RI14001, 17 January 2014 Computer Science

IBM Research Report

Challenge: Loosely Synchronized Multi-Modal Plans for Traffic Improvement and Commuter Convenience

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Challenge: Loosely Synchronized Multi-Modal Plans for Traffic Improvement and Commuter Convenience

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Abstract

We pose an innovative problem of how citizens should commute in a city which balances their need for convenience with the city's need for streamlined traffic flow. Towards solving the problem, we discuss promising AI techniques, provide sample data and explain the process of how to generate it from more public sources.

Introduction

At a general level, the traffic problem is understood as a situation of mismatch between supply (i.e., roads and their capacity) and demand (i.e., travel needs). When this mismatch increases past a tolerance threshold, city administrators tend to respond by creating infrastructures (e.g., new roads, expanding capacity) or policy changes (e.g., banning traffic movement during major games)(et al 2009), but ignore the critical *optimization* dimension to the problem.

Recent work(Srivastava 2011) suggests that traffic management is best viewed as a dual objective problem of minimizing resources for both the public (e.g., roads, traffic police personnel) and private citizens. Some examples of the overall problem are: (*P1*) For a given day, minimize overall time covered by citizens on road networks while minimizing individual commute time, and (*P2*). For a given day, minimize overall distance covered by citizens on road networks while minimizing individual commute time. While the benefit of saving citizen's time may be obvious, the benefit of saving overall time or distance is that it helps the city reduce its traffic pollution, traffic management cost and save current supply (infrastructure) for future demand. It is also imperative that the two sets of objectives *align*, i.e., that the optimization of public resources does not lead to sub-optimal travel plans for individual road users or vice versa. Not only can the two objectives be in conflict, but also further compounding the issue is the fact that private resources are fragmented down to the level of individuals, which may lead to conflict between every citizen's desire to optimize their resources.

The aim of problem solving is to find customized optimal travel plans for individuals (in the city) while also optimizing its public resources. The promise is that it will minimize the overall carbon footprint of traffic, reduce congestion, offer useful, context-sensitive route planning advice to individual users and generally improve the overall traffic situation in the city.

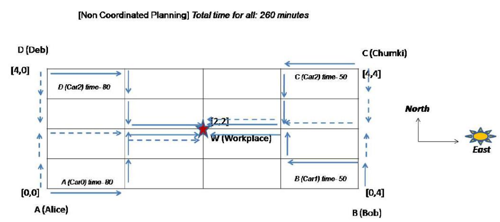

Figure 1: Non-coordinated planning in the example. Two sets of plans are shown with solid and dotted lines.

Illustrative Example

Consider the example in Figure 1.A small region has its road network as a 5x5 grid. There are four travelers in the region, A, B, C, and D who live as shown on the map. Their workplace is W[2,2].

The commuting constraints are: (1) Speed of all travelers, by default, is 1 hop (traversal of a single edge on the grid) per 10 minutes. (2) Speed is reduced by half if sun is on the face while commuting. (3) If two persons travel on the same road, their speeds reduce by half. (4) The two slowing factors work independently.

Hence, the time taken from [0,0] to [0,1] is 20 minutes in the morning, and 10 minutes for the rest of the day. If two people go from [0,0] to [0,1] in the morning, both will take 40 minutes. All travelers can independently plan their daily routes to work in the morning and back to home, using their favorite planning strategy. We call this *un-coordinated travel planning* (UTP). Figure 1 shows two plans for UTP by the 4 persons. In the first one in solid lines, total travel time for everyone is 260 minutes, while individually, A and D take 80 minutes, and B and C take 50 minutes. In the second plan in dotted lines, total travel time for everyone is 320 minutes, while individually, A and D take 100 minutes, and B and C take 60 minutes.

