Logistics Route Optimization

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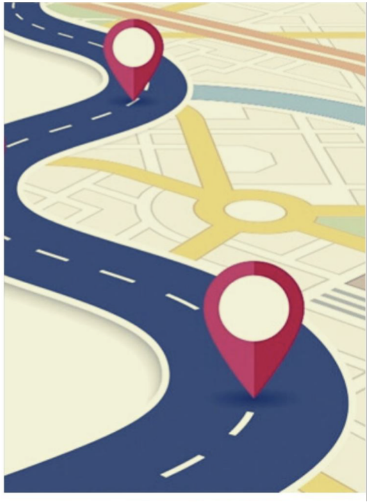
MITSloan MANAGEMENT



Agenda

- Problem & Objectives
- Methodology & Formulation
- Analysis & Results
- Conclusion & Recommendations

Current Logistics Operations

Pick-up and delivery of medical specimens from clients such as physician offices to the laboratory.

Problem Statement

Routes are structured to minimize the cost of logistics fleet and do not optimize for delivery time to the lab, resulting in:

- **Narrow time windows to process specimen**
- **Tight turnaround time to report back to clients**
- **Excess capital investment at the lab**
- **High production costs due to overtime wage**

Project Objectives

We aim to develop **an optimal route structure** through the construction and implementation of **an optimization model** in order to **prioritize earlier arrival of specimens to the lab over time**.

Data Cleaning + Visualization	Distance between Stops	Optimization Formulation
R + Tableau	Google Distance Matrix API (Javascript)	Julia + Gurobi

Data Processing

Raw Data

9 months, 1M+ line entries, 4k+ stops, 38 variables

Data Cleaning

Remove duplicate entries, weekends, outdated stops

Scope

100 stops within Boston Metropolitan area
(97 clients, 3 PSCs, 2 hubs, 1 lab)

Demand Calculation

Average daily demand per client
(no. of specimen)

Pick-up Time Windows

24/7 for PSC, least restrictive interval for clients.
Even distribution by hour

Travel Time

~5,000 travel time durations for 100 stops

Methodology & Formulation

Objective

$Minimize \sum_{i \in N_l} \sum_{h=19}^{24} (h-19)^2 \, del_{ih}$

Inputs

a_i: Earliest allowed arrival time to site i

b_i: Latest allowed arrival time to site i

t_{ij}: Time to travel from site i to site j

d_i: Quantity of samples to collect at site i

K: Maximum allowed routes to occur at the same time/in total

$limit$: Limit set on total time any route can run

$target$: Average number of specimens to be picked up daily

Decisions

$x_{ijk}: \begin{cases} 1, if\ connection\ from\ site\ i\ to\ site\ j\ is\ in\ route\ k \\ 0, otherwise \end{cases}$

$e_{jk}: \begin{cases} 1, if\ hub\ or\ lab\ j\ ends\ route\ k \\ 0, otherwise \end{cases}$

$g_{ik}: \begin{cases} 1, if\ client\ site\ i\ begins\ route\ k \\ 0, otherwise \end{cases}$

s_{ik}: Arrival time at site i on route k

q_{ik}: Total quantity of specimens picked up at site i by route k

del_{ih}: Total number of specimens delivered to lab i in period h

inv_{jk}: Total number of specimens delivered to hub j by route k

$y_k = \begin{cases} 1, if\ route\ k\ is\ chosen\ to\ be\ used\ in\ the\ model \\ 0, otherwise \end{cases}$

$z_{ikh} = \begin{cases} 1, if\ route\ k\ delivers\ to\ lab\ i\ in\ period\ h \\ 0, otherwise \end{cases}$

Methodology & Formulation

Constraints

$x_{ijk} \leq y_k, \forall i, j, k$ (1)

$\sum_k y_k \leq K$ (2)

$\sum_j \sum_k x_{ijk} = 1, \forall i \in N_c$ (3)

$s_{jk} - s_{ik} \leq limit, \forall i, j, k$ (4)

$\sum_{j \in N_c} x_{ijk} + \sum_{j \in N_h} x_{ijk} + \sum_{j \in N_h, N_l} e_{jk} = \sum_{j \in N_c} x_{jik} + \sum_{i \in N_c} g_{ik}$ (5)

$e_{jk} = \sum_{i \in N_c} x_{ijk} - \sum_{i \in N_h, N_l} x_{jik}, \forall, j \in N_h, N_l, k$ (6)

$g_{ik} = \sum_j x_{ijk} - \sum_{j \in N_c} x_{jik}, \forall i \in N_c, k$ (7)

$\sum_{j \in N_h, N_l} e_{jk} = 1, \forall k$ (8)

$\sum_{i \in N_c} g_{ik} = 1, \forall k$ (9)

$x_{ijk} = 0, \forall i \in N_h, j \in N_c, k$ (10)

$x_{ijk} = 0, \forall i \in N_l, j \in N_c, N_h, N_l, k$ (11)

$s_{ik} + t_{ij} - M(1 - x_{ijk}) \leq s_{jk}, \forall i, j, k$ (12)

