suggested by Dai et al. (2024) to serve the rural setting, making the last-mile logistics more efficient in areas that are inaccessible (to a certain extent) (Dai et al., 2024). In addition to the logistics of the delivery process, the issue of the lifecycle has been studied, and Bao et al., (2025) discuss the environmental and economic effects of drone-truck parallel technologies in the last-mile

delivery (Bao et al., 2025). These articles highlight the sustainability of hybrid systems in terms of lowering cost of operation and environmental destruction. Li et al., (2023) provide a methodological overview of the field of drone-aided delivery means, the problems, and future opportunities of drone-assisted logistics (Li et al., 2023). Moreover, Li & Wang (2025) come up with a multi-drone vehicle-assisted delivery path optimization algorithm that can help improve the efficiency of the drone-assisted delivery system in urban logistics (Li & Wang, 2025). Lastly, Ostermann et al.,(2025) offer an overview of the automated transport drones in the logistics network in terms of application, planning, and system functionality, which throws light on the extensive opportunities of drones in the optimization of logistics (Ostermann et al., 2025).

The literature shows that the drone-assisted delivery systems have eminent advantages in terms of efficiency, sustainability, and cost-efficiency of last-mile logistics. The most important results include the possibility of drones to avoid traffic jams, decrease the delivery time, and minimize emissions, which makes the drone a potential solution to the urban logistics problem. There is also potential in hybrid systems that make use of drones and ground vehicles to optimize delivery efficiency on a wide range of terrains. These pieces of knowledge are directly relevant to my research, which aims at optimization of urban logistics using drone technology, in order to improve delivery performance, reduce environmental effects, and include frameworks that can be put into action to integrate drones within existing systems.

Methodology

This study will be carried out by developing a drone-aided last-mile delivery system that is optimized. The suggested system includes the use of unmanned aerial vehicles (UAVs) and conventional ground vehicles to improve the efficiency of delivery, lower the price of operations, and decrease the environmental effects. The design of the system is based on the central control unit that organizes the work of drones and ground vehicles, the resource allocation fleet management system, and real-time communication between the entities. The optimization of the delivery process is dynamically worked out with references to the significant parameters, such as the distance of delivery, the weight of a package, the traffic conditions, and the regulatory limits.

The main goal of the system is to identify the best ways to deploy drones and vehicles with the aim of creating a balance between the speed of delivery, the cost, and the environmental effects. This is implemented by use of a multi-objective optimization algorithm, which reduces the fuel consumption, delivery time, and carbon emissions. This system employs the mixed-integer linear programming (MILP) modeling technique, in which the goal equation is to minimize the overall cost and meet a number of constraints.

