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Poster: Criticality-aware Drone Routing for Post-Disaster Delivery under Deadline and Energy Constraints

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***Abstract*—We propose a battery-aware multi-trip drone routing framework for post-disaster delivery that considers the mixed criticality of supplies under deadline and energy constraints. In this framework, each delivery request is assigned a criticality level and a delivery deadline, and drones are allowed to switch to a high-speed flight mode for urgent deliveries at the cost of increased energy consumption. The proposed optimization model simultaneously determines the number of drones, the delivery routes, and the flight speed mode for each segment, enabling a trade-off between energy consumption and urgency. Low-criticality deliveries may be skipped to prioritize high-criticality ones. Experimental results show that the proposed method improves the on-time delivery success rate for high-criticality items from 59.2% to 89.3%, compared to a baseline. In addition, the delivery rate for low-criticality items also slightly increases from 38.6% to 45.3%, supported by the increased number of drones. These results demonstrate the effectiveness of criticality-aware planning and provide insights into how to allocate and configure drone fleets for effective disaster response logistics.**

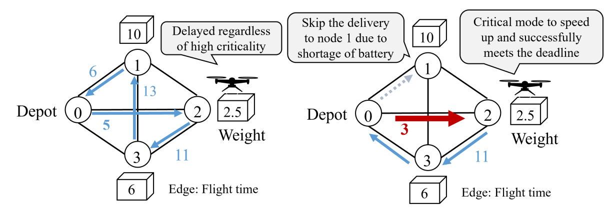
***Index Terms*—Drone routing, post-disaster, mixed criticality**

I. Introduction

Unmanned aerial vehicles, also known as drones, have become vital assets in disaster relief logistics. They offer fast and flexible delivery of supplies even when traditional infrastructure is disrupted, as in the aftermath of earthquakes or floods. In such emergency situations, drones are capable of reaching isolated communities without relying on roads or railways [1]. However, optimizing drone-based delivery, especially in post-disaster settings, requires not only efficient routing and scheduling but also careful prioritization of what to deliver. Delivering all supplies equally without regard to urgency can result in the failure to reach those in critical need.

Existing studies on drone delivery optimization typically aim to minimize travel time or energy consumption, assuming all deliveries are equally important [2]. Yet in real disaster scenarios, supply criticality varies significantly. While life-saving medicine and infant nutrition must arrive within tight time limits, other supplies such as blankets or hygiene products may tolerate some delay. Failing to reflect this variation risks wasting limited drone capacity and energy on non-urgent deliveries.

To address this issue, we propose a drone routing problem that incorporates differences in supply urgency through mixed criticality. Each delivery has its own deadline and importance level. High-criticality items must be delivered on time, while low-criticality items may be skipped if needed. As illustrated in Fig. 1, our framework allows drones to skip certain deliveries, delay others, or activate high-speed mode selectively on arcs to ensure urgent items meet deadlines under energy constraints. This arc-level control enables fine-grained prioritization without unnecessary global energy costs.



Name	Weight	Quantity	Deadline	Target	Criticality
Water	1.0	10	30	1	Low
Medkit	0.5	5	**4**	2	High
Blanket	0.3	20	20	3	Low

Fig. 1. Concept of the proposed criticality-aware drone delivery system. Drones deliver supplies with varying deadlines and criticality levels under energy constraints. The system allows skipping low-priority items, accepting delays when necessary, and using high-speed modes to meet urgent deadlines.

We formulate an optimization model using mixed integer linear programming and simulate multiple scenarios involving diverse shelter locations and supply requests. Through experiments comparing with a baseline model that lacks criticality awareness, we demonstrate that our approach significantly improves the success rate of urgent deliveries, particularly under tight energy and time constraints.

II. System Model

In this model, multiple homogeneous drones $d \in D$ are deployed to deliver relief supplies from a central depot (node 0) to a set of shelters $i \in N \setminus \{0\}$ after a disaster. Each drone is allowed to execute up to k trips, with each trip $k \in K$ forming a closed route that starts and ends at the depot. The supplies to be delivered are indexed by $t \in T$, and for each item t, the model is given a delivery location i, required quantity q_{it}, weight w_t, delivery deadline T_{it}, and a criticality level $c_{it} \in \{High, Low\}$ representing how critical the delivery is from optional to strictly required.

