SCM - 518 Analytical Decision Modeling

Last-Mile Delivery by the UAVs

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I. Motivation / Background Information

In today's world, each and every e-commerce company or transport company is looking to improve its last-mile delivery and make it more cost and time-efficient. We wish to test a prototype system that combines trucks and drones for last-mile delivery services. The test run considers a set of orders that must be delivered to known locations. A delivery truck starts from a depot and visits "launch sites" corresponding to the customers' locations. From each launch site, the truck deploys a series of drones (depending on the company's budget) that deliver the orders and return back to meet the truck at the launch site. Once all the drones are recovered, the truck moves to the next launch site and repeats the process until all orders are delivered.

II. Current Scenario

As per the current scenario, the majority of transportation and e-commerce companies are delivering the last mile deliveries as a door to door service to each customer. It is obvious that this would cost them a lot more in terms of transportation costs and manpower. There is a lot of uncertainty around products not being delivered to the correct location and the delivery being later than expected. We will be tackling this problem based on different scenarios.

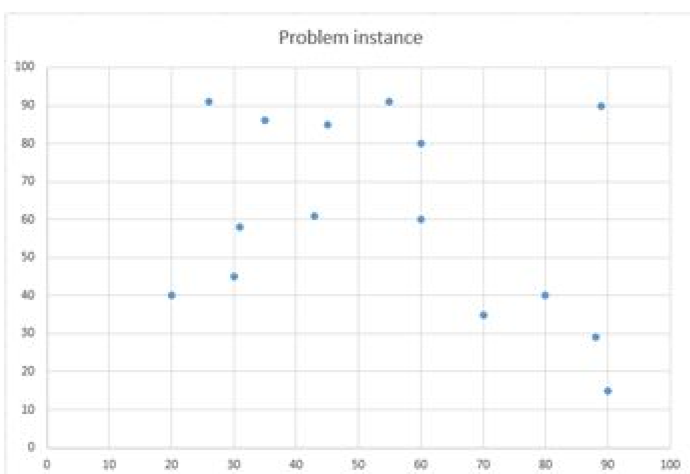
III. Dataset and Information

We have considered random data points for our customers on a plane.

Also, we have considered

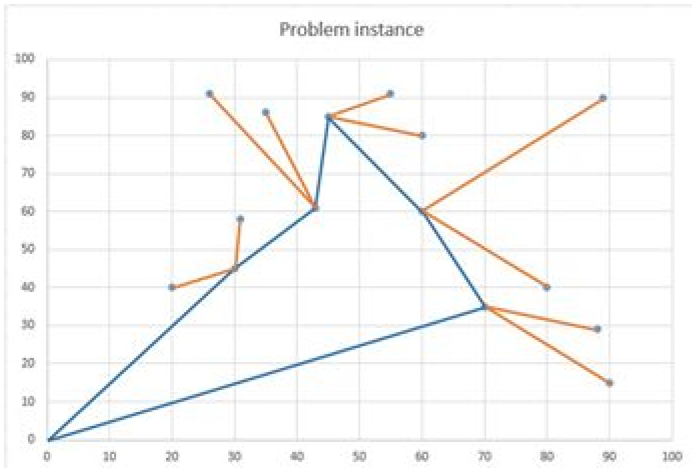
- We have considered that the warehouse is located at (0,0).
- To find the distance between two points on a plane we have used Euclidean distance.
- The truck must start and end at the warehouse.
- The truck can deploy up to K drones at each stop in a launch site.
- The drones have limited cargo capacity and as a result, they can only visit 1 customer (not counting the starting point) before returning to the truck.
- Each customer should be visited at least once by a drone. The customer locations used as launch sites will be visited by the truck and also will serve as the starting and ending point of a drone tour.

ID	x	y
0	0	0
1	28.33	78.71
2	99.05	3.96
3	89.87	87.24
4	97.26	26.03
5	15.70	46.08
6	7.05	44.21
7	45.59	68.26
8	39.41	61.24
9	26.46	24.32
10	87.63	78.42
11	92.54	61.71
12	96.76	1.08
13	20.28	18.68
14	0.95	12.25
15	10.03	1.88
16	29.36	26.25
17	67.40	18.36
18	71.32	65.94
19	76.37	71.94
20	28.65	41.88
21	48.23	19.26
22	14.00	97.63
23	67.84	4.10
24	10.32	12.92
25	15.65	45.78
26	17.92	0.34
27	51.13	34.02
28	42.75	3.09
29	9.72	78.21
30	5.76	63.78



IV. Solution Approach

We have considered only one warehouse and one truck to test the feasibility of the solution. The figure shows our solution approach.