Figure 2 highlights the potential of coordinated planning, with the total travel time for everyone now reduced to 200 minutes, while individually A and D see

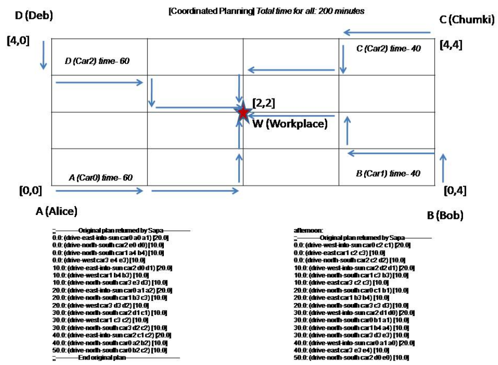

Figure 2: Coordinated planning in the example; also shown is the planner output.

a reduction of their one-way commute by 20 minutes each, and B and C by 10 minutes. While optimal individual and global plans might be serendipitously arrived at in UTP mode, one may obtain these plans in a more systematic manner.

Problem

We now introduce our problem setting formally. Consider the general scenario:

- A city has a non-negative population of p.
- There are n non-negative traffic points (nodes) where one can start or end his visits in the city.
- The road network is given by $n \times n$ matrices R_d, R_s and R_t, giving the distances, achievable speed and likely travel time between traffic points they connect, respectively. Only R_t changes over the day based on traffic severity.
- There are r number of uni-directional roads edges in the city.
- Every person who plans to travel in the city independently starts his PDA and enters the start and end locations of his journey, and the preferred start time or destination arrival time. This creates a travel planning problem instance p^i.
- The PDA gives a set of alternatives S^i that is considered applicable for the person in terms of route. S^i includes the top recommendation denoted by s^i_*. The option a person selects is unknown.
- It is known that in the aggregate, the top recommendation of PDA for individual i, s^i_*, is accepted by all citizens with a probability ρ.
- The city updates matrix R_t, the likely travel time between traffic points on city's roads.

  Now, traffic problem occurs in the following way.
- Every hour, a subset (fraction $k.p$) of the city's population travels between random traffic points (x, y) on the city's road network.
- City planners have objectives for managing traffic while travelers have their own commuting objective.

1. Public objective: Minimize the time (or distance) for $k.p$ trips every hour. That is, $min \sum_{k.p} time(s^i_*)$ (or, $min \sum_{k.p} distance(s^i_*)$) referred by *P1* (and *P2*) earlier.
2. Private objective: $\forall i, min(time(s^i_*))$.

The formulation handles a single mode of transportation on roads. It is straight forward to extend it to additional commute modes on the road network or consider additional networks (e.g., rail).

Discussion: Towards Solution

Solving the basic problem described above can be attempted in multiple ways using AI techniques. For illustration purposes only, we outline three directions: (1) planning, (2) mechanism design, and (3) reinforcement learning.

Planning

The field of AI Planning is an obvious candidate since it looks at automatic techniques to take an agent from initial to goal state, given the valid actions as input. We illustrate two ways the travel plans, S^i, may be created on the PDA.

Centralized coordinated travel planning (CCTP) problem: 1. Whenever p^i is created, the PDA sends it to a central server which has the latest R_t (in addition toR_d, R_s). 2. The central server returns S_i to (PDA of) person i. 3. Note: the city does not have to broadcast R_t and the central server can provide the top recommendation s^i_*, instead of the complete set of alternatives.

Decentralized coordinated travel planning with coordination via central server (DCTP) problem.

1. The central server broadcasts R_t every ϕ minutes to the PDAs. 2. Whenever p^i is created, the PDA produces the set of recommended travel plans S_i. 3. The PDA informs the central server about s^i_*, the top alternative the person i had. 4. The central server updates the R_t, R_d and R_s matrices based on the s^i_* that it receives. 5. Notes: broadcast of R_t by city and sending back of s^i_* is critical.

Mechanism Design

A way to generate S^i and ensure the commuters choose s^i_* is by designing a mechanism that takes private utilities of commuters into account and incentivises optimal behavior. Let $\theta_i = (n_s, n_e, v_1, \ldots, v_{24})$ denote the private information of commuter i, where n_s is the starting point, n_e is the end point, and v_k are valuations that commuter i derives by starting in each of the 24 one hour window of day. In a basic mechanism, each commuter would report her private information to the city and the city would allocate a route as well as a starting time to each commuter. Advanced methods will consider dynamic allocation and flexible incentives(Bergemann and Valimaki 2010).

