THE SELECTIVE TRAVELING SALESMAN PROBLEM WITH RELEASE DATES AND DRONE RESUPPLY

New and innovative use of drones to assist in parcel delivery

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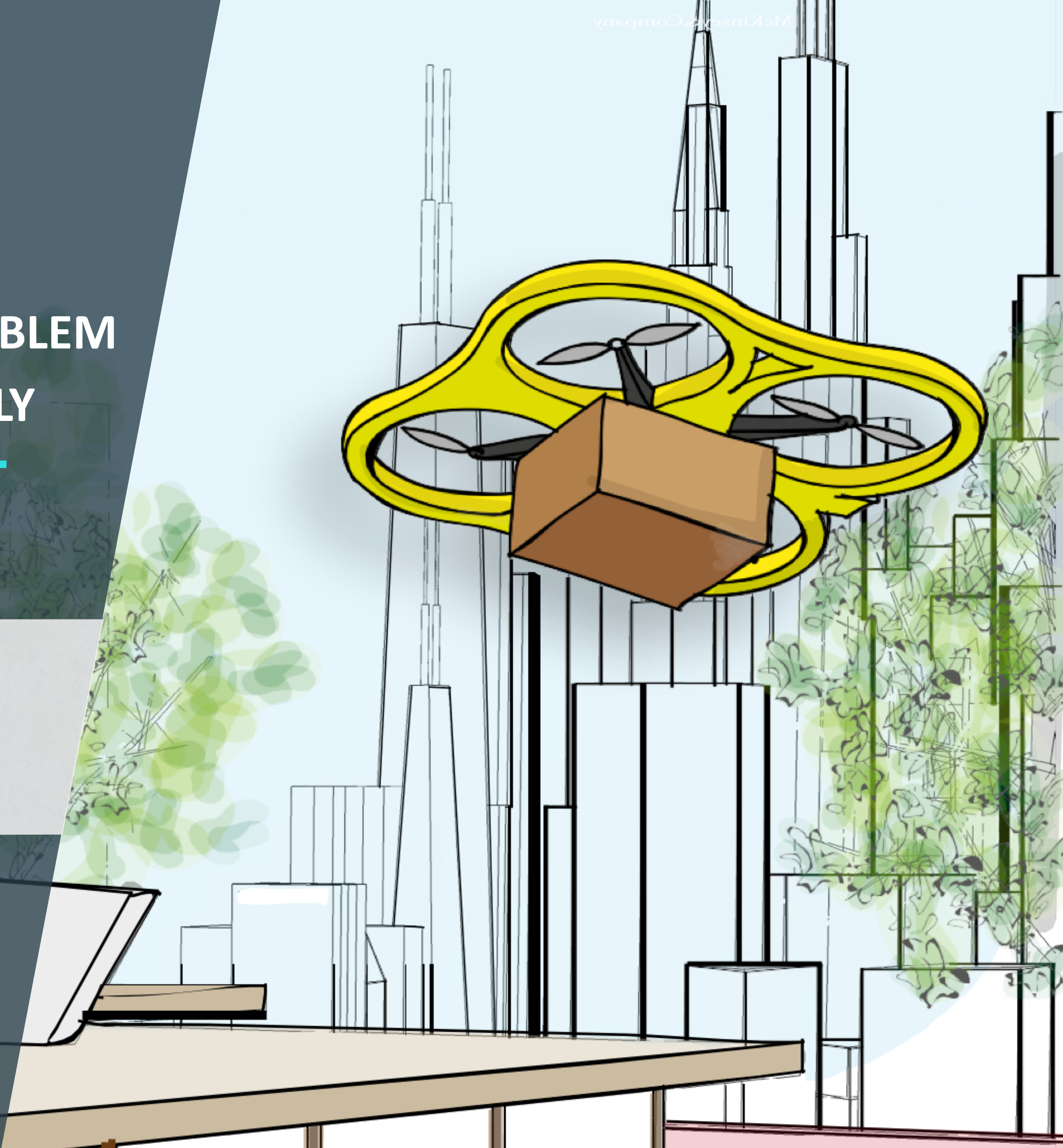
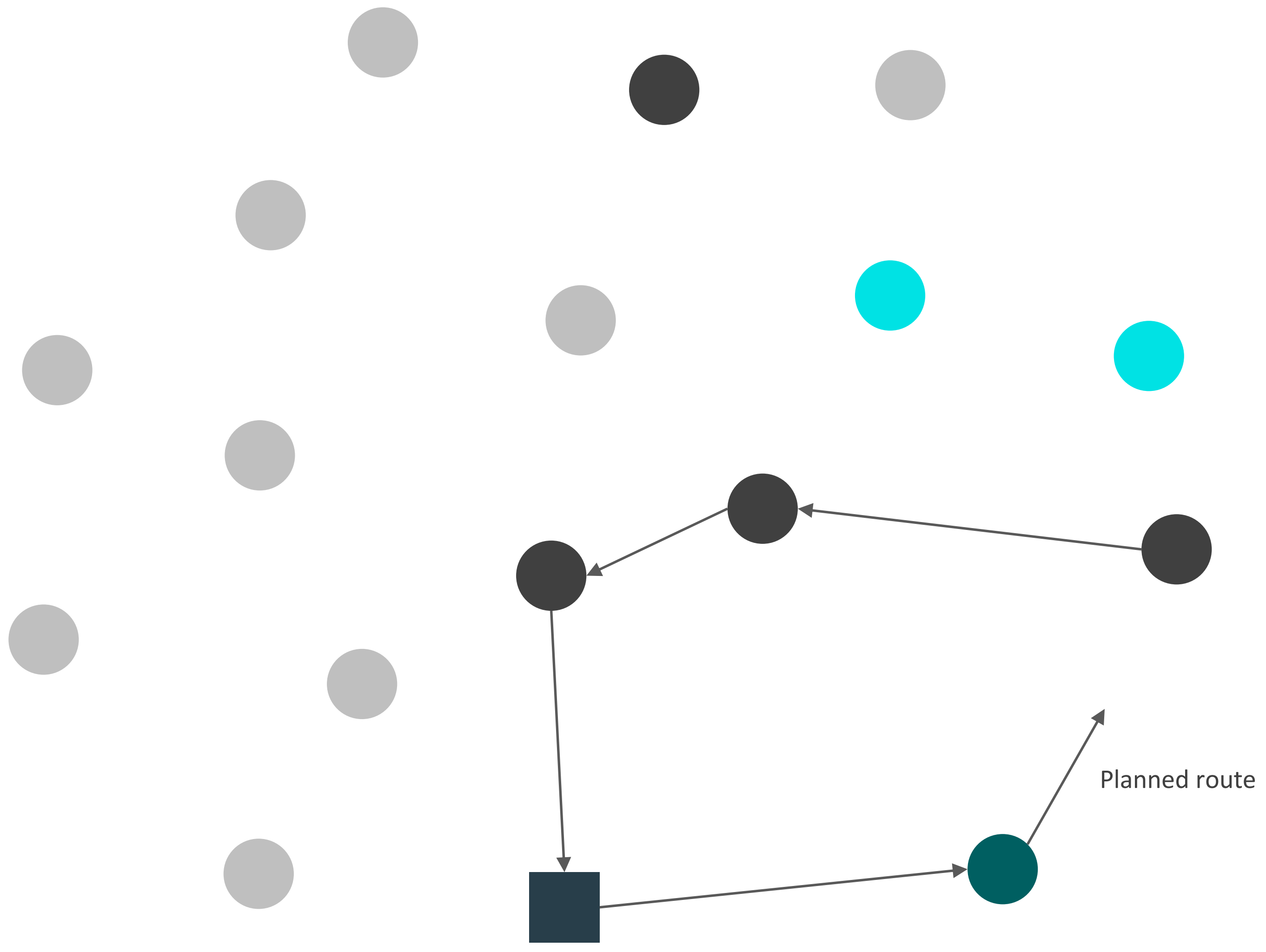


MOTIVATION

- Delivering a set of orders within a limited time frame
- Orders become available for dispatch at different times
- Vehicles can only deliver parcels loaded onto them before leaving the depot
- Using drones to resupply dispatch vehicles while en route
- No need for trucks to return to pick up new available orders

HOW DOES THIS NEW DELIVERY SYSTEM WORK?

Customers whose order arrived at the depot
Customers served so far
New orders available at the depot
Orders sent by the drone