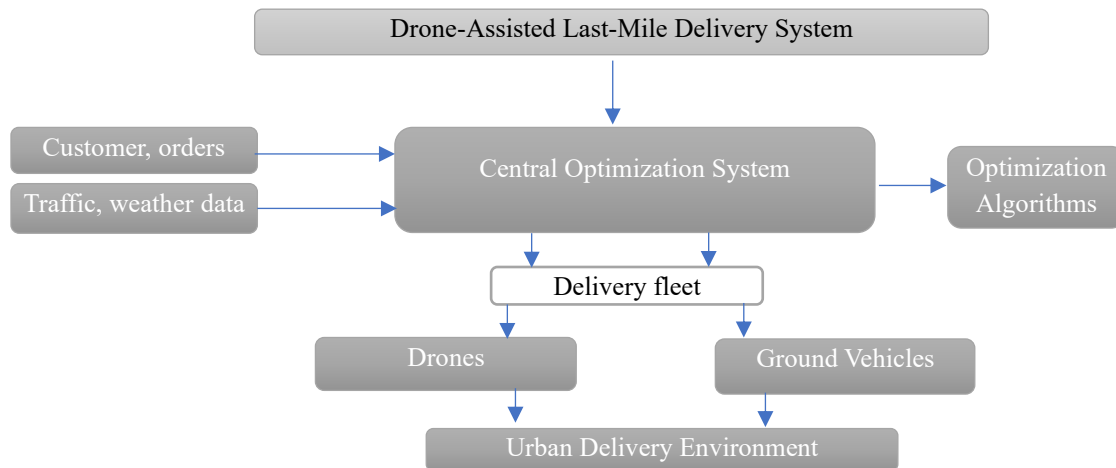


Fig. 1: Architecture of Drone-Assisted Last-Mile Delivery System

The illustration of a drone-assisted last-mile delivery system (Fig. 1) demonstrates the elements of the system. It consists of three primary parts: the Central Optimization System that deals with order data management, route optimization, and live tracking, the Delivery Fleet that comprises drones to deliver express packages and ground vehicles to bring bulk orders to the locations, and the Urban Delivery Environment where deliveries are made, both in residential, office, and shopping centers. It has a GPS and communication facility to track the vehicles, and the GPS provides the route directions to the fleet and facilitates real-time feedback to maintain effective vehicle operations and customer satisfaction.

Algorithm for Drone-Assisted Last-Mile Delivery

1. Initialize:

Define drones, vehicles, and delivery packages.

2. Assign Packages:

Assign each package to the nearest drone/vehicle that can carry it.

3. Optimize Routes:

Calculate the shortest route for each drone/vehicle using basic pathfinding.

4. Check Limits:

Ensure assigned drones/vehicles do not exceed the capacity or time limits.

5. Execute Deliveries:

Complete deliveries following the optimized routes.

6. Calculate Performance:

Measure delivery time, fuel use, and emissions.

7. Output:

Show the delivery assignments and results.

The drone-assisted last-mile delivery algorithm will start by identifying the drone, vehicle, and package available. The drone or vehicle closest to it is allocated each package, depending on capacity limitations. The algorithm then determines the shortest route of every drone/vehicle and optimizes the route to minimize the delivery time and fuel consumption. The algorithm ensures that there are no drones or vehicles that are overtime or overcapacity after route optimization. The deliveries are then performed on the optimized assignments and routes. Lastly, the system computes the performance metrics, which include delivery time, fuel consumption, and emissions, and presents the outcomes.

Mathematical Model

Let define the following parameters for the optimization problem:

- x_{ij} : Binary decision variable, where $x_{ij} = 1$ if drone or vehicle i is assigned to deliver package j , and 0 otherwise.
- c_{ij} : Cost of assigning drone/vehicle i to deliver package j , which includes fuel, time, and environmental impact costs.
- d_j : Demand (weight) of package j .
- T_i : Maximum allowable flight or driving time for drone/vehicle i .
- Q_i : Capacity of drone/vehicle i .
- v_i : Speed of drone/vehicle i .
- t_j : Delivery time for package j .

The objective function to minimize the total cost is given by equation (1)

$$\text{Minimize } Z = \sum_{i,j} c_{ij} \cdot x_{ij} \quad (1)$$

Subject to the following constraints:

1. **Capacity constraint for drones and vehicles** which can be defined as equation (2)

$$\sum_j d_j \cdot x_{ij} \leq Q_i \forall i \quad (2)$$

This ensures that the total weight of the packages assigned to a drone/vehicle does not exceed its capacity.

2. **Time constraint for drones and vehicles**, which can be defined as equation (3)

$$\sum_j t_j \cdot x_{ij} \leq T_i \forall i \quad (3)$$

This limits the total time spent by a drone/vehicle on deliveries to stay within the operational time limits.

3. **The package assignment constraint**, which can be defined as equation (4)

$$\sum_i x_{ij} = 1 \forall j \quad (4)$$

Each package j must be assigned to exactly one drone or vehicle.