$a_i \leq s_{ik} \leq b_i, \forall i, k$ (13)

Explanations

1) A connection in a route can only occur if the route exists
2) Limit on the number of routes that can be selected
3) Each client site is visited once and only once
4) Limits time duration of route (which in this case equals a car) to be less than or equal to a set number of hours
5) Conservation of flow in the network, so that samples picked up earlier in a route remain with that route throughout its run, given that the routes do not form a complete loop
6) This expression determines whether hub or lab j ends route k, since it will equal 1 if and only if there is a connection in the route to the hub/lab and no connection leaving that location
7) Determines whether client site i begins a route k
8) Routes must end at only one hub or the lab
9) Routes must begin at only one client site
10) Routes cannot travel from a hub to a client site
11) Cars cannot travel anywhere else after visiting a lab
12) Cars cannot reach another location in a route before traveling there
13) Each route must arrive within the set allowed times for each client or lab site i

Methodology & Formulation

Constraints

$a_{i\in N_l} = 19, b_{i\in N_l} = 25$ (14)

$\sum_k q_{ik} = d_i, \forall i \in N_c, k$ (15)

$q_{ik} \le M \sum_j x_{ijk}, \forall i \in N_c, k$ (16)

$\sum_{i\in N_l} \sum_h del_{ih} = target$ (17)

$\sum_h \sum_i z_{ikh} \le 1, \forall k$ (18)

$\sum_{i\in N_c} q_{ik} - M\left(1 - \sum_{i\in Nc} x_{ijk}\right) \le inv_{jk} \le \sum_{i\in N_c} q_{ik} + M\left(1 - \sum_{i\in Nc} x_{ijk}\right), \forall j \in N_h, k$ (19)

$inv_{jk} \le M \sum_{i\in N_c} x_{ijk}, \forall j \in N_h, k, inv_{jk} \ge 0, \forall j \in N_h, k$ (20)

$\sum_k q_{jk} = \sum_k inv_{jk}, \forall j \in N_h, k$ (21)

$q_{jk} \le M \sum_{i\in N_h, N_l} x_{jik}, \forall j \in N_h, k$ (22)

$-M(1 - z_{ikh}) \le s_{ik} - h \le M(1 - z_{ikh}) + 1, \forall k, i \in N_l, h$ (23)

$-M\left(1 - z_{jkh}\right) + \sum_k \sum_{i\in N_c, N_h} q_{ik} \le del_{jh} \le \sum_k \sum_{i\in N_c, Nh} q_{ik} + M\left(1 - z_{jkh}\right), \forall j \in N_l, h$ (24)

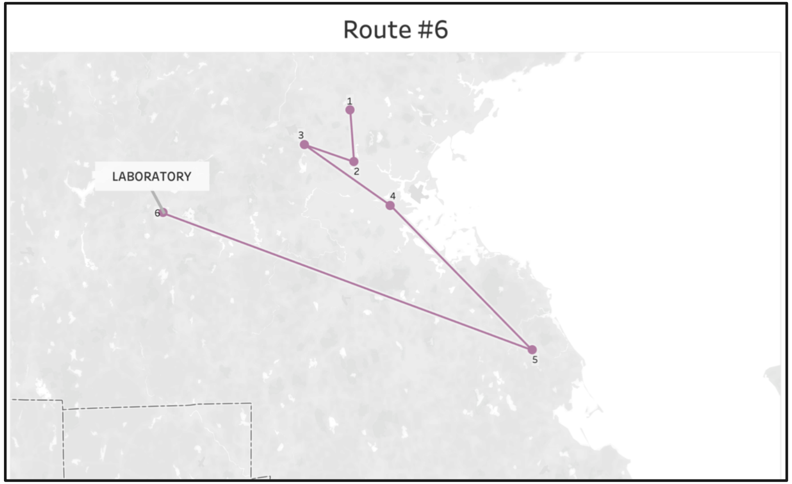
$del_{ih} \ge 0, \forall i \in N_l, h$ (25)