Scenario - I

In this scenario, we have considered that as the company is a start-up and they do not wish to spend more on the last-mile delivery. Hence, we have considered the availability of a single drone with 30 customer locations. We have pre-decided that there would be 5 stop locations for a truck.

Distance covered by Truck	257.6380909
Distance Covered by Drone	1309.726463
Total Distance	1567.364554

Scenario - II

In this scenario, we have decided that a company can use k - number of drones based on the investment and requirement. We have decided to solve this problem with K=2 and 10 customer locations. Here we will be optimizing the time of the delivery. There might be a case where an organization wants to provide the utmost customer satisfaction and hence they are ready to spend a little more.

Total time	23.61255247
Truck time	3.501785797
Drone Time	20.11076668

Scenario - III

In this case, we have used the same number of drones and customer locations as scenario - 2. But our objective is changed to the distance traveled by truck and drones. We are focusing on optimizing the distance

truck distance	198.0218371
drone distance	405.3207958
total	603.3426329

V. Algebraic Model

Scenario I:

Parameters:

(x_i, y_i) : x and y locations of customer *i* respectively

(x_j, y_j) : start location of the truck = (0,0)

i ∈ {1,2…..30}
j ∈ {1,2…..5}

Decision:

(x_j, y_j) : stop locations x and y for truck *j* to stop *j* respectively

C_{ij} : customers *i* to be served at stop *j*

Objective:

Minimize distance = truck & drone

$$\sum_i \sum_j 2 \cdot \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} + \sum_{j=0}^{5} \sqrt{(x_{j-1} - x_j)^2 + (y_{j-1} - y_j)^2}$$

Constraints:

$C_{ij} \in \{0, 1\}\ , \forall j$ **:** binary

$(x_j, y_j) \neq (x_j, y_j)$: truck stops are different

$\sum_i C_{ij} = 1$: all customers can be delivered only once

<u>Scenario II:</u>

Parameters:

(x_i, y_i) : x and y locations of customer *i* respectively

(x_j, y_j) : start location of the truck = (0,0)

s_v : speed of vehicle *v*

i ∈ {1,2…..30}

j ∈ {1,2…..5}

v ∈ {1,2}

Decision:

(x_j, y_j) : stop locations x and y for truck *j* to stop *j* respectively

C_{ijk} : customers *i* to be served at stop *j* by drone *k*

k ∈ {1,2}

Objectives:

Minimize Time

$$\frac{\sum_{j=0}^{5} \sqrt{(x_{j-1} - x_j)^2 + (y_{j-1} - y_j)^2}}{\quad} + \sum_{j=1}^{5} max(td_1, td_2)$$

$$s_1$$

Calculated Variable: time taken by drone k

$$td_k = \frac{\sum_i \sum_j 2 \cdot \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}}{s_2}$$

Constraints:

$C_{ijk} \in \{0, 1\}$: binary

$(x_j, y_j) \neq (x_j, y_j)$: truck stops are different

$\sum_i C_{ijk} = 1, \forall k, \forall j$: all customers can be served only once

Scenario III:

Parameters:

(x_i, y_i) : x and y locations of customer *i* respectively

(x_j, y_j) : start location of the truck = (0,0)

s_v : speed of vehicle *v*

$i \in \{1,2.....30\}$
$j \in \{1,2.....5\}$
$v \in \{1,2\}$

Decision:

(x_j, y_j) : stop locations x and y for truck *j* to stop *j* respectively

C_{ijk}: customers *i* to be served at stop *j* by drone *k*

$k \in \{1,2\}$

Objectives:

Minimize Distance

$$\sum_{j}\sum_{i}\sum_{k} 2\cdot\sqrt{(x_j - x_i)^2 + (y_j - y_k)^2} + \sum_{j=0}^{5}\sqrt{(x_{j-1} - x_j)^2 + (y_{j-1} - y_j)^2}$$

