An Empirical Study on Time-Dependent Delivery Route Planning

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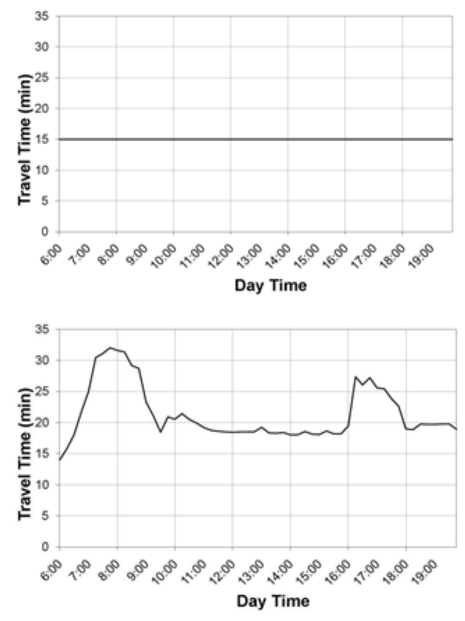
Introduction

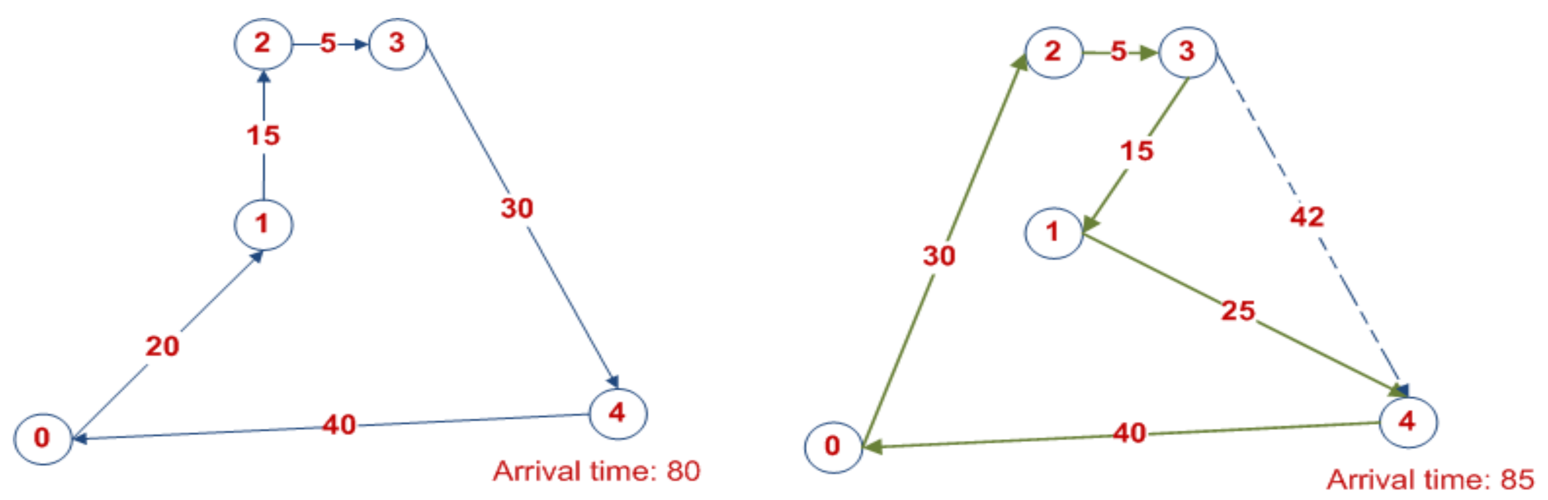
- The majority of delivery companies design truck routes based on the assumption that travelling times on road segments are constant.
- In the real world, travelling time on each road segment is time-dependent, where travel time is determined by arrival time.

AM vs. PM



Time-dependent Route Planning with Time-window Constraint

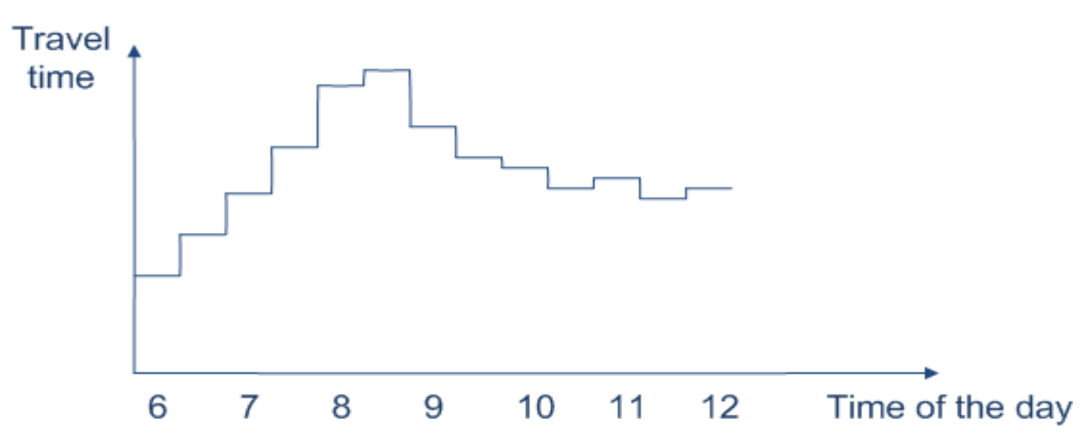
- Starting from node 0, the delivery vehicle need to visit customer 1 to customer 4 and come back to node 0 as early as possible.
- The time window for each customer is [10,90]. If the vehicles arrives at a customer earlier than 10 or later than 90, there will be a high penalty cost.