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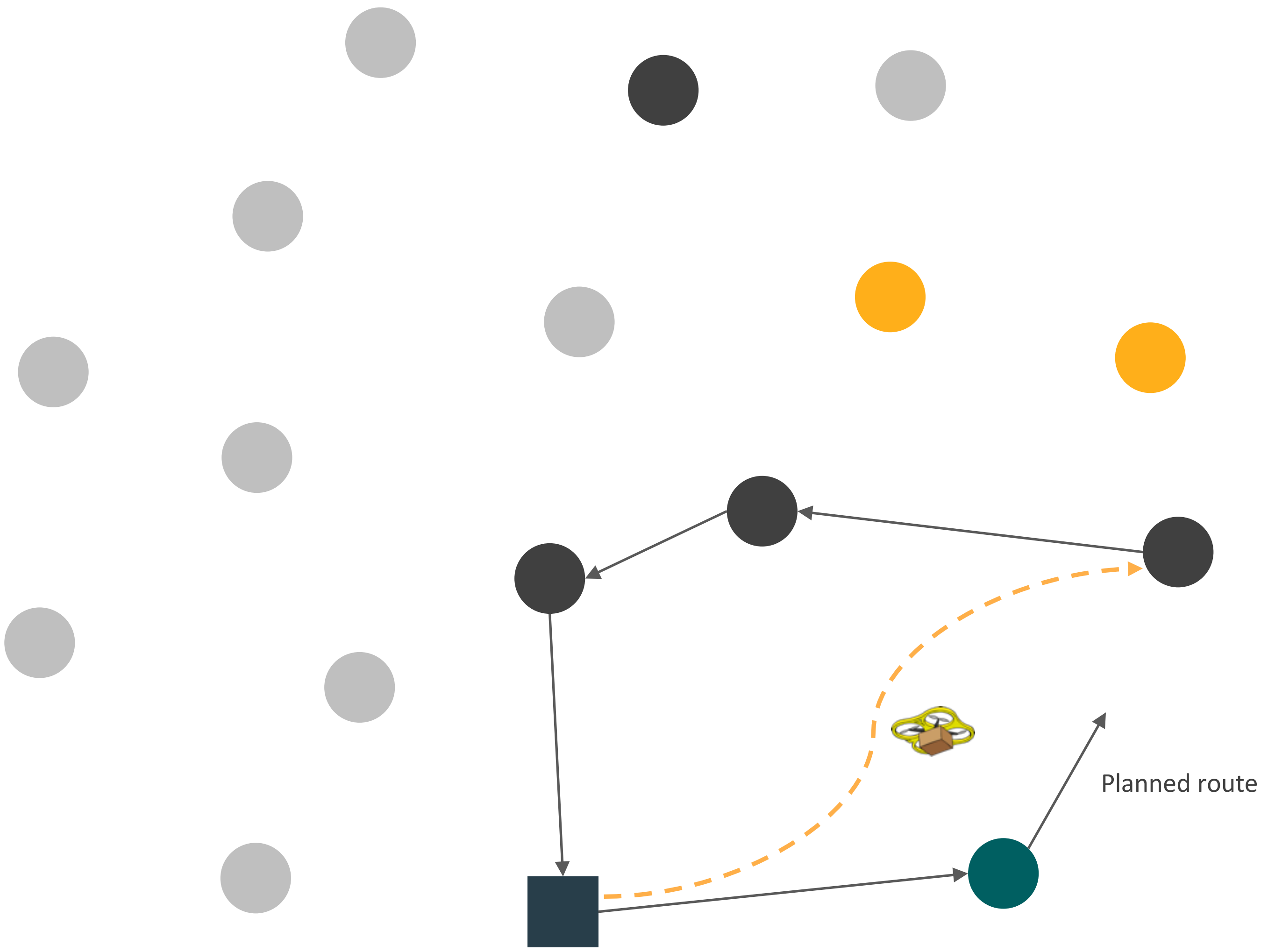

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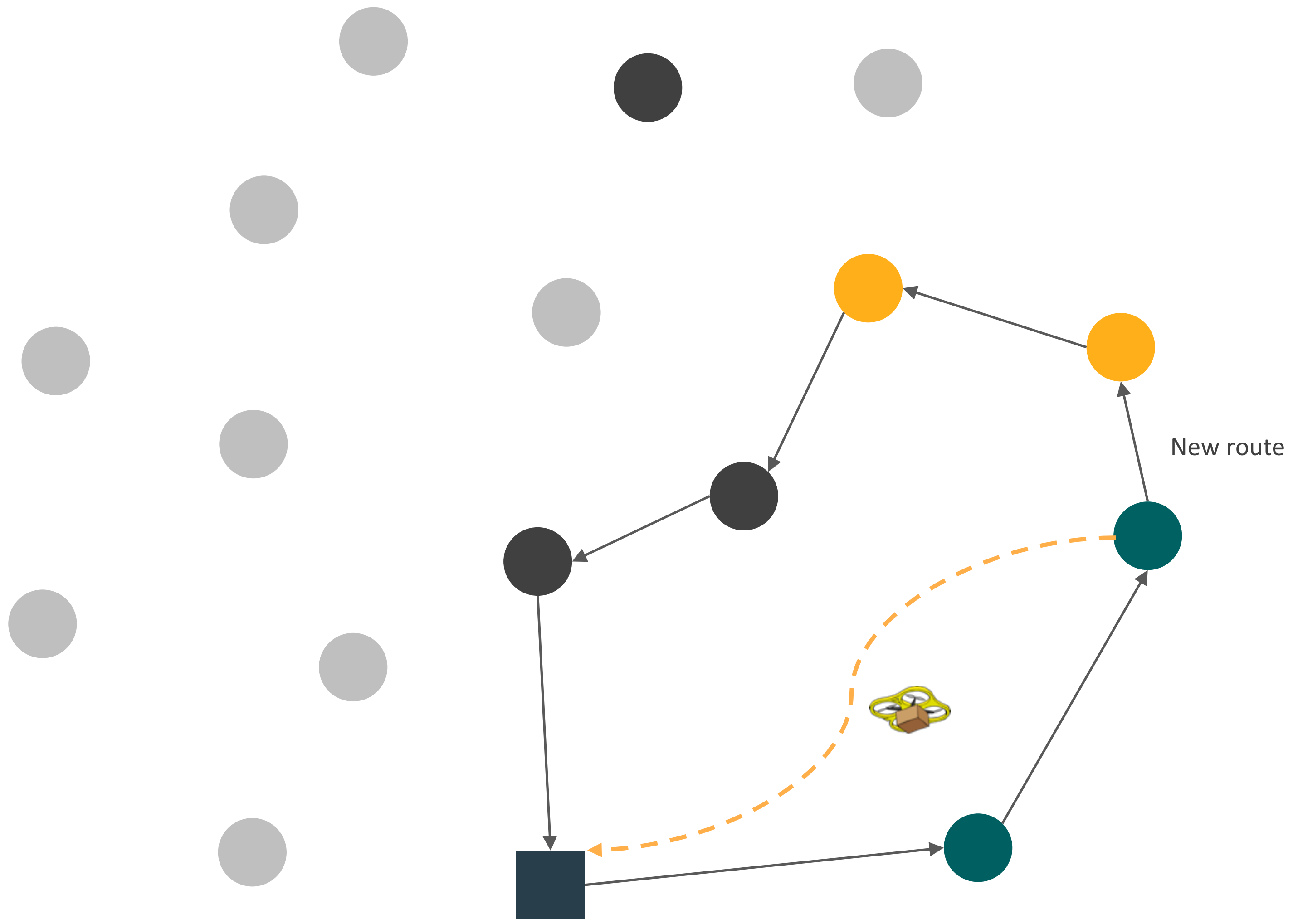