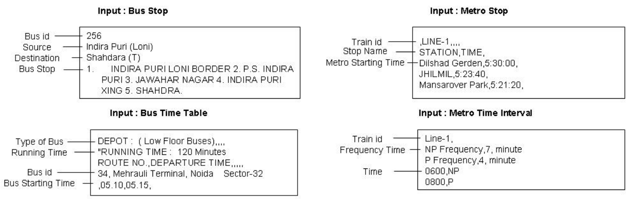

Figure 3: Input for bus and metro schedules in Delhi.

Reinforcement Learning

The common setting today is that there is no communication between the city and the commuters, and if users already know their plans, reinforcement learning techniques suit naturally in selecting them (Sutton and Barto 1998). Each commuter maintains self-valuation of each of the possible states. From each state, the commuters may take an action that maximizes expectation on the long-term reward (e.g., short commute times). The valuations of states visited on a commute are then updated based on the actual commute time taken.

Discussion: Sample Data

The data for the proposed problem consists of two parts: (a) city data consisting of its traffic points and roads, and (b) the modes of travel which specify the actions for moving in the city. For city data, there are many options - one can obtain it freely from OpenStreetMap(OSM 2012) by simply specifying the region of interest and downloading the data in preferred format. If only personal vehicles are allowed on a city's road, this data will suffice to solve the problem.

If the city additionally has public transportation like buses and metros, more processing is needed for this data. Our approach is to take published unstructured data from different public agencies, clean, consolidate and then re-publish them in machine-processible, structured format.

Sample Data

We consider Delhi (India) as the city of interest and two modes of public transport, buses and metros.

Figure 3 (left) shows the data for the bus mode. The data is provided in two different files: first specifies the bus id, source stop name, destination stop name and stop name sequence in order; the second has type of the bus, running time to complete the route, bus id and starting time. The right side shows the data for the metro mode. The data is provided in two different file: first specifies the train id, stop names in order and the metro starting time; the second specifies the train id, frequency at peak and non-peak hours, and the latter's durations.

Structured Data Format

We adopt the General Transit Feed Specification(GTFS 2012) to represent the output dataset. GTFS has been developed by Google and has provision to represent public transportation information like agencies, stops, routes, fares, frequency and transfers. However, authors are not aware of any city's data being made available for research via GTFS. A sample of the data we create is shown in Figure 5.

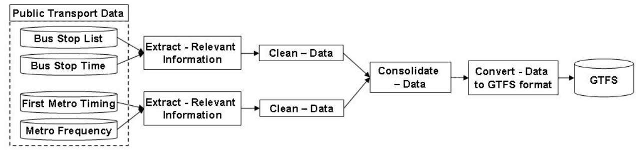

Figure 4: Key steps to create the data set.

Agency
agency_id, agency_name, agency_url,
agency_timezone, agency_phone, agency_lang
DTC, Delhi Transport Corporation, http://www.dtc.com,
GMT + 530, 01123232433, en
Stop
stop_id, stop_code, stop_name
345, , INDIRA PURI LONI BORDER
Route
route_id, route_short_name, route_long_name, route_desc, route_type
R102, 256, 256, 256, 3
R103, Line 1,Line 1,Line 1,2
Trip
route_id, service_id, trip_id, direction_id
R102, A, 0A_R102, 0
R102, A, 1A_R102, 1
Stop Times
trip_id, arrival_time, departure_time, stop_id, stop_sequence
0A_R102, 0:0:00, 0:1:00, 345, 0
0A_R102, 0:6:00, 0:7:00, 412, 1
Frequency
trip_id, start_time, end_time, headway_secs
0A_R102, 7:25:00, 7:50:00, 5

Figure 5: A sample of the structured data.

Process Used to Prepare Data

In Figure 4, we show the process we have used to create the structured output from the published data. The critical steps are cleaning the data (e.g., spelling mistakes) and consolidating it (e.g., bus and metro stops at the same location).

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