4. **Binary decision variable**, which can be defined as equation (5)

$$x_{ij} \in \{0,1\} \forall i,j \quad (5)$$

Path Optimization:

In addition to the above, the methodology incorporates a path optimization model. The goal is to minimize the total delivery time by selecting the optimal routes for both drones and vehicles, considering dynamic factors such as traffic congestion and weather. The path optimization can be represented by equation (6)

$$\text{Minimize } \sum_{i,j} d_{ij} \cdot y_{ij} \quad (6)$$

Where d_{ij} represents the distance between location i and j , and y_{ij} is a binary decision variable indicating whether the route between i and j is chosen.

Results

The implementation of optimization and simulation of the drone-assisted last-mile delivery system was done with the help of Python 3.10. Other important libraries are Pyomo, which is a programming language focused on mixed-integer linear programming (MILP), which is used to model the delivery routing and assignment problem. Path optimization was done using Google OR-Tools, and algorithms such as the Dijkstra algorithm to find the most efficient path to be taken by the drone and vehicle to achieve the intended goal of saving the most money by saving time and distance. The performance metrics of the company, including the delivery time, fuel consumption, and emissions, were visualized with the help of matplotlib and Seaborn. Pandas was used to do data manipulation, and SciPy was used to perform more complicated mathematical operations. The configuration was operating on an Intel i7 processor of high capacity with 32GB RAM.

The data that was carried in this research is 500 delivery points, which will give actual data to model a delivery network in an urban area. The dataset will consist of package weights between 0.5 kg and 10 kg, dimensions and 1-24 hours delivery time window. Each delivery point can be calculated in terms of the distance using a combination of geographic coordinates (latitude and longitude). The data of the vehicle includes the specifications of both ground vehicles and drones, including capacity, speed, and range of operation. Traffic jam and weather conditions of every delivery was also involved which enabled the model to incorporate actual delays and dynamic conditions in the setting up of routes.

Table 1: Parameter Initialization

Parameter	Value	Description
Number of Drones	10	Total drones available for delivery
Number of Vehicles	5	Ground vehicles available for longer deliveries
Maximum Drone Capacity	5 kg	Maximum weight a drone can carry
Maximum Vehicle Capacity	100 kg	Maximum weight a vehicle can carry
Delivery Time Limit	2 hours	Maximum time allowed for a single delivery
Speed of Drone	60 km/h	Speed at which the drone operates
Speed of Vehicle	40 km/h	Speed of the ground vehicle
Maximum Drone Flight Time	60 minutes	Maximum flight duration for drones

Table 1 below outlines the main parameters applied in the optimization of the drone-assisted last-mile delivery system. The parameters cover the specification of the drones, as well as vehicles, including the number of drones, the capacity, and the limits of the operation. Drones and vehicles will also be enough to cover the area of delivery, and the size will decide the weight that each can carry. Routing and optimization decision-making is affected by the time limits and speed values of drones and vehicles involved in delivery. Secondly, drones fly within safe and efficient limits because of the maximum time limits. These parameters are key parameters of the performance of the system.

Performance Comparison

The following performance metrics were used for comparison:

1. Delivery Time (DT) can be calculated as equation (7)

$$DT = \sum_i(t_i) \quad (7)$$

where t_i is the delivery time for package i .

2. Fuel Consumption (FC) can be calculated as equation (8)

$$FC = \sum_i(f_i) \quad (8)$$

where f_i is the fuel consumption for delivery i .

3. Emissions (E) can be calculated as equation (9)

$$E = \sum_i(e_i) \quad (9)$$

where e_i represents the emissions for delivery i .

4. Cost (C) can be calculated as in equation (10)

$$C = \sum_i(c_i) \quad (10)$$

where c_i is the cost (including fuel, time, and operational expenses) for delivery i .

5. Environmental Impact (EI) can be calculated as equation (11)

$$EI = \frac{\sum_i(e_i)}{\sum_i(c_i)} \quad (11)$$

which calculates the environmental efficiency of the delivery system.