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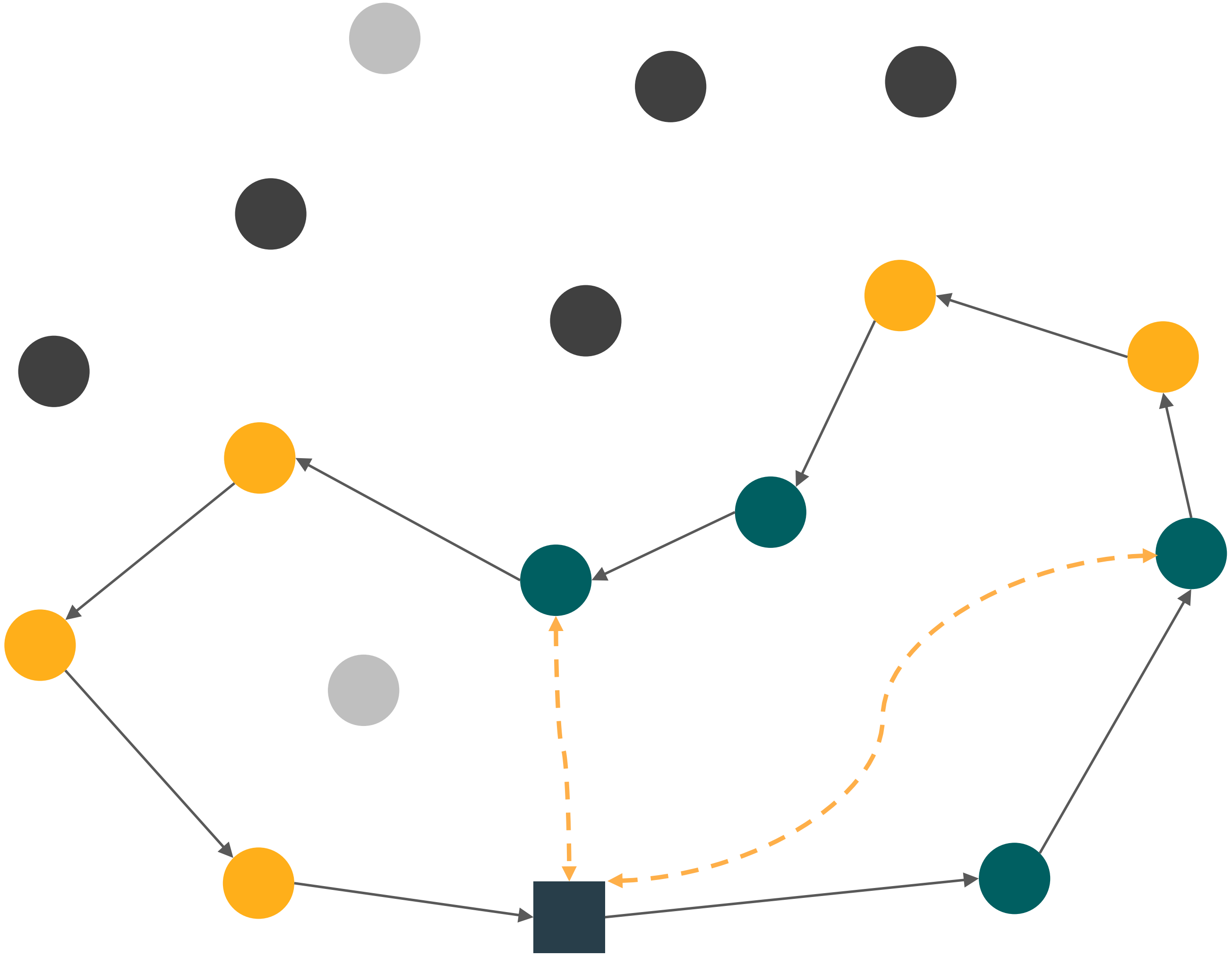
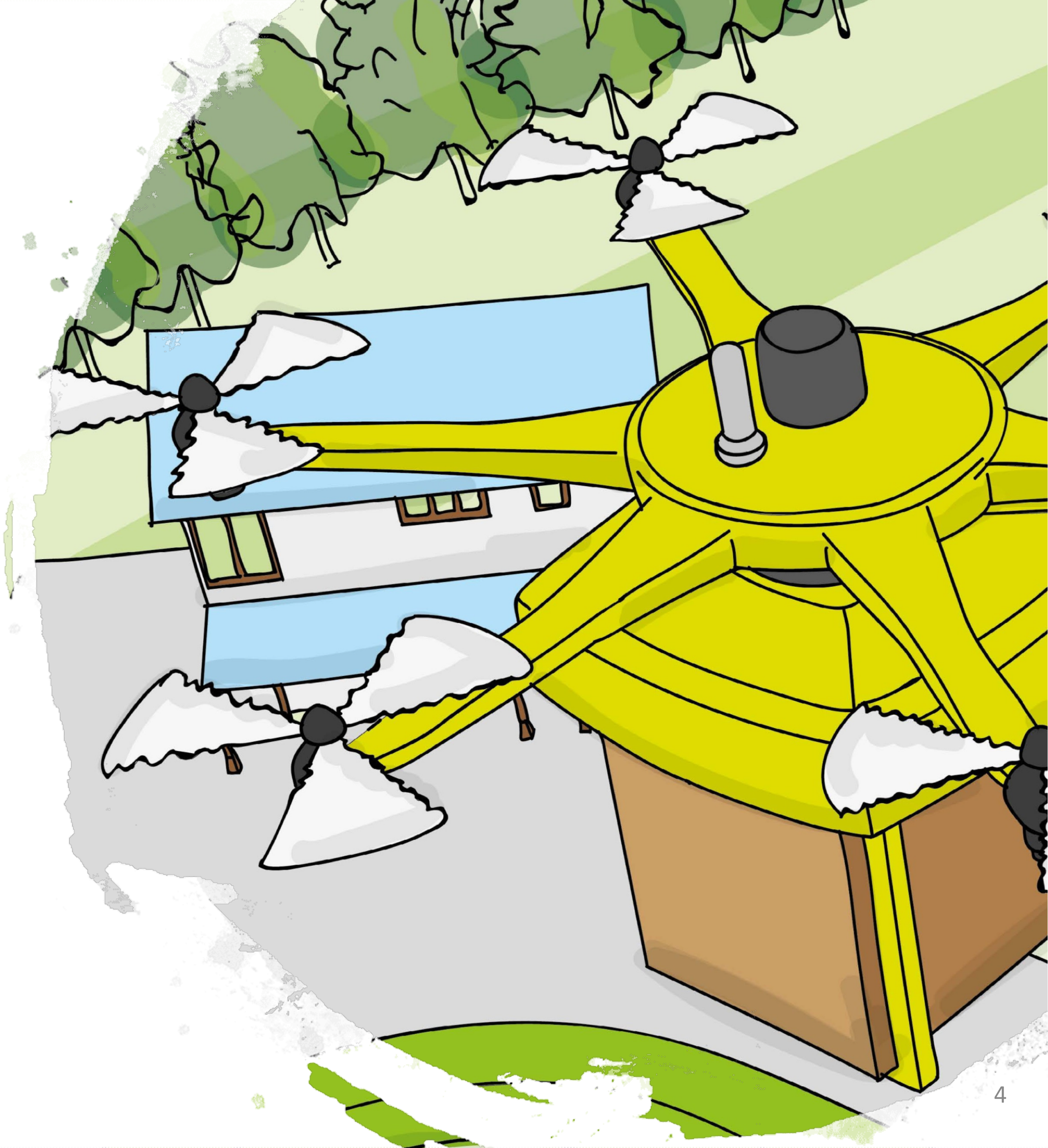


PROBLEM STUDIED

Find a dispatch route for a single truck, synchronized with drone resupply, to minimize distribution costs and penalties incurred for not delivering.

ASSUMPTIONS AND CONSIDERATIONS:

- Single truck and single drone
- **Deterministic case:** Release dates are known in advance
- The drone has a given load capacity and flight endurance
- The truck is uncapacitated



MIP MODEL

PARAMETERS:

Release dates

Truck and drone travel times

Load capacity and flight endurance of the drone

Cost for wait times of the driver for the drone

Time for unloading orders from the drone

Transportation and penalty costs

Cost per use of the drone

Length of the delivery day

MIP MODEL

VARIABLES:

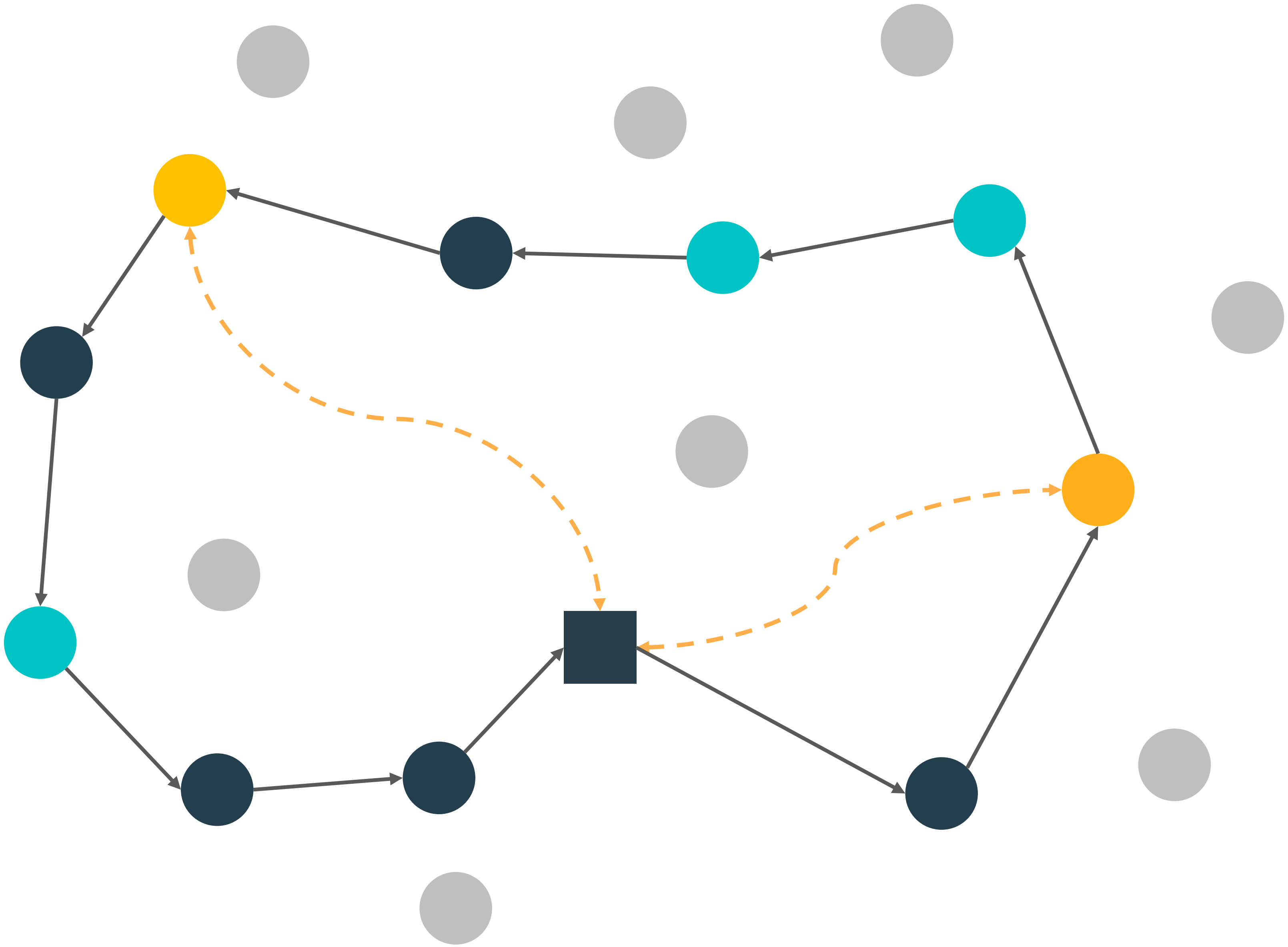
- x_{ij}: 1, if node j is visited immediately after node i by the truck. 0, otherwise.
- z_i: 1, if node i is visited by the truck. 0, otherwise.
- r_{ij}: 1, if node j is visited after node i by the drone. 0, otherwise.
- u_i: 1, if the drone flies to node i for resupplying the truck with new orders. 0, otherwise.
- y_{ij}: 1, if the order of customer j is loaded onto the truck at node i. 0, otherwise.
- T_i: Time when the truck departs node i.
- s_i: Time when the drone is launched for node i.
- ϵ_i: Elapsing time between arrival and departure of the truck at node i.

