Multimodal Public Transit Trip Planner with Real-Time Transit Data

Nilesh Borole\textsuperscript{a}, Dillip Rout\textsuperscript{a}, Nidhi Goel\textsuperscript{a}, Dr. P. Vedagiri\textsuperscript{b}\textsuperscript{1}, Dr. Tom V. Mathew\textsuperscript{b}

\textsuperscript{a}Research Scientist, Dept of Civil Engineering, IIT Bombay, Powai, Mumbai- 400076, India
\textsuperscript{b}Faculty Associate, Dept of Civil Engineering, IIT Bombay, Powai, Mumbai- 400076, India

Abstract

Trip planner is a smart travel assistance tool which provides pre-trip travel plan information to the commuter for the given origin and destination stops. It is built-up with information such as road network and vehicles' schedule from various transport agencies. The schedules are static and deviates much in actual due to delays caused by dwell time, traffic congestion and accidents etc. Therefore, many real-time trip planners were developed to produce more accurate plans in terms of time and transit vehicles which use data from Global Positioning System (GPS) enabled vehicles. However, the methodologies for vehicle positioning in real-time, dealing with interrupted GPS signals and just-in-time update of transit network is still not crystallized. Mostly the vehicle positioning is handled by a third party. In addition, most of the real-time planners do not consider arterial routes. In this paper we present development of a multimodal intracity transit trip planner using public transport. It incorporates the delays into the transit network at real-time to minimize the gap of our prediction model. K-shortest path algorithm is being used to compute multi-criterion optimal plans. Here we consider both delays in all routes including arterial ones and frequently missing GPS signals. Our system handles all these with some heuristics and simulation. Besides the web interface, trip planning can also be done by sending Short Messaging Service (SMS) from any mobile phone to the server. The results have shown that the system produces plans which are acceptable in terms of response time, feasibility and accuracy.

© 2013 The Authors. Published by Elsevier Ltd. Open access under CC BY-NC-ND license. Selection and peer-review under responsibility of International Scientific Committee.

Keywords: Transit trip planner; Real time; plan search; BFS; multimodel trip planner; GPS tracking.

1. Introduction

Transit trip planner is an application of Intelligent Transportation System. It assists transport users to plan their trip according to their preferences. Travellers input parameters will be source stop, destination stop, departure...
optimal travel plan for specified source to destination stops will be generated by transit trip planner system based on given inputs. Most transit trip planning systems are based on static schedules provided by transit agencies which suggest plans that are not dynamically responding to delays in transit operations, caused by traffic congestions or accidents. Therefore, there is a great need to develop real time transit trip planner.

Real time transit trip planner includes installation of Vehicle Mounted Unit (VMU) to public transport vehicle (bus). Vehicle mounted unit has an in-built GPS receiver and a Global System for Mobile communications (GSM) modem that transmits and receives location information of vehicle and few other commands. This unit provides real time location of a vehicle. It receives latitude and longitude information of the vehicle from the GPS satellites. It transmits position with various sensor information to the server. It provides real time information which is used to track the movement of bus vehicles. Then, system predicts bus's arrival time and departure time at the stops which is estimated by a prediction model. Travellers can get expected arrival time of a vehicle at a particular bus stop and can plan their trip accordingly. This will save traveller's waiting time at the stops during their journey. This intelligent trip planner will attract more passengers to the transit system.

Transit trip planner system is accessible by visiting website over internet. Also, real time position is shown on the map along with expected arrival time at next bus stop for each tracked vehicle. Users can also access the transit trip planner service from mobile by sending SMS to trip planner server. Travellers can get travel plan, next arrival time for particular route number at bus stop via SMS on mobile.

Development of real time transit trip planner system includes implementation of real time transit network based on historical GPS data received from vehicles. Plan search algorithm is implemented to search travel plan in real time transit network. An interface to receive real time GPS data from vehicle is provided. GPS server is implemented to monitor all active vehicles in network. GPS server computes speed of vehicle and maps the position of vehicle on the transit route based on which it predicts expected arrival time for next bus stops on route. Real time transit network is updated based on the real-time speed. The system is implemented in Java and MySQL database server is used to store data.