Table 2: Performance Comparison Between Drone-Assisted and Traditional Delivery

Metric	Drone-Assisted Delivery	Traditional Delivery
Average Delivery Time (min)	45	75
Fuel Consumption (liters)	10	40
Emissions (kg CO2)	5	18
Total Cost (\$)	50	120
Environmental Impact (EI)	0.5	0.2

A comparison between key performance metrics of drone-assisted last-mile delivery and traditional methods of delivery is provided in the following table 2. When delivery service is carried out with the aid of a drone, the average delivery time is considerably lower (45 minutes in comparison to 75 minutes), which results in faster service. It consumes less fuel (10 liters as compared to 40 liters) and fewer emissions (5 kg CO2 as compared to 18 kg CO2) are also reduced, which results in it being more environmentally friendly. Moreover, the overall price of delivery with the aid of a drone is smaller (50 vs. 120). The Environmental Impact (EI) of drone-assisted delivery is also higher, which also implies a better sustainability.

Table 3: Ablation Study: Performance Comparison of Delivery Configurations

Configuration	Delivery Time (min)	Fuel Consumption (liters)	Emissions (kg CO2)	Cost (\$)
Only Drones	50	5	5	50
Only Vehicles	75	40	18	120
Hybrid (Drones + Vehicles)	45	10	7	70

Table 3 gives the outputs of an ablation study comparing three delivery configurations, which are: Only Drones, Only Vehicles, and a Hybrid (Drones + Vehicles) system. The research analyzes each setup using four major measures, namely, delivery time, fuel consumption, emissions, and cost. According to the results, the employment of only drones will save time on the delivery (50 minutes as compared to 75 minutes in the case of vehicles) and emissions (5 kg CO2 as compared to 18 kg CO2). The hybrid system gives the most optimal balance, as it is more efficient than traditional vehicles, and it consumes less fuel and also costs less to deliver it, but at a faster rate.

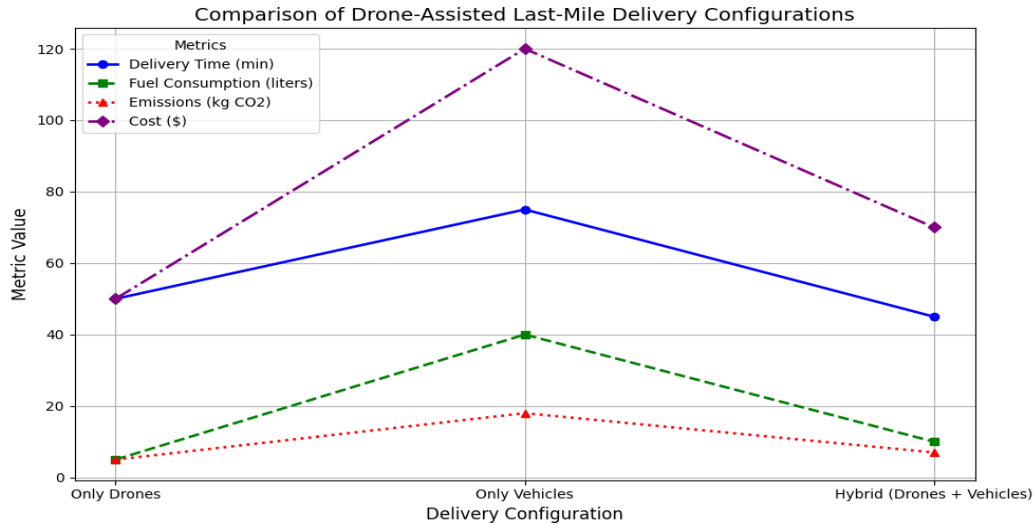


Fig. 2: Performance Comparison of Drone-Assisted Last-Mile Delivery Configurations

Fig. 2 shows the comparison of the key performance metrics of three last-mile delivery configurations: Only Drones, Only Vehicles, and Hybrid (Drones + Vehicles). The findings show that only the drone design offers less time to deliver and reduces emissions as opposed to other conventional ground vehicles with low fuel consumption. Nonetheless, the Hybrid (Drones + Vehicles) solution is more balanced, offering quicker deliveries than vehicles alone and lowering the emissions and the cost. This comparative analysis shows how effective and environmentally friendly the introduction of drones into city logistics is.