OBJECTIVE FUNCTION

$$\min \underbrace{\sum_{(i,j)\in A} c_{ij}x_{ij}}_{\text{TRAVEL COSTS}} + \underbrace{\sum_{i\in N} h \cdot \epsilon_i}_{\text{COSTS FOR THE TRUCK STOPS}} + \underbrace{\sum_{i\in N} f \cdot u_i}_{\text{COST OF USING THE DRONE}} + \underbrace{\sum_{i\in N} p(1 - z_i)}_{\text{PENALTY COSTS FOR NOT MAKING DELIVERIES}}$$

CONSTRAINTS

Customers not served
Orders sent by the drone
Nodes visited by the drone



CONSTRAINTS

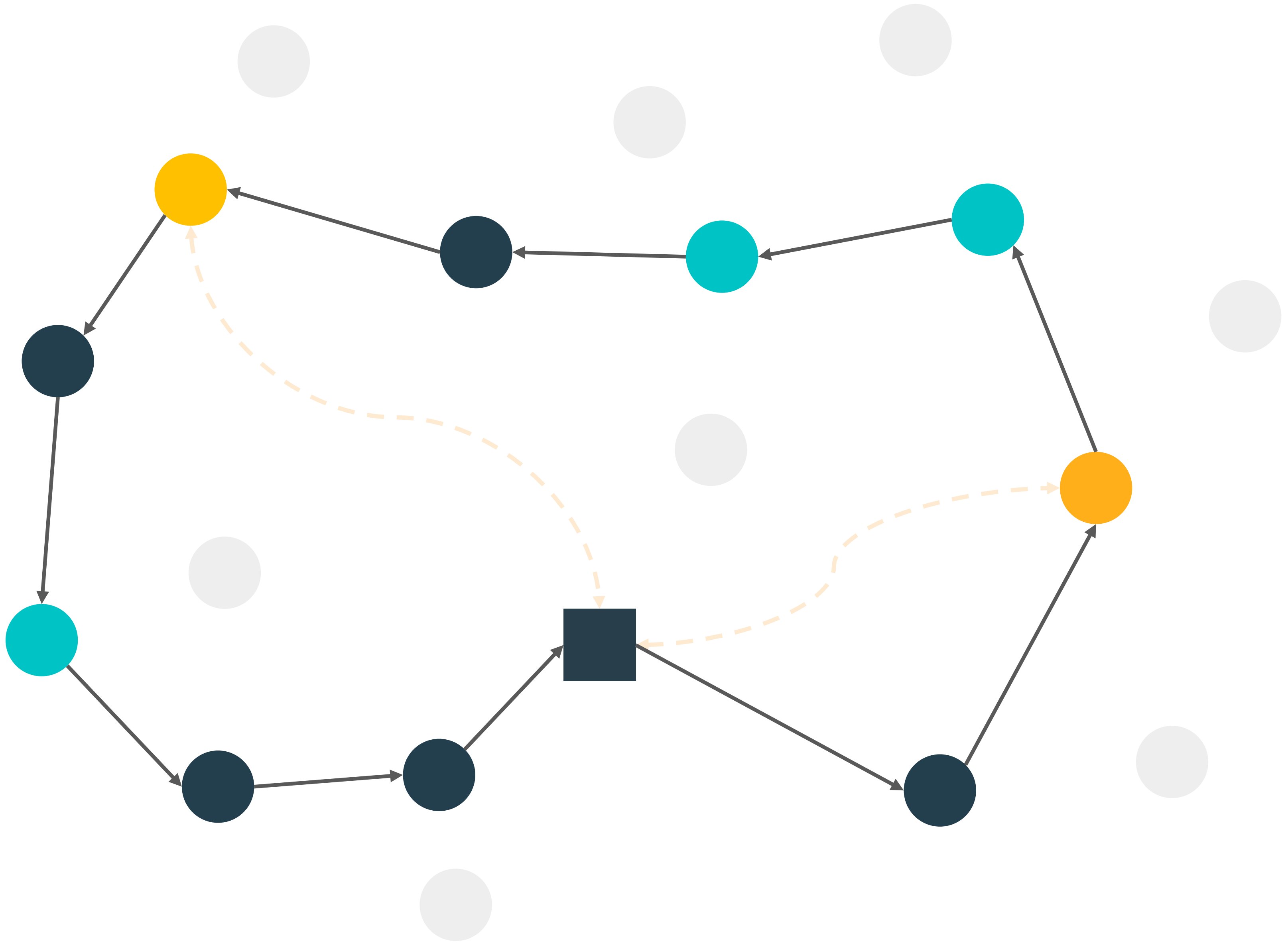
1

TRUCK ROUTE:

Which customers?

Which sequence?

Deadline



CONSTRAINTS

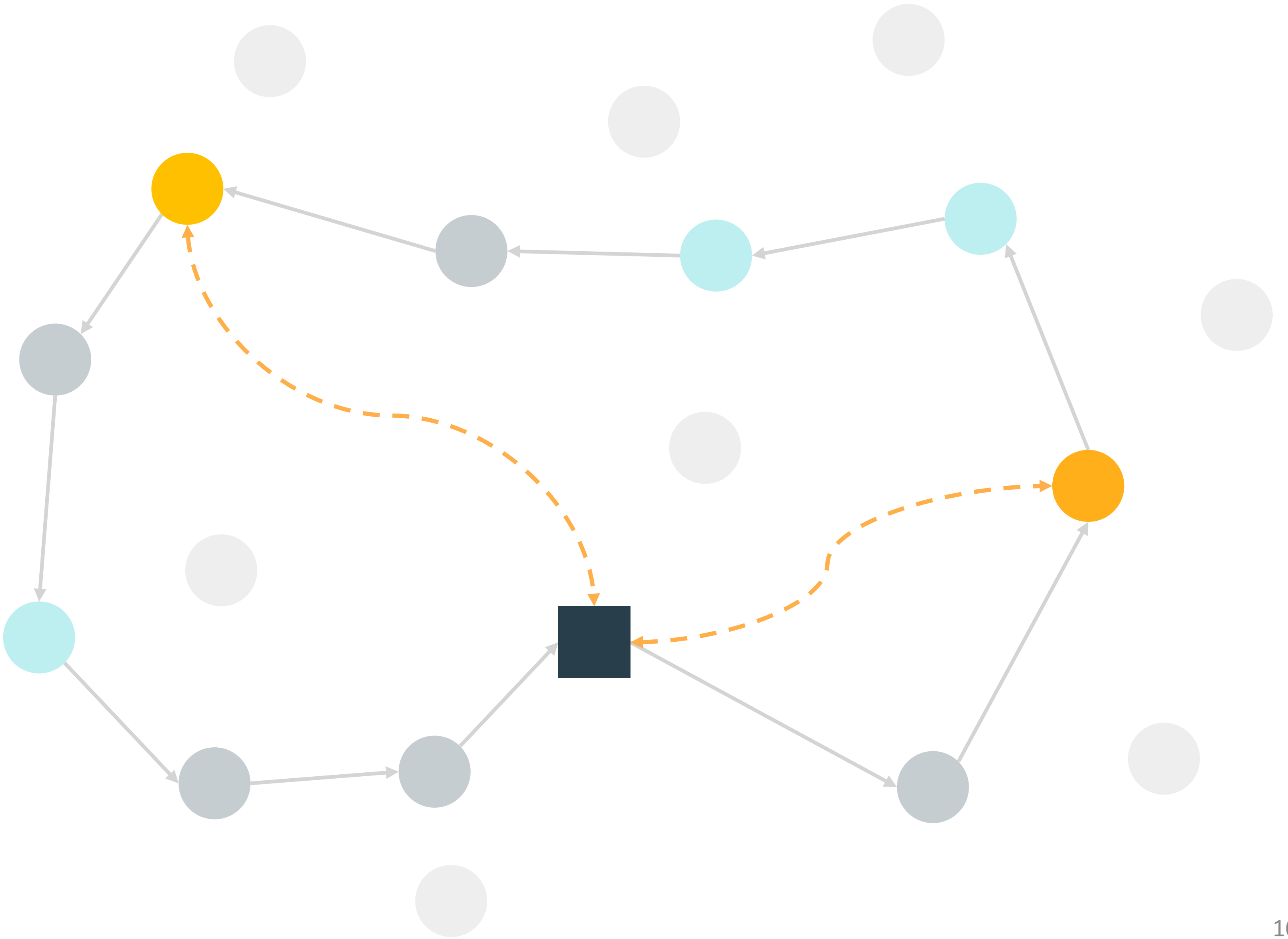
2

DRONE FLIGHTS:

Which nodes?

Which sequence?

