Towards m-Traveling Salesmen Problem in Time-dependent Road Networks

Lian Liu, Ugur Demiryurek and Cyrus Shahabi

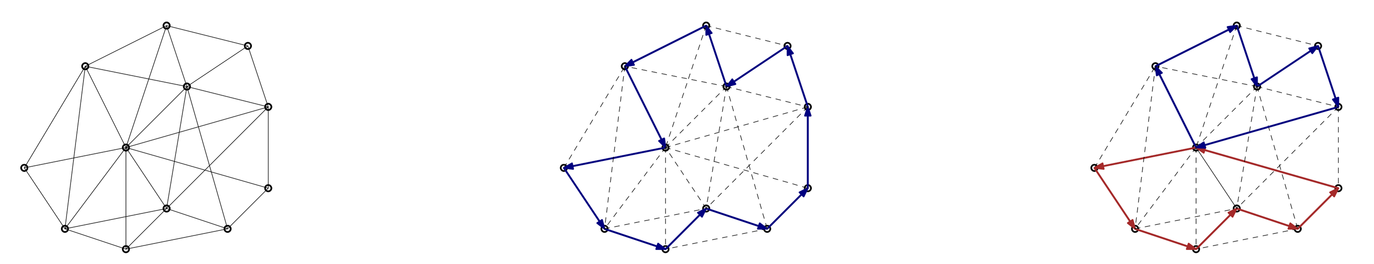
Integrated Media Systems Center

University of Southern California

Icampus ✓ IWatch CT ✓

Introduction

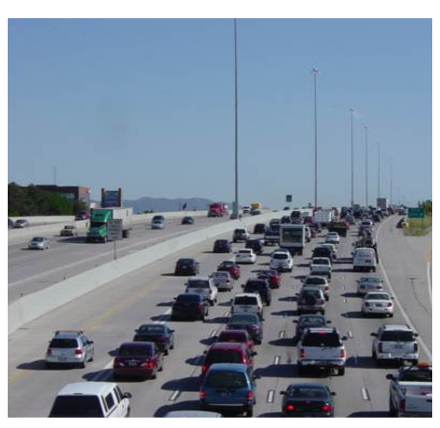
- *Traveling Salesman Problem* (TSP): Given a set of cities and their pairwise distances, find the shortest possible route for a salesman such that each city is visited exactly once and finally returns to origin.
- *m-Traveling Salesman Problem* (m-TSP) is an extension of TSP where multiple salesmen are involved.
  - Each node is visited by at least one salesman;
  - The total traveling time of each salesman is ≤ h, where h is a pre-defined parameter

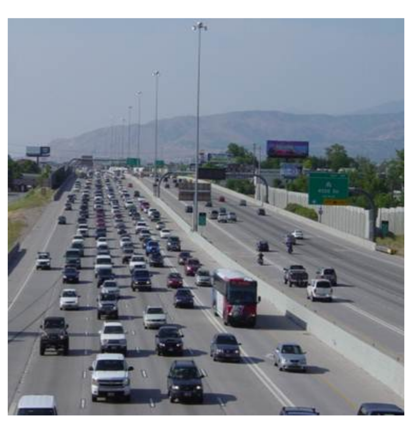


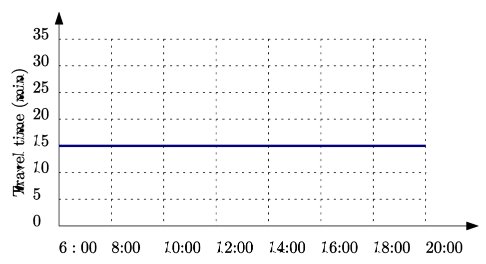
Road network **TSP** **m-TSP**

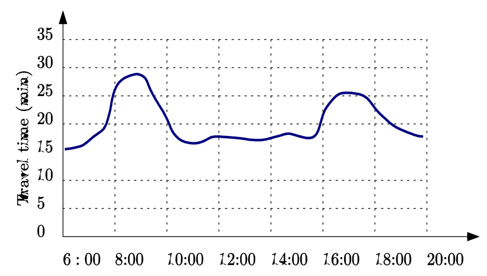
Time-dependent m-TSP

- Time-dependent m-TSP is a variant of m-TSP in the sense that optimal routes are computed in the context of a *time-dependent road network* instead of a static road network.
  - A time-dependent road network is a road network where the traveling time of the road segments varies with time.









Challenges

- m-TSP is an NP-hard problem, which derives directly from the NP-hardness of TSP.
- Difficult to find a solution to an NP-hard problem that is both optimal and efficient.
- Challenges also arise from time-dependency:
  - Unpredictability of future traffic condition. We solve this problem was solved by analyzing historical traffic information and using this knowledge to predict future traffic data.
  - Expanded search space. Since the time dimension is added to shortest path computing, we will have a much larger search space. It was proved that there might be an exponential number of shortest paths when traffic condition changes with time (Foschini et al, SODA'11).
  - Existence of multiple shortest paths. The shortest path also depends on the departure time from the source.

Problem size	50	60	70
Easy problem	0.0025 seconds	0.0036 seconds	0.0049 seconds
NP-hard problem	3855 centuries	2×10^8 centuries	∞

Related Work

- Time-dependent shortest path computation
  - First solved by Dreyfus (JOR'69) with a variant of Dijkstra's algorithm.
  - First attempt on time-dependent k-NN query processing: Demiryurek et al, (DEXA'10).
- Traveling salesman problem
  - Fist defined in 1800s by mathematicians W. R. Hamilton and Thomas Kirkman.
  - First approximation algorithm proposed by Christofides, H. (1976) where the approximation ratio is upper bounded my 1.5.

Algorithm

- Due to the NP-hardness of time-dependent m-TSP, we focus on an approximation solution using greedy approach.