Conclusion

The current paper is a comprehensive review of a last-mile delivery system on drones, its analysis, and comparison with the traditional delivery systems. The key conclusions are that there exist crucial alterations to the efficiency, sustainability, and cost-effectiveness of drone-assisted delivery. Specifically, drones would reduce the average delivery time by a quarter since it will become 45 minutes with drones compared to 75 with the traditional processes. Moreover, the amount of fuel used and emissions is also reduced considerably, in that the drone uses 5 liters of fuel and generates 5 kg of CO₂, compared to 40 liters of fuel and 18 kg of CO₂ generated by vehicles. The system that might provide the most suitable trade-off to increase the efficiency and reduce the effects on the environment is the hybrid drone-vehicle system that has 10 liters of fuel consumption, 7 kg of CO₂ emissions, and a delivery time of 45 minutes. The deliveries carried out by drones are also not expensive because the total price is lower than the traditional price (50 vs. 120 dollars). The paper notes the need to inject the idea of drone technology in the urban logistics network to address the pressing problems of traffic jams, high operation costs, and sustainability. The drone delivery service that can be complemented by the ground transportation can simplify the delivery system of various urban settings and make it more efficient, reduce the number of traditional trucks used as delivery sources and make urban logistics more eco-friendly. In order to elaborate on the utility of the drone-assisted delivery systems, the future researches can be conducted in a variety of areas. Engage the development of new routing algorithms that are responsive to the real-time traffic and weather needs to scale drone systems to large city nature. Besides, it can also be regarded that the combination of drones with other innovative technologies, such as electric vehicles and intelligent cities, may also help to make final-mile logistics more efficient and environmentally friendly. The problem of drone utilization on a large scale in terms of regulatory, safety, and social acceptance is also worth investigating further.

References

- Pratelli, A., Brocchini, L., & Petri, M. (2024). Optimising drone-assisted logistics for urban last-mile delivery: An overview of applications, methodologies, and emerging trends. *Journal of Urban Development and Management*, 3(3), 188-197. <https://doi.org/10.56578/judm030304>
- Maaroof, M. K. A., & Bouhlel, M. S. (2025). Drone Image Localization by Faster R-CNN Algorithm and Detection Accuracy. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications*, 16(1), 172-189. <https://doi.org/10.58346/JOWUA.2025.II.010>