Drone endurance



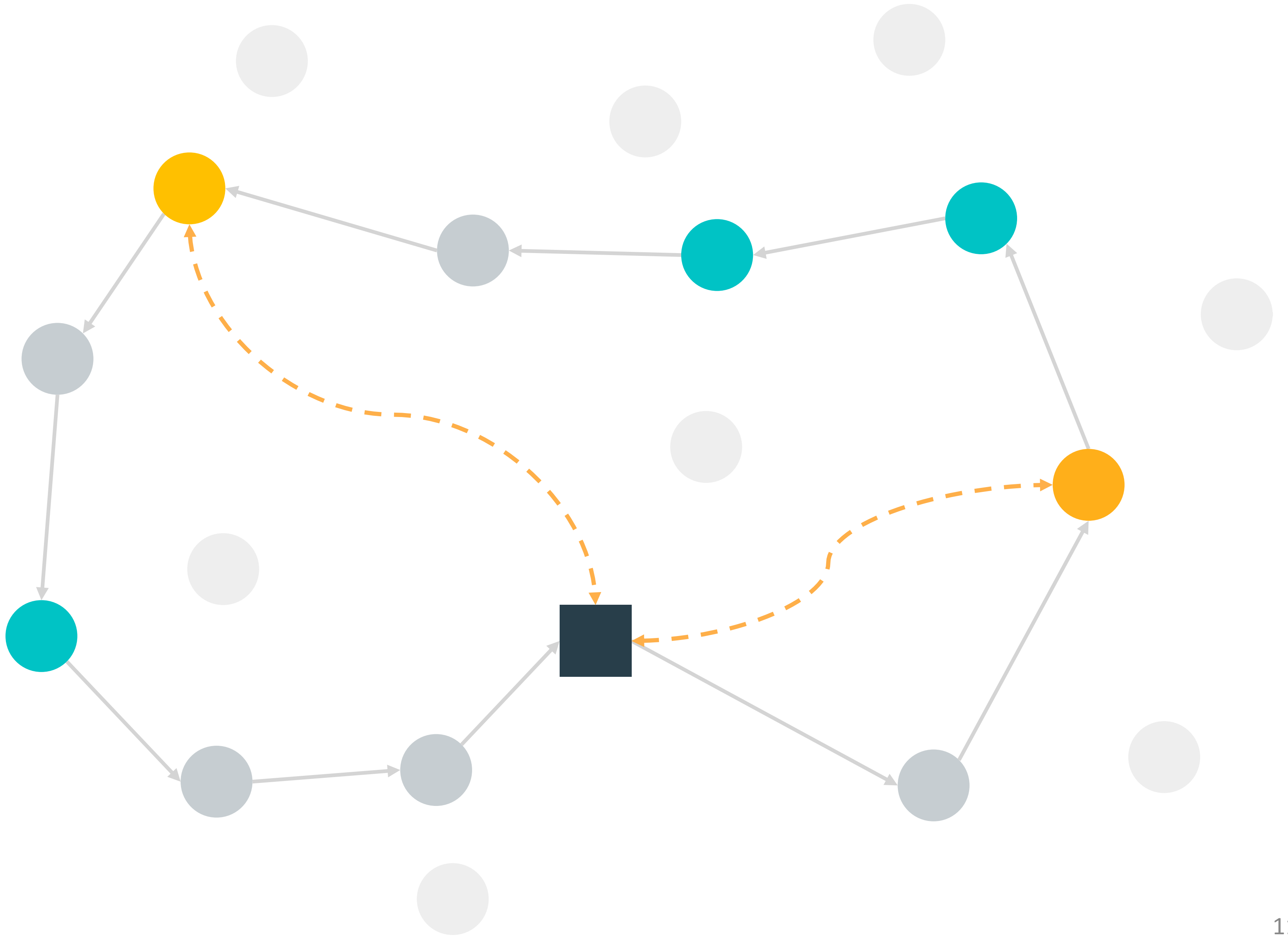
CONSTRAINTS

3

DRONE RESUPPLY:

Which orders?

Load capacity of drone



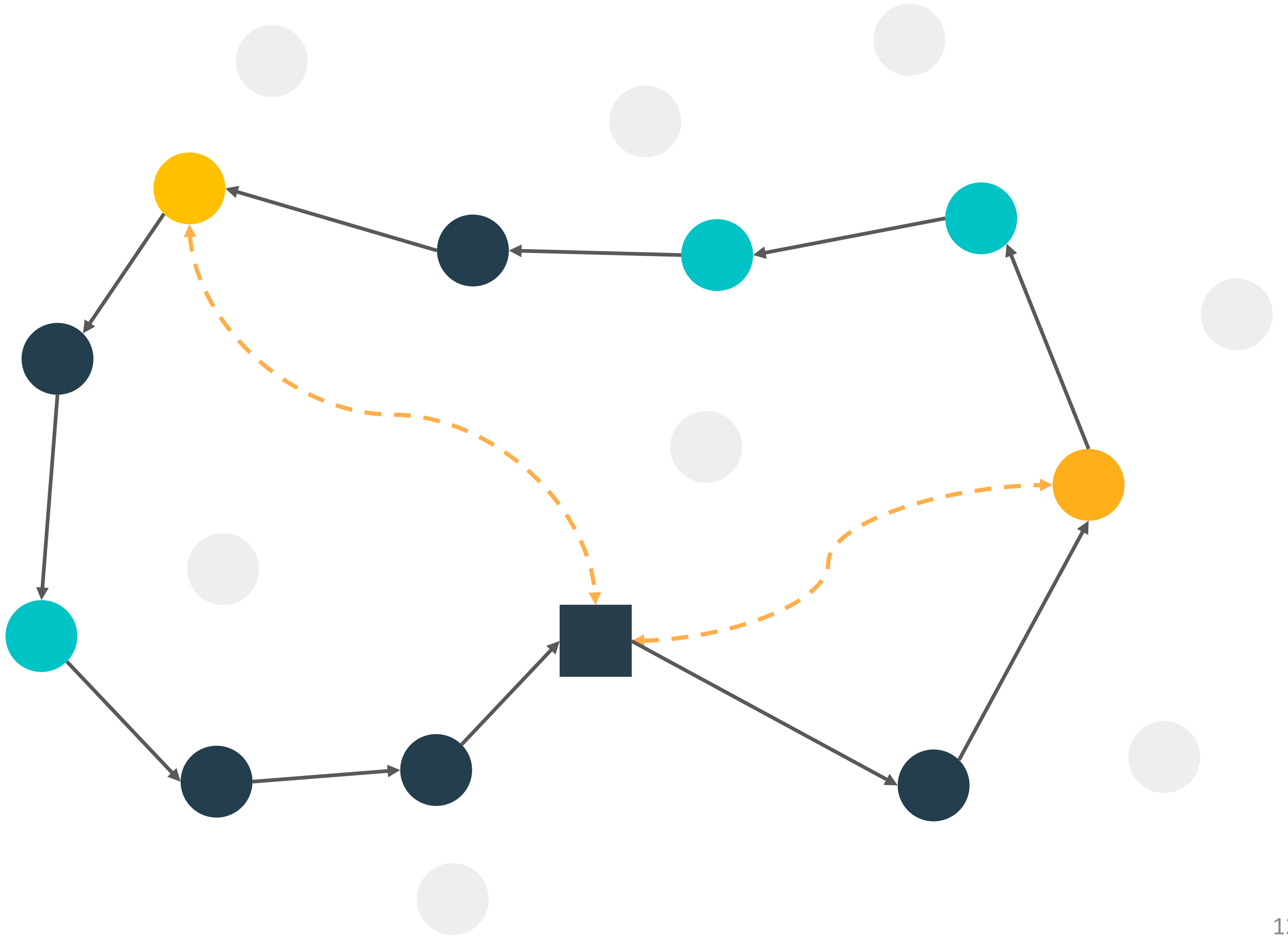
CONSTRAINTS

4

TIMING:

MTZ timing constraints

Synchronization of the routes

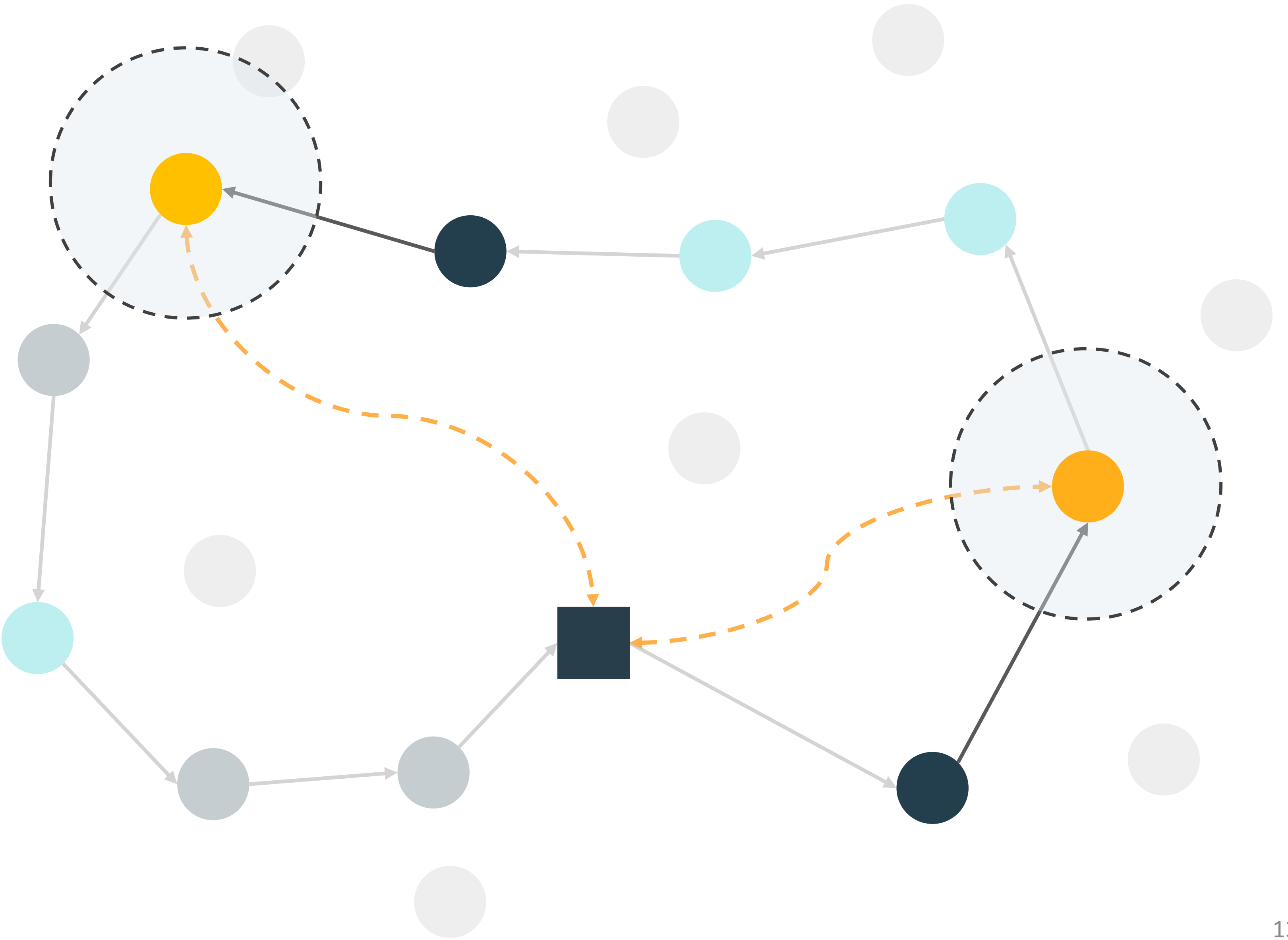


CONSTRAINTS

5

WAIT TIMES:

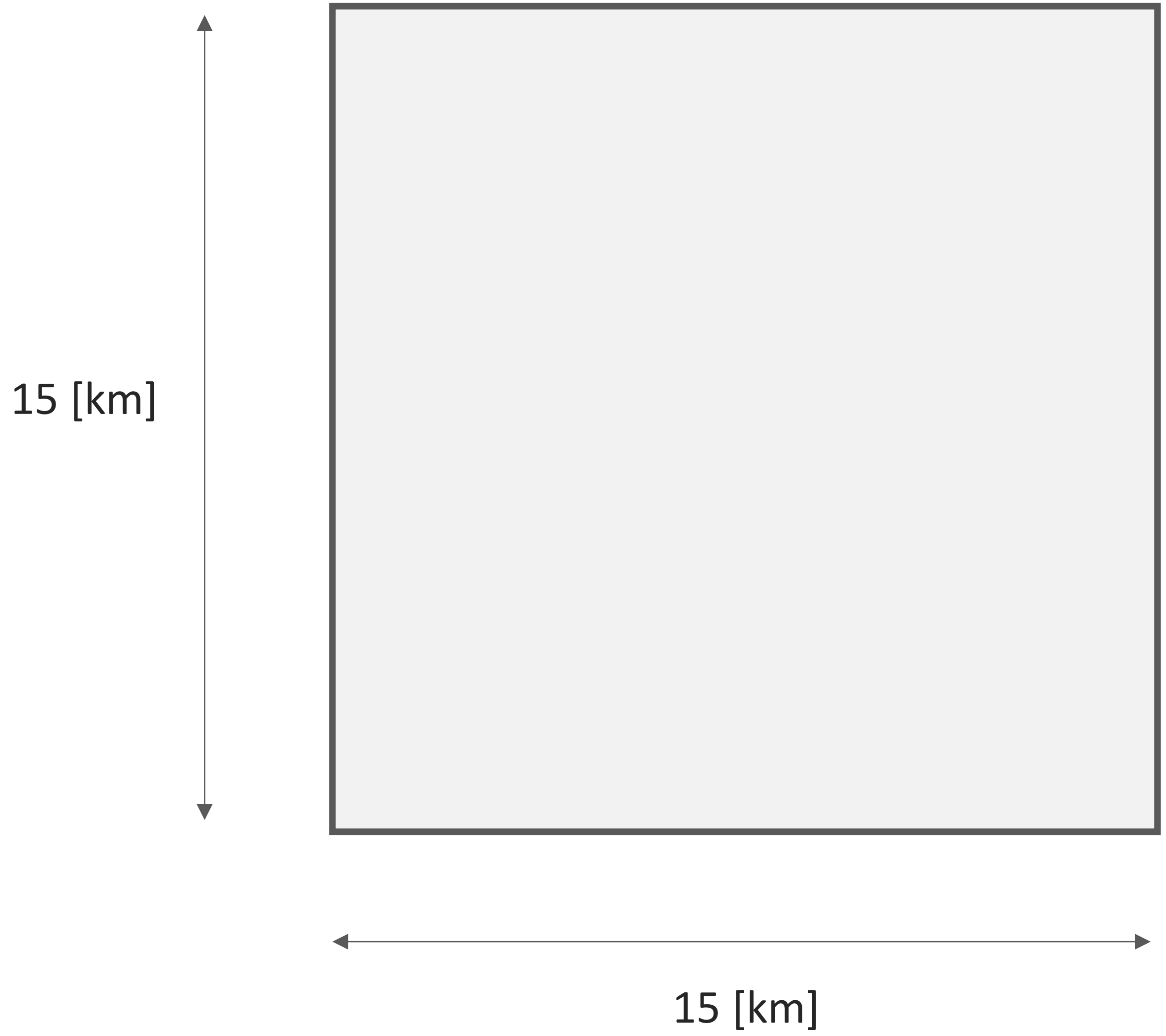
Elapsed time between arrival and departure of the truck at each node



COMPUTATIONAL EXPERIMENTS

- Programed in Java and use of CPLEX 12.8 for solving MIP models
- Intel(R) Xeon(R) Gold 5118 CPU @2.30 GHz (12 cores) with 64 GB RAM

INSTANCE GENERATION



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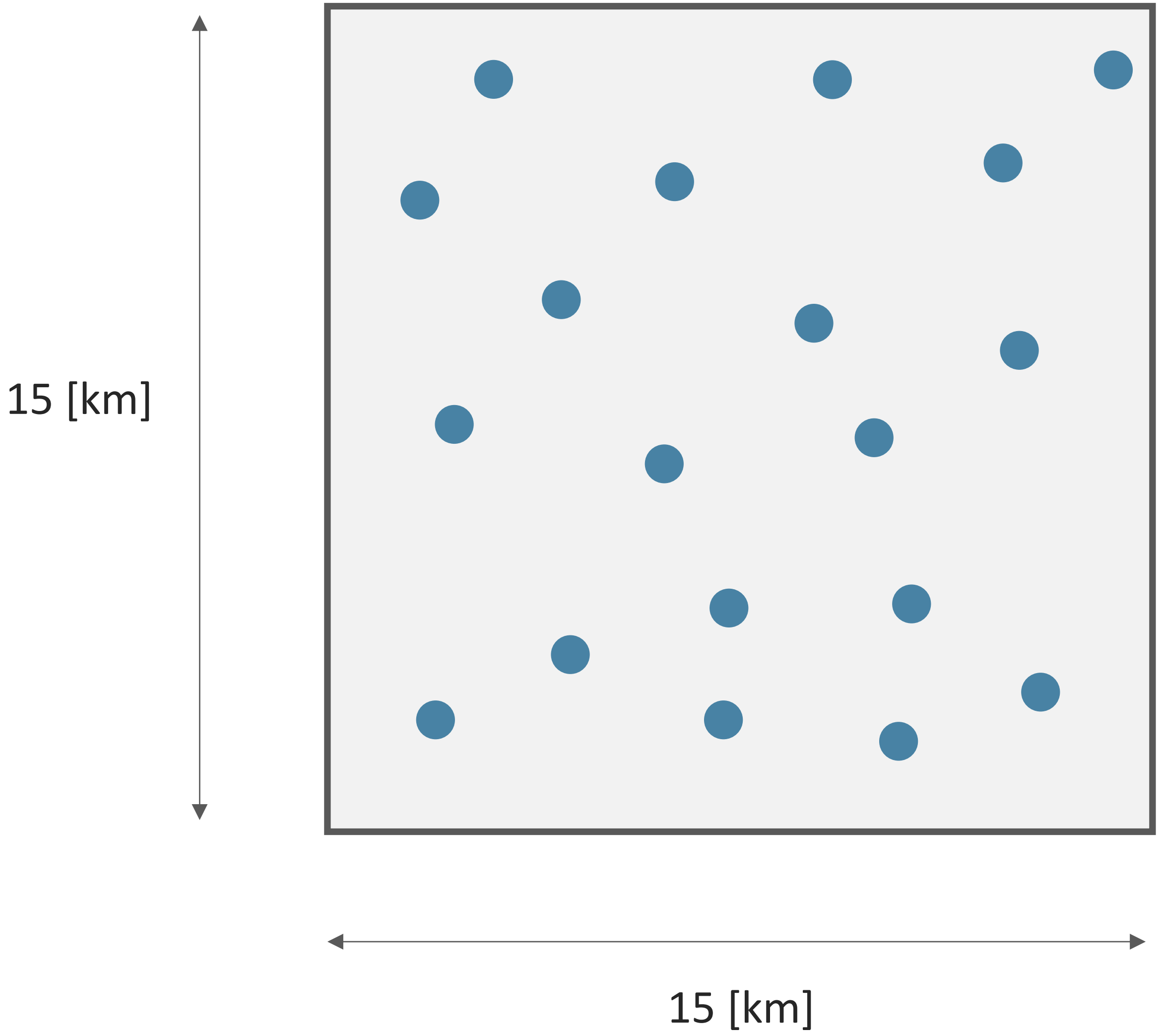

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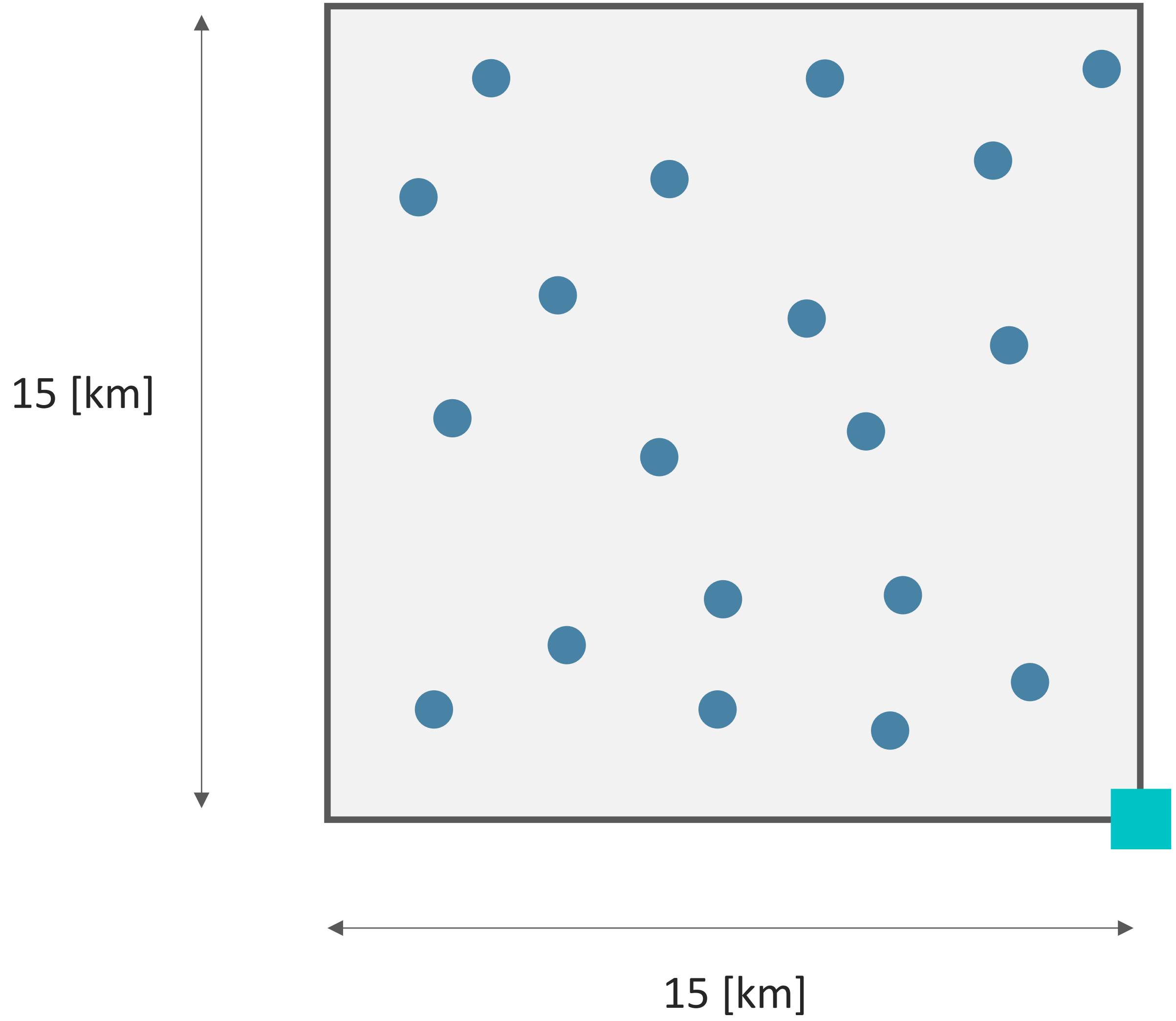