Constraints:

$C_{ijk} \in \{0, 1\}$: binary

$(x_j, y_j) \neq (x_j, y_j)$: truck stops are different

$\sum_{i} C_{ijk} = 1, \forall k, \forall j$: all customers can be served only once

VI. Assignment matrix (Derived solution)

Drone	2
Truck speed	60
Drone speed	10

ID	x	y
1	92.54	61.71
2	96.76	1.08
3	20.28	18.68
4	0.95	12.25
5	10.03	1.88
6	29.36	26.25
7	67.40	18.36
8	71.32	65.94
9	76.37	71.94
10	28.65	41.88
Inputs		
Decision	493.67	
Calculated		
Constraints		
Objective		

Total time	22.8436335
Truck time	2.992406476
Drone Time	19.85122703

Truck location

location 1	X	Y		location 2	X	Y		location 3	X	Y		location 4	X	Y		locatio
distance	10.03163684	1.878558		distance	0.943269693	12.25403		distance	20.29512649	18.68005		distance	29.36143394	26.24564		distance
	distace	10.20601			distace	13.79307			distace	20.39088			distace	11.80831		
	time	0.1701			truck time	0.229884			truck time	0.339848			truck time	0.196805		

Customer for each location

customer distance from stop 1		Drone 1	Drone 2	customer distance from stop 2		Drone 1	Drone 2	customer distance from stop 3		Drone 1	Drone 2	customer distance from stop 4		Drone 1	Drone 2	custom
customer 1	203.8408366	0	0	customer 1	208.192962	0	0	customer 1	168.1797985	0	0	customer 1	144.9057359	0	0	custome
customer 2	173.4633933	0	0	customer 2	192.9307127	0	0	customer 2	156.926284	0	0	customer 2	143.8840305	0	0	custome
customer 3	39.36773548	0	0	customer 3	40.76291848	0	0	customer 3	0.020696887	0	1	customer 3	23.63103156	0	0	custome
customer 4	27.5706814	0	0	customer 4	0.022679948	1	0	customer 4	40.76047251	0	0	customer 4	63.33160466	0	0	custome
customer 5	0.005174473	0	1	customer 5	27.5908109	0	0	customer 5	39.38012152	0	0	customer 5	62.20900164	0	0	custome
customer 6	62.20603927	0	0	customer 6	63.35169633	0	0	customer 6	23.6166824	0	0	customer 6	6.55228E-05	0	1	custome
customer 7	119.3699402	0	0	customer 7	133.4648289	0	0	customer 7	94.20328052	0	0	customer 7	77.685936	0	0	custome
customer 8	177.3121865	0	0	customer 8	177.0310399	0	0	customer 8	139.0957799	0	0	customer 8	115.5170444	0	0	custome
customer 9	192.9649464	0	0	customer 9	192.3651664	0	0	customer 9	154.6686546	0	0	customer 9	131.1095335	0	0	custome
customer 10	88.246265	0	0	customer 10	81.13092489	0	0	customer 10	49.31826182	0	0	customer 10	31.29870155	0	0	custome
		0				1				0				0		
		1				0				1				1		

Drone time

		Drone 1	Drone 2			Drone 1	Drone 2			Drone 1	Drone 2			Drone 1	Drone 2	
distance 1	0.005174473	0	0.005174	distance 2	0.022679948	0.02268	0	distance 3	0.020696887	0	0.020697	distance 4	6.55228E-05	0	6.55E-05	distance
time 1	0.000517447	0	0.000517	time2	0.002267995	0.002268	0	time 3	0.002069689	0	0.00207	time 4	6.55228E-06	0	6.55E-06	time 5

VII. Possible Improvements and Conclusion

- Instead of fixing the number of stops for the truck, we can consider variable stops and derive that solution along with the assignment matrix.
- We have to consider that the stops we are deriving for a truck are feasible enough to be considered in a real-world scenario as a stop location.
- If required, we can vary the size of the drones and program the drones so that they do not come back to the truck and instead can fulfill multiple deliveries at the same time.
- From the solutions, we can derive that this particular can be very efficient for any organization in terms of time and cost.
- There are several other benefits as well if this can be implemented for delivering blood and medicine. From saving time and costs to reducing auto emissions and improving air quality.