When the traveling time between customer 3 and customer 4 increases by 40% during peak time, static planning leads to an arrival time of 92 at customer 4, which violates the time window.

Modeling

- Divide a day to multiple periods. The arrival time determines the travelling time between two nodes.



- Decision variables:

$X_{ij}^{t}=1$ if link (i, j) is utilized by a vehicle at time t, $X_{ij}^{t}=0$ otherwise

T_i : time a vehicle leaves node i

Yu_i, Yl_i=1 if upper, lower time window at node i is violated; $Yu_i, Yl_i = 0$ otherwise

- Parameters:

K : number of available vehicles

P : penalty cost of violating time window

B : a large enough number

f : traffic data updating frequency

Sj : service time at node j

T_{ij}^{t} : travelling time on link (i, j) at period t

U_i, L_i : upper and lower time windows of customer i

Set C: set of depot and customers (depot is node 0)

Set M: set of time periods

Mixed-Integer Programming Formulation

- With an objective of minimizing total travelling time and penalty cost

$$Min \sum_{i,j,t} X_{ij}^{t} \cdot T_{ij}^{t} + \sum_{i} (Yu_i + Yl_i) \cdot P$$

s.t.

$$T_0 = 0$$

$$\sum_{t \in M} \sum_{j \in C, j \neq 0} X_{0j}^{t} \leq K,$$

$$\sum_{t \in M} \sum_{j \in C, j \neq i} X_{ij}^{t} = 1, \quad \forall i \in C, i \neq 0$$

$$\sum_{t \in M} \sum_{j \in C, j \neq i} X_{ij}^{t} = \sum_{t \in M} \sum_{j \in C, j \neq i} X_{ji}^{t}, \quad \forall i \in C$$

$$T_j - T_i - B \cdot X_{ij}^{t} \geq T_{ij}^{t} + S_j - B \quad \forall i,j \in C, j \neq 0, i \neq j$$

$$T_i + B \cdot X_{ij}^{t} \leq f \cdot (t+1) + B \quad \forall i,j \in C, i \neq j$$

$$T_i \geq f \cdot t \cdot X_{ij}^{t} \quad \forall i,j \in C, i \neq j$$

$$T_i - B \cdot Yu_i \leq U_i \quad \forall i \in C$$

$$T_i + B \cdot Yl_i \geq L_i \quad \forall i \in C$$

$$T_i \leq U \quad \forall i \in C$$

$$X_{ij}^{t}, Yu_i, Yu_i = 0/1 \quad \forall i,j \in C$$

$$T_i \geq 0 \quad \forall i \in C$$

- Formulation inspired by Malandraki and Daskin (1992)
- Different objects could be used, for instance, maximizing the number of customers visited before 12pm, minimizing the number of delivery routes, etc.

Solution Strategy

- Time-dependent vehicle routing problem is NP-hard.
- Optimization software like CPLEX could solve small problem cases with less than 8 nodes and 20 time periods optimally.
- Heuristics have been proposed to solve large problem sets efficiently, including
  - Nearest-neighbor
  - Mathematical-programming-based heuristic
  - Genetic algorithm
  - Tabu search
  - Local search

Experiments

Dataset:

•Los Angeles road network with 304,162 edges, and 258 typical delivery customer zones

•Time-dependent edge travel-times are generated based on two years of historical data collected from 6300 traffic sensors. The sampling rate of the data is 1 reading/sensor/min.

•Sensor data is spatially and temporally aggregated by assigning interpolation points (for each 5 minutes) that depict the travel-times on the edges

•Static path and time-dependent shortest path between any two nodes was pre-computed using our previous research method

Evaluation:

For randomly selected sets of customers, find the optimal objective using CPLEX 12.3

a) Time-dependent route planning and its corresponding object cost TT*

b) Static planning with real-world travel time and its corresponding object cost TT

c)report TT/TT*-1

Conclusion and Future Work

- Time-dependent planning reduces time window violations, increases the number of customers visited and reduces the number of delivery vehicles
- Time-dependent vehicle routing is NP-hard. Designing efficient heuristics is important to test on large empirical cases and provide good schedule for delivery companies.

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