B: Large-Scale Campus Takeout Delivery with Human and Autonomous Agents

Background

Modern university campuses often resemble small cities. Hundreds of restaurants operate across campus, and hundreds of thousands of students rely on takeout food delivery every day. During peak periods, such as lunch and dinner hours, the volume of delivery orders can surge dramatically, placing significant strain on traditional human delivery riders.

To improve efficiency and reliability, universities are considering autonomous delivery technologies, such as ground-based delivery robots and aerial drones, as supplements to human riders. These agents differ in speed, capacity, cost, operating constraints, and reliability. Designing an effective delivery system that integrates human riders with autonomous agents is a complex logistical challenge.

You are asked to develop a mathematical model to support large-scale campus takeout delivery operations, with the goal of ensuring timely delivery while balancing operational cost, system robustness, and scalability.

Problem Description

The campus is divided into multiple zones containing:

Restaurants (order sources),

Student residential zones (order destinations), and

Logistics hubs where delivery agents are dispatched.

Each takeout order is generated dynamically and is associated with a strict delivery deadline. Orders not delivered on time are considered failures. The delivery system consists of three types of agents:

Human riders

Autonomous ground vehicles (AGVs)

Delivery drones

Each agent type has distinct characteristics, such as speed, payload capacity, operational cost, and environmental constraints (e.g., drones may be grounded during adverse weather).

Requirements

1. Demand Modeling

Analyze and model large-scale takeout demand across the campus, with particular emphasis on:

Time-of-day demand surges,

Spatial imbalance between restaurant zones and residential zones,

Variability and uncertainty in order arrivals.

Your model should be capable of forecasting demand during peak periods and identifying system bottlenecks.

2. Network Representation

Model the campus delivery system as a multi-layer flow network:
Nodes represent restaurants, residential zones, logistics hubs, and intermediate transfer points.
Edges represent feasible delivery routes with associated travel times and capacities.
Different layers correspond to different delivery agent types.
Each unit of flow corresponds to a delivery order. Capacity constraints represent limited numbers of agents and infrastructure restrictions.

3. Delivery Strategy Design

Using your network model, design a delivery strategy that:
Assigns orders to delivery agent types,
Routes agents through the network efficiently,
Respects delivery time windows and agent constraints.
You should consider both static strategies (fixed allocation rules) and adaptive strategies (time-dependent or demand-responsive rules).

4. Performance Evaluation

Define appropriate metrics to evaluate system performance, such as:
On-time delivery rate,
Average delivery delay,
Agent utilization,
Operational cost and energy consumption,
System robustness under demand surges or partial agent failure.
Use these metrics to compare different delivery strategies.

5. Model Expansion and Technology Assessment

Extend your model to explore:
The marginal benefit of introducing autonomous agents,
Trade-offs between human riders and autonomous systems,
The impact of adverse conditions (e.g., weather, traffic congestion, system failures).
Discuss under what conditions autonomous delivery provides the greatest value.

Your submission should include:

A clear description of modeling assumptions,
The mathematical formulation of your network and decision process,
Computational or simulation results,
Sensitivity and scenario analysis,
Practical recommendations for campus delivery system design.
Your final report should be written entirely in English and follow standard MCM/ICM formatting and style.

Evaluation Criteria

Solutions will be evaluated based on:
Quality and scalability of the modeling framework,
Correctness and insightfulness of network abstractions,
Effectiveness and feasibility of proposed delivery strategies,
Depth of analysis and interpretation of results,
Clarity, organization, and professionalism of the written report.

Appendix: A simplification data of the problem.

Campus Structure ： To simplify analysis, the campus is divided into zones.

Restaurant Zones (Order Sources)

- **R1**: North Dining Cluster
- **R2**: Central Dining Cluster
- **R3**: South Dining Cluster

Residential Zones (Order Destinations)

- **S1**: North Dorm Area
- **S2**: East Dorm Area
- **S3**: South Dorm Area

Logistics Hub

- **H0**: Central Dispatch Hub (all delivery agents start here)

All delivery paths follow:

H0 → Restaurant Zone → Residential Zone

Travel Time Data (Minutes)

From / To R1 R2 R3 S1 S2 S3

H0	6	4	7	–	–	–
R1	–	–	–	8	10	12
R2	–	–	–	9	7	8
R3	–	–	–	12	9	6

The total delivery travel time is the sum of the two legs.

Order Arrival Data (Peak Period)

Peak period: **11:30–12:30** (60 minutes)

Orders arrive in **10-minute intervals**.

Time Interval	R1 Orders	R2 Orders	R3 Orders
11:30–11:40	18	22	15
11:40–11:50	25	30	20
11:50–12:00	32	38	28
12:00–12:10	35	42	30
12:10–12:20	28	34	22
12:20–12:30	20	26	18

Residential demand proportions (for all intervals):

- **S1**: 35%
- **S2**: 40%
- **S3**: 25%

Delivery Time Requirement

- Each order must be delivered within **30 minutes** of its order time.
- Orders delivered after the deadline are considered **unsuccessful**.

Delivery Agents

Three types of delivery agents are available:

Human Riders

- Number available: **20**
- Speed: baseline (use travel times as given)
- Cost per delivery: **1.0 unit**

Autonomous Ground Vehicles (AGVs)

- Number available: **10**
- Speed: **0.8** × human travel time
- Cost per delivery: **0.6 units**

Delivery Drones

- Number available: **6**
- Speed: **0.5** × human travel time
- **Cannot serve the route R3 → S1**
- Cost per delivery: **0.4 units**

AGVs and Delivery Drones deliver orders to a designated pickup point within each residential zone where the students will pickup their orders While the delivery driver will directly deliver the order to the student.