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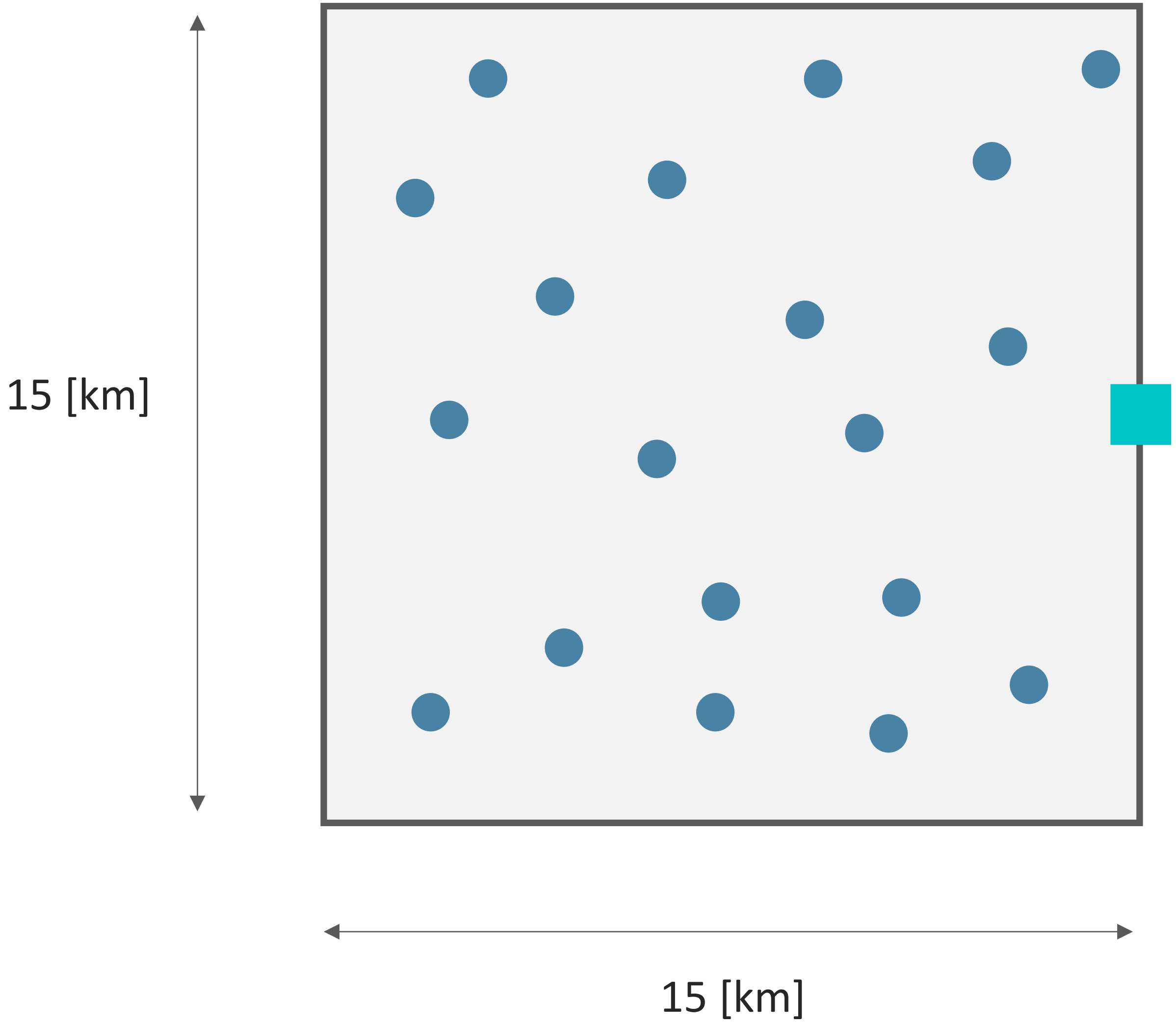

INSTANCE GENERATION

- 90 randomly generated instances of 10, 20, and 30 customers (30 for each size)
- Deliveries can be made between 8 AM and 6 PM
- Orders are only accepted until 4 PM
- All orders are the same size
- **Truck:** Speed of 30 km/hr and Manhattan distances
- **Drone:** Speed of 60 km/hr and Euclidean distances
- **Drone:** Flight endurance of 30 minutes and load capacity of 4 orders

MIP MODEL RESULTS

Table 1: Average results over the set of instances, considering a run-time of 30 minutes.

Layout	n	CPU	Cost	GAP	Fill-rate	Drone	Orders
Right	10	0.15	60.58	0.00%	100.00%	0.03	0.03
	20	99.82	82.65	0.01%	100.00%	0.70	1.53
	30	904.44	151.79	2.24%	98.22%	1.23	3.63
Corner	10	0.17	64.13	0.00%	100.00%	0.07	0.10
	20	115.54	88.04	0.00%	100.00%	0.83	1.87
	30	1226.00	241.26	4.53%	96.33%	1.13	3.23

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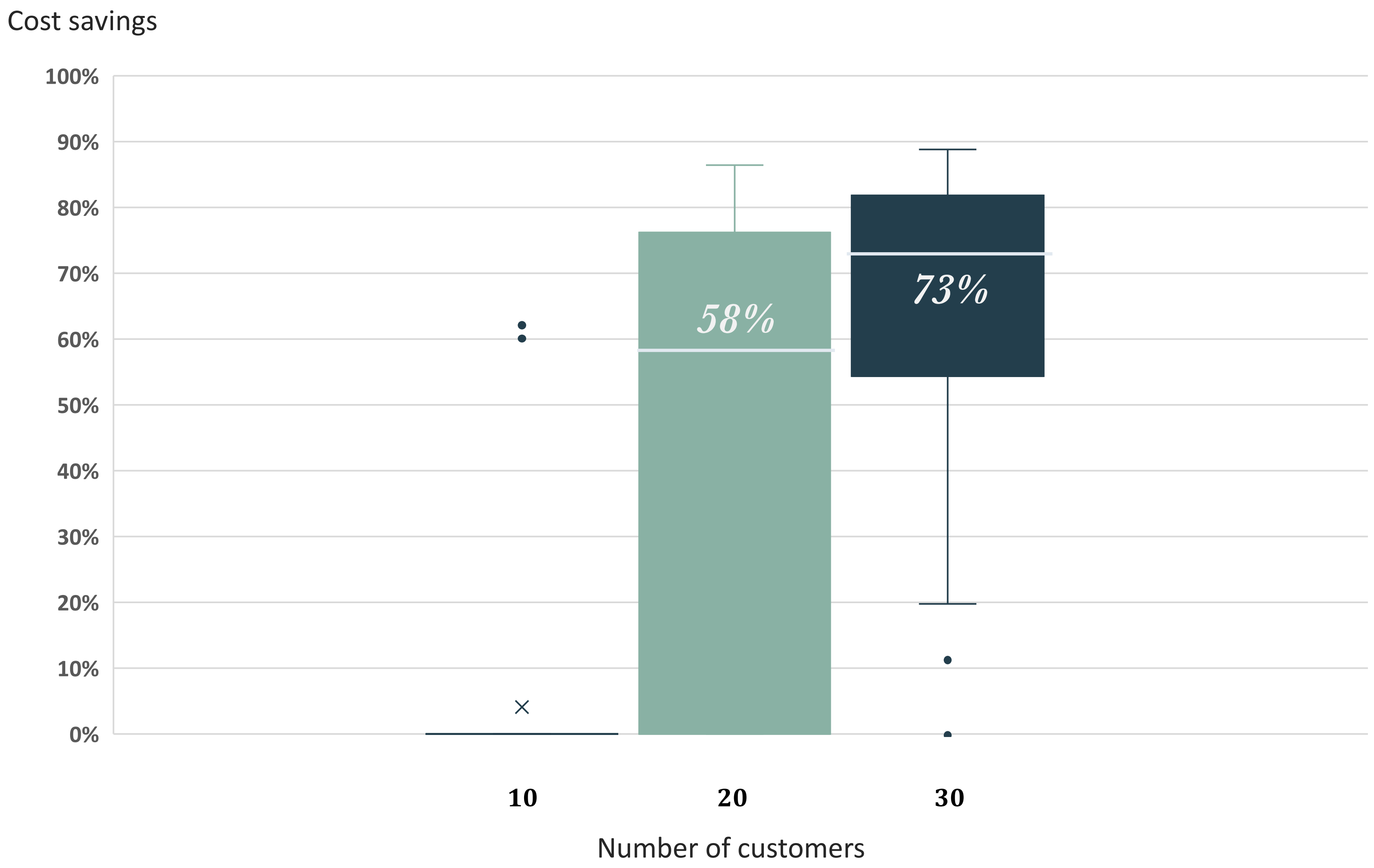
BENEFITS OF USING DRONES TO RESUPPLY VEHICLES