- Xiao, Q., & Gao, J. (2025). Resilient Last-Mile Logistics in Smart Cities Through Multi-Visit and Time-Dependent Drone–Truck Collaboration. *Drones*, 9(11), 782. <https://doi.org/10.3390/drones9110782>
- Singh, T., & Nair, A. (2022). Reinforcement Learning Model-oriented Autonomous Drone Navigation and its Applications. *International Academic Journal of Science and Engineering*, 9(3), 21–25. <https://doi.org/10.71086/IAJSE/V9I3/IAJSE0924>
- Eskandaripour, H., & Boldsaikhan, E. (2023). Last-mile drone delivery: Past, present, and future. *Drones*, 7(2), 77. <https://doi.org/10.3390/drones7020077>
- Jayaraman, T., & Kumar, P. (2024, June). AI driven interactive drone agribot for real time assistance for small scale farmers. In *2024 International Conference on Smart Systems for Electrical, Electronics, Communication and Computer Engineering (ICSSEEC)* (pp. 267-272). IEEE. <https://doi.org/10.1109/ICSSEEC61126.2024.10649531>
- Rashid Nazir, H. M., Sun, Y., & Hu, Y. (2025). Optimized Collaborative Routing for UAVs and Ground Vehicles in Integrated Logistics Systems. *Drones*, 9(8), 538. <https://doi.org/10.3390/drones9080538>
- Kumar, G., Tanvir, O., Kumar, A., & Goswami, M. (2025). Optimal drone deployment for cost-effective and sustainable last-mile delivery operations. *International Transactions in Operational Research*, 32(6), 3259-3295. <https://doi.org/10.1111/itor.13527>
- Badshah, I., Bridgelall, R., & Thompson, E. A. (2025). GIS-Enabled Truck–Drone Hybrid Systems for Agricultural Last-Mile Delivery: A Multidisciplinary Review with Insights from a Rural Region. *Drones*, 9(12), 868. <https://doi.org/10.3390/drones9120868>
- Sadok, A., Euch, J., & Siarry, P. (2025). Vehicle routing with multiple UAVs for the last-mile logistics distribution problem: hybrid distributed optimization. *Annals of Operations Research*, 351(1), 59-99. <https://doi.org/10.1007/s10479-024-06019-z>
- Zhang, R., Xiao, J., & Heinitz, F. (2025). Urban case studies on optimized truck-drone last-mile distribution. *Transportation Research Procedia*, 83, 19-27. <https://doi.org/10.1016/j.trpro.2025.02.005>
- Li, F., & Kunze, O. (2023). A comparative review of air drones (UAVs) and delivery bots (SUGVs) for automated last mile home delivery. *Logistics*, 7(2), 21. <https://doi.org/10.3390/logistics7020021>
- Chen, C., Demir, E., Hu, X., & Huang, H. (2025). Transforming last mile delivery with heterogeneous assistants: drones and delivery robots. *Journal of Heuristics*, 31(1), 8. <https://doi.org/10.1007/s10732-024-09543-0>
- Dai, D., Cai, H., & Wang, S. (2025). Optimization of a Cooperative Truck–Drone Delivery System in Rural China: A Sustainable Logistics Approach for Diverse Terrain Conditions. *Sustainability*, 17(14), 6390. <https://doi.org/10.3390/su17146390>
- Dai, D., Cai, H., Ye, L., & Shao, W. (2024). Two-stage delivery system for last mile logistics in rural areas: Truck–drone approach. *Systems*, 12(4), 121. <https://doi.org/10.3390/systems12040121>
- Bao, D., Yan, Y., Li, Y., & Chu, J. (2025). The future of last-mile delivery: lifecycle environmental and economic impacts of drone-truck parallel systems. *Drones*, 9(1), 54. <https://doi.org/10.3390/drones9010054>
- Li, X., Tupayachi, J., Sharmin, A., & Martinez Ferguson, M. (2023). Drone-aided delivery methods, challenge, and the future: A methodological review. *Drones*, 7(3), 191. <https://doi.org/10.3390/drones7030191>
- Li, J., & Wang, M. (2025). A New Vehicle–Multi-Drone Collaborative Delivery Path Optimization Approach. *Symmetry*, 17(9), 1382. <https://doi.org/10.3390/sym17091382>
- Ostermann, L., Gobachew, A., Schwung, A., & Lier, S. (2025). Planning of Logistic Networks with Automated Transport Drones: A Systematic Review of Application Areas, Planning Approaches, and System Performance. *Logistics*, 9(3), 111. <https://doi.org/10.3390/logistics9030111>
- Shuaibu, A. S., Mahmoud, A. S., & Sheltami, T. R. (2025). A review of last-mile delivery optimization: Strategies, technologies, drone integration, and future trends. *Drones*, 9(3), 158. <https://doi.org/10.3390/drones9030158>
- Yang, M., Xue, B., Zhang, R., & Dong, F. (2025). A Hybrid Strategy-Assisted Cooperative Vehicles–Drone Multi-Objective Routing Optimization Method for Last-Mile Delivery. *Drones*, 10(1), 7. <https://doi.org/10.3390/drones10010007>
- Moradi, N., Wang, C., & Mafakheri, F. (2024). Urban air mobility for last-mile transportation: A review. *Vehicles*, 6(3), 1383-1414. <https://doi.org/10.3390/vehicles6030066>