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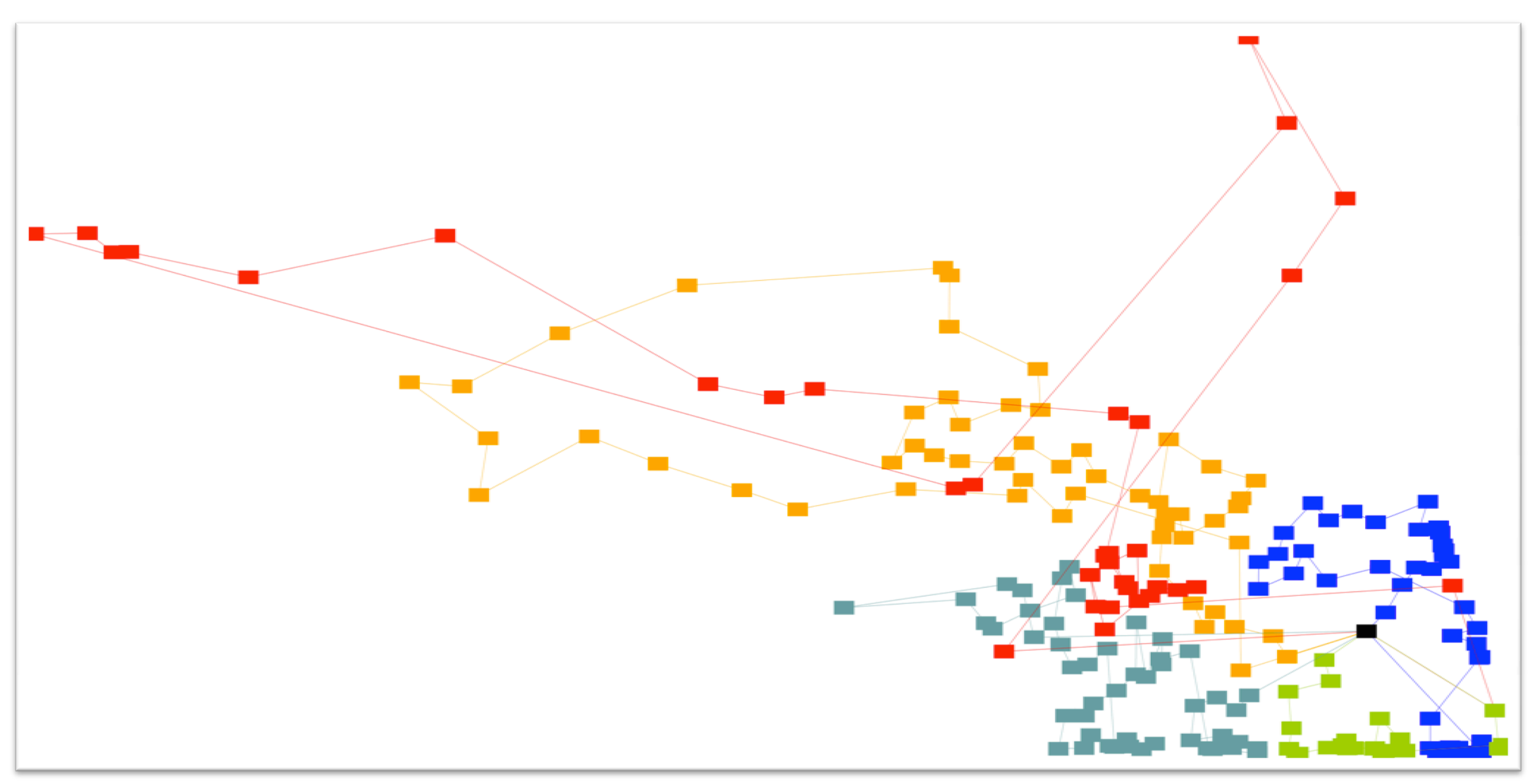
Algorithm: m_TSP(G, C, c0)
Input: Road network G (V, E). Delivery centers C ⊆ V. Origin c0 ∈ C.
Output: S, a set of salesmen with their routes.
1: S ← {};
2: while C is not empty;
3:     add_salesman(S, C, c0);
4: return S;
```

```
Algorithm: add_salesman(S, C, c0)
Input: S a set of salesmen. C a set of delivery centers. Origin c0.
Output: null.
1: s ← a salesman and his route r ← {c0};
2: c ← the closest delivery center to c0 in C;
3: while c can be added to r without violating time constraint
4:      r ← r ∪ the path from c0 to c;
5:      C ← C – {c};
6:      c ← the closest delivery center to c in C;
7: S ← S ∪ {s};
```

Experiments

- Dataset
  - Los Angeles road network with ~1.5×10^5 nodes and 258 delivery centers.
  - Time-dependent edge travel-times are generated based two-years of historical data collected from 6300 traffic sensors. The sampling rate of the data is 1 reading/sensor/min.
- Evaluation
  - How much total transportation time is saved (hours) by time-dependent shortest path planning compared with traditional shortest path planning.
  - Average time for computing delivery routes: ~150 seconds.
  - Experiments show that in average we need ~1-2 less drivers to cover all LA delivery centers by using time-dependent route planning instead of static route planning.



Conclusion

- Time-dependent m-TSP is a variant of m-TSP, where the traveling time depends on not only the distance but also the traffic condition of the roads that varies with time.
- Time-dependent m-TSP is more general and realistic approach than traditional m-TSP; time-dependent route planning saves ~25.9 hours' total delivery time compared with static route planning that does not consider time dependency.
- m-TSP is NP-hard. It takes a intolerably long time to find the optimal routes. Therefore, we focus on approximate solutions using a greedy approach.