COMPARISON WITH A DELIVERY SYSTEM USING A TRUCK ONLY



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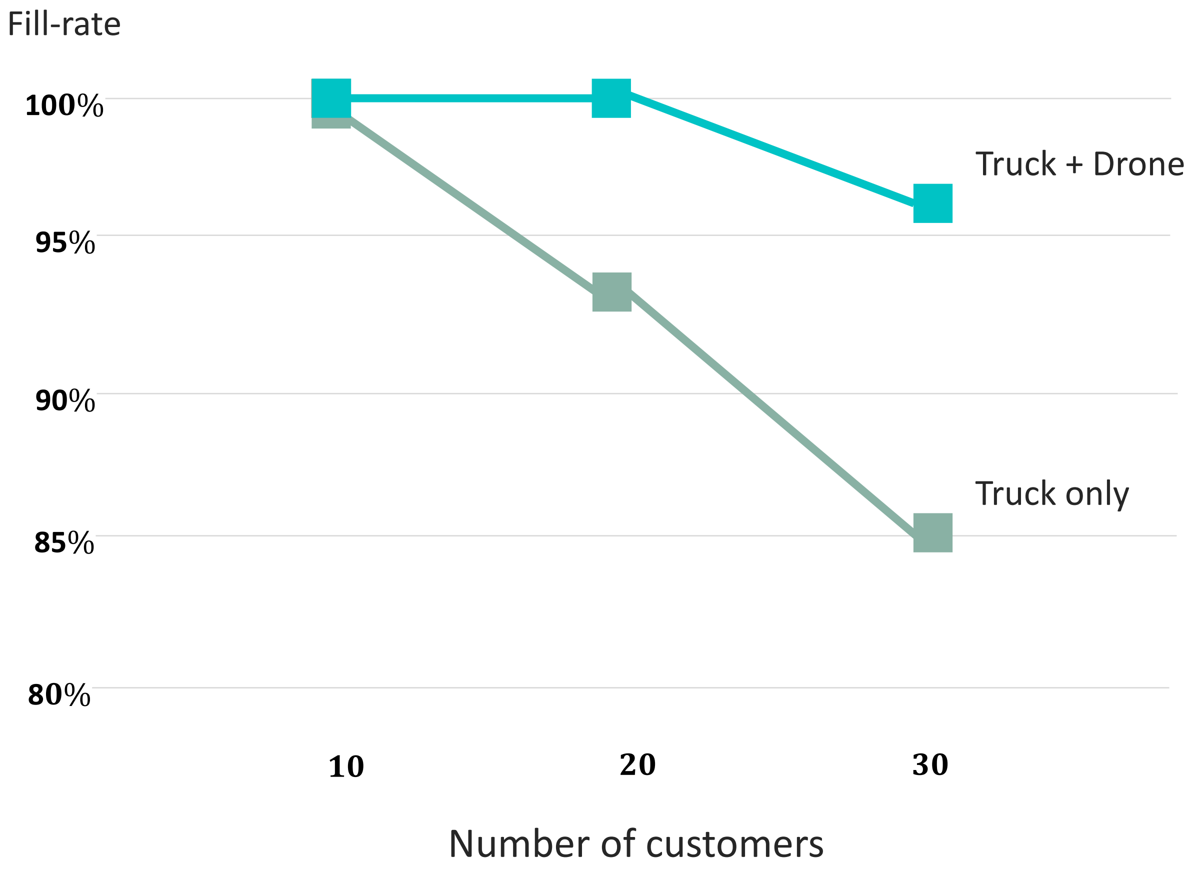
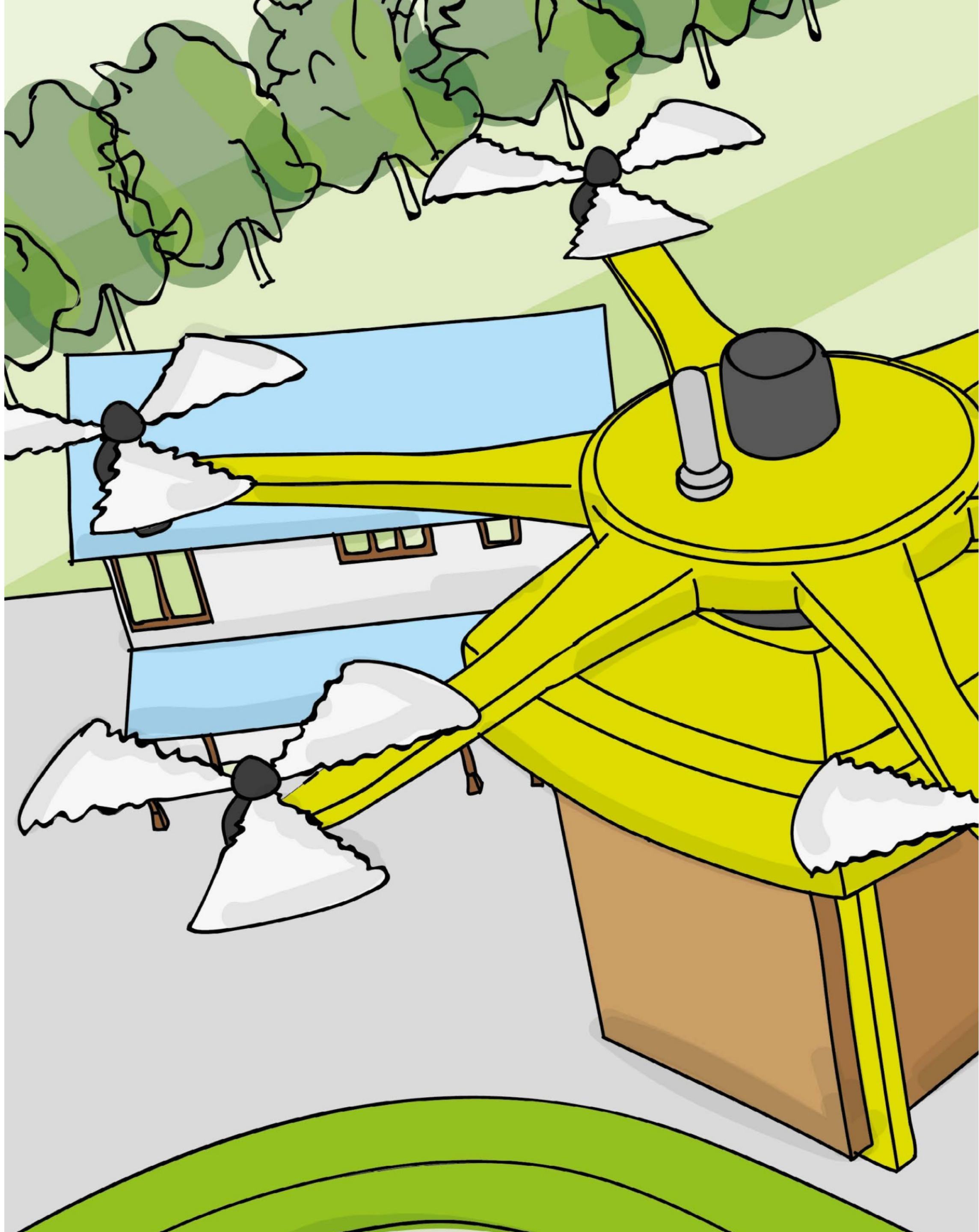


FILL RATE

CONCLUSIONS

- Using drones to resupply vehicles can significantly reduce distribution costs and increase the number of orders delivered
- The MIP model is able to provide good gaps after a few minutes
- Extensions of the problem include considering a fleet of vehicles and drones, multiple depots and different load capacities
- Heuristic approaches could be developed to solve large size instances



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This research was partially funded by **Toyota** Material Handling North America through their University Research Program

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Joers, M., Schroder, J., Neuhauss, F., Klink, C. & Mann, F. (2016). Parcel delivery: The future of last mile. Travel, Transport and logistic: Mckinsey & Company. Published online on URL: https://mck.co/2n4sABU

KEY CONCEPTS ADDRESSED

RELEASE DATES

Moment when orders become ready to dispatch

Cattaruzza et al. (2016)

Archetti, Feillet, and Speranza (2015)

DELIVERY USING DRONES

Use drones to reduce last-mile delivery costs

Murray and Chu (2015)

Otto et al. (2018)

DEADLINE

Selection of customers to be visited

Feillet, Dejax, and Gendreau (2005)

Laporte and Martello (1990)

Balas (1989)

DRONE RESUPPLY

Using drones to resupply dispatch vehicles

Dayarian et al. (2018)

McCunney and Van Cauwenberghe (2019)

BENEFITS OF USING DRONES TO RESUPPLY VEHICLES

Table 2: Comparison between the new delivery system and a delivery system using a truck only.

n	Full MIP Model				Truck Only Model			
	CPU	Cost	GAP	Fill-rate	CPU	Cost	GAP	Fill-rate
10	0.17	64.13	0.00%	100.00%	8.70	72.07	0.00%	99.33%
20	115.54	88.04	0.00%	100.00%	1269.53	260.62	7.90%	93.00%
30	1226.00	241.26	4.53%	96.33%	1747.81	657.70	18.96%	85.33%