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The movement of each drone during a trip is encoded by edge selection variables $x_{d,k,i,j}$, which determine whether drone d travels from node i to node j during trip k. These variables construct the flight path of the trip. Each arc may be traversed in normal mode or high-speed critical mode. The latter consumes more energy but may be necessary to meet tight delivery deadlines. The quantity of each supply item t carried across an arc is represented by $f_{d,k,i,j,t}$ and must respect the drone's capacity cap_d constraint when summed over all t.

The delivery time $a_{d,k,t}$ for a supply item is calculated based on the trip's start time $s_{d,k}$ and flight duration, which depends on both the selected speed mode and arc distance. If the item is delivered later than its deadline T_{it}, a slack variable $\xi_{d,k,t}$ records the delay. Energy consumption $e_{d,k}$ is linearly approximated as a function of the drone's empty weight, the payload weight, and the length and speed mode of each arc. After each trip, the drone can recharge a certain amount $r_{d,k}$, which is linked to a recharge time $\tau_{d,k}$, and its remaining battery $b_{d,k}$ is updated accordingly. All drones must operate within a global energy budget E_0, and the optimization problem seeks to allocate energy wisely across trips and drones. A key characteristic of this problem is its formulation under the mixed criticality framework [3]: not all deliveries are mandatory. It is permissible to skip or delay lower-criticality items if doing so allows for the timely delivery of higher-priority items or improves overall efficiency. The optimization procedure balances objectives such as minimizing missed deliveries and delays, limiting drone and trip usage, and staying within the energy constraint, while automatically determining feasible and efficient delivery schedules; however, we have to omit the detail due to page limitation.

III. Simulation

A. Setup

To evaluate the effectiveness of our proposed criticality-aware multi-trip, multi-drone delivery model, we performed optimization-based simulations to test whether switching to a high-speed mode improves on-time delivery of critical supplies under energy and time constraints.

We simulate five cases of post-disaster delivery scenarios with one depot and ten nodes to deliver, where each node requests items (e.g., water, medical kits) with specific quantities, deadlines, and criticality levels (loose or critical), which are randomly generated. Up to 10 drones are available, each capable of four delivery trips. Drones travel at 10 m/s in normal mode or 15 m/s in critical mode, with the latter consuming 2.25 times more energy. Each drone carries up to 30 kg, weighs 10 kg when empty, and starts with 2.0×10^8 J of energy. Energy use is proportional to distance and weight; drones may recharge 100 W between trips.

As a baseline for comparison, we consider a method that uses the same optimization framework but disables the use of critical mode, forcing all deliveries to be carried out at the normal speed regardless of urgency. This allows us to isolate the effect of critical speed selection on delivery success rates.

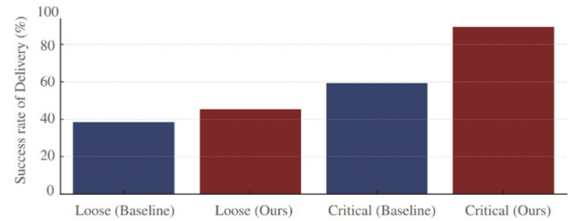

Fig. 2. Experimental results: Ours achieves higher success rate of deliveries for critical items, compared to baseline.

TABLE I
Comparison of the number of drones and trips between baseline and proposed method

Case	Baseline		Ours	
	No. of drones	No of. trips	No. of drones	No. of trips
1	3	4	6	4
2	2	4	6	4
3	2	4	2	4
4	2	4	4	3
5	2	4	5	4

B. Results

As shown in Fig. 2, our method improves the delivery success rate for critical items from 59.2% to 89.3%. For loose items, the rate increases from 38.5% to 45.3%, while increasing number of drones. These results show that allowing critical mode improves urgent deliveries. However, some low criticality deliveries are sacrificed due to higher energy use.

Table I shows the number of drones and trips. Since critical mode consumes more energy, drones complete fewer deliveries per trip, necessitating additional units to fulfill demands on time. This underscores the framework's value in estimating required fleet size under constraints, and suggests that increasing battery capacity could alleviate the need for extra drones.

IV. Conclusions

This paper proposed a criticality-aware multi-trip multi-drone delivery model for post-disaster logistics and conducted simulations to evaluate its performance under energy and time constraints. The results demonstrated that selectively using high-speed mode improves on-time delivery of critical supplies, while fleet size and energy budget influence overall effectiveness. The proposed framework also enables sensitivity analyses on drone design parameters, offering practical guidance for planning efficient and resilient drone-based disaster relief operations.

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