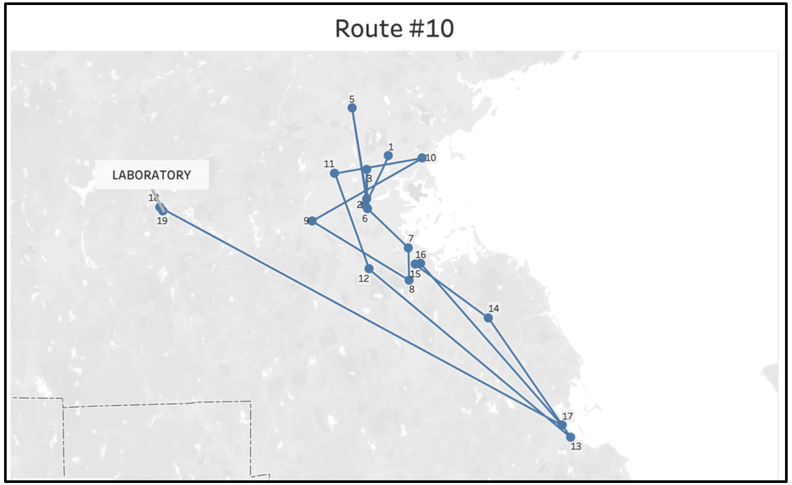
Explanations

14) Limits on when to deliver to lab (we cannot deliver before 7 pm or after 1 am)
15) Quantity picked up from each client site i by each route equals number of specimens available at that site
16) Routes cannot pick up samples unless they visit client site i
17) Number of samples delivered to labs must equal total number of samples to pick up
18) Each route can only deliver to the lab at most once
19) For a given hub, if the route visits that location, the inventory stored at the hub equals the sum of the samples picked up by the route from all client sites. Otherwise, it is unconstrained.
20) These constraints force the inventory at hub j from route k to be zero if the hub is not visited by the route
21) Quantity picked up from hub j equals amount delivered to hub j
22) A route cannot pick up samples from the hub if it is not visiting another hub or the lab at the end of the route
23) Setting value of z_{ikh} to be 1 if $0 \le s_{ik} - h \le 1$ and 0 otherwise
24) Setting value of del_{jh} based on whether samples were delivered in period h or not
25) Lower limit so the above constraint works correctly

Analysis & Results

Tested the model on 75 stops. Optimal solution constitutes 10 routes, using 10 cars.





Analysis & Results

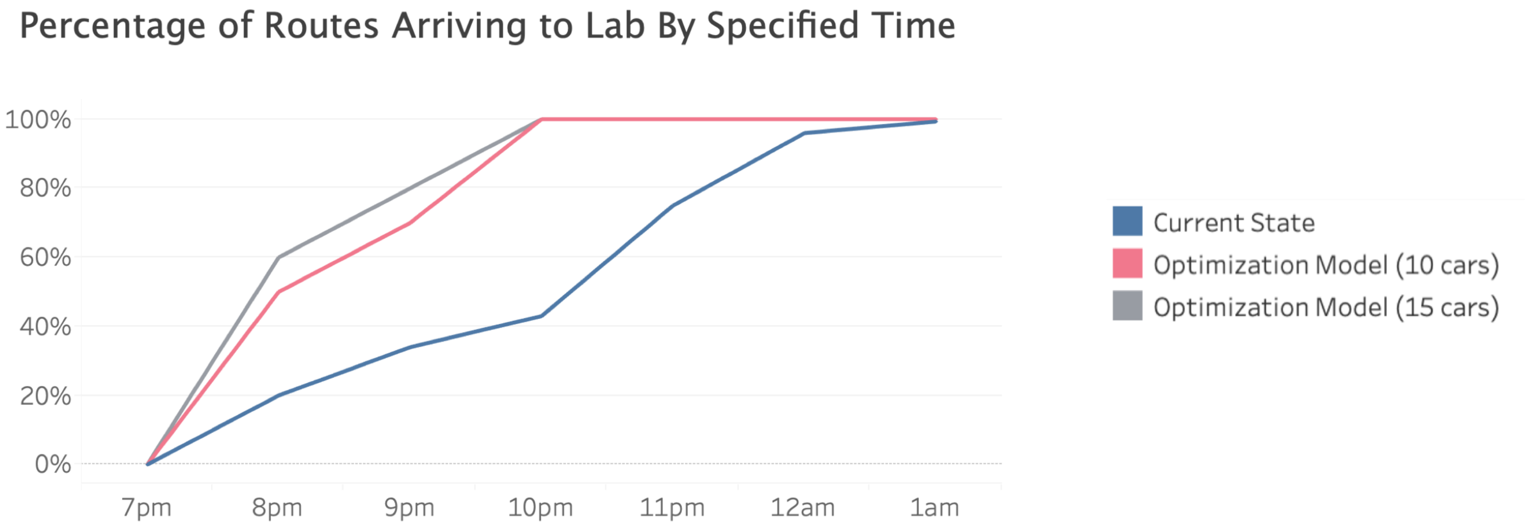
Sensitivity analysis can be leveraged to examine trade-off between logistic fleet costs and laboratory costs

Table 1 - Percentage of Routes Arriving to Lab After Specified Time

Time	Current State	Optimization Model (10 cars)	Optimization Model (15 cars)
8pm	77%	50%	40%
9pm	52%	30%	20%
10pm	46%	0%	0%

Analysis & Results

Sensitivity analysis can be leveraged to examine trade-off between logistic fleet costs and laboratory costs



Business Impact

- **Improved productivity** by optimizing schedules of laboratory staff
- **Reduced overtime costs** with potential for earlier shifts due to reduced variation in specimen arrival
- **Increased employee satisfaction** from reduced frequency of forced overtime for early morning hours
- **Optimized lab resources** due to earlier specimen arrival and better allowing for lean flow
- **Decreased required capital investments** by reducing max capacity requirements in the laboratory
- **Provided greater flexibility** of logistics fleet in start of route

Thank you!