The objective of this paper is to develop multimodal public transit trip planner with real time transit data. The rest of this paper is structured as follows. Section 2 will take a look at existing real time transit trip planner systems and their advantages along with disadvantages. Section 3 depicts detailed system architecture which includes system components, input parameters and results generated from the system. Also it shows technical difficulties in implementation of real time transit trip planner system. Section 4 describes vehicle tracking and route detection along with real time network updater. Also, it describes graphical representation of real time transit network. Section 5 shows deployed system which has been tested for few Mumbai public transport routes. Also, based on received real time data, results were generated and compared to find out the accuracy of system. Section 6 includes system evaluation results. Load test is carried out on system deployed for Mumbai public transport to evaluate the system's response time, scalability and to find out number of concurrent users, followed by concluding remarks in section 7.

2. Literature Survey

Over the years there are significant changes in transportation due the introduction of Intelligent Transportation Systems (ITS). The data generated by the ITS devices are making the transportation system more sophisticated but at the same time the management of such huge data is being complex. Over last two decades various Trip Planner systems have been developed and many researches on this area is still under search.

Chen et al (1999) proposed a multi-modal daily itinerary planner. The idea is to provide the travelers (especially tourists) about the schedules of the transports (public). A computer software program called Itinerary Planner was developed to help travelers find a suitable itinerary by generating alternative travel plans for a single Origin-Destination (OD) pair. It can compute plans with constraints such as time and mode of travel. It didn't
consider the real-time scenario but the unique one to start the Multimodal Trip Planner with constraints. Similar to it Ranade et al. (2005) developed Mumbai Navigator at Computer Science department, IIT Bombay for Mumbai City. The system uses bus routes’ information provided by Brihanmumbai Electric Supply and Transport Undertaking (BEST), Mumbai. It provides alternative plans for single OD pair with the information about the time of departure or arrival.

Li et al. (2010) proposed a multimodal trip planner which supported Park-n-Ride (P+R) mode. The transportation networks used consists of parking lots besides the stops, stations and intersection. It uses K shortest path which are executed time as the cost for traversal. At system level it has both web-based and cell-based User Interface which can be used for arrival time prediction, trip planning. In addition to web browsing, users can query by email or cell messages. Jariyasunant et al. (2010) developed a mobile based real-time transit trip planner application. The vehicle positioning is provided by a 3rd party and dynamic (frequently changing link attributes) K-shortest path was used to find the route. The data being processed for running the routing algorithm. Apart from the transit graph, all feasible OD pair’s paths were pre-calculated and stored. Also the results are cached for future use for the common OD pairs. The analysis shows that the accuracy is more in case of long travel time. The paper does not take uncertainty into consideration which is a limitation.

Apart from the system and data constraints some authors focused on the path finding algorithm for Multi-Modal Trip Planner only. Yang and Yu (2007) presented an optimization model based on Coarse-grain Parallel Ant Colony algorithm for Bus Network. Again Li et al (2012) developed another model which also supports P+R mode of travel for public transportation. The algorithm search space is reduced by restricting the expansion of search by a minimum bounding box (mbb) applied to the geographical coordinates of OD pair.

Similarly Xu et al (2012) proposed an algorithm for finding the K shortest paths in a schedule-based transit network. It finds all shortest paths available between given source and destination node. Walsh and Antsfeld (2012) has proposed an algorithm to find optimal paths in multi-modal public transportation networks using hub nodes and transit algorithm. It has been tested on Sydney metropolitan and New South Wales state public transport networks. The most advanced trip planner till today to the best of our knowledge is Google Transit which is provided by Google inc. Google Transit has developed trip planner system for different countries (including India). To make routing fast in dense transit networks, Bast et al (2010) suggested an algorithm which capitalizes on having look-up tables for direct-routes and transfer patterns.

In addition to the Intra-City Trip Planner there exist some Inter-city Travel Planner. For e.g. the model developed by Su and chang (2010) is an intercity Trip Planner which combines the modes like bus, train, high speed train, airlines, ships etc. It also incorporated the landmark-to-landmark travel planning apart from mode restriction and other constraint options. The results show that it generates feasible plans for the Taiwan city. In comparison to other existing similar Trip Planners it is quite good in terms of accessibility and result. It also updates the network elements and the timetable regularly.

3. System Overview

The architecture of the Real-Time Transit Trip Planner is shown in figure- 1 and also all the major components with their respective modules are explained in this section as well.

3.1. GPS Data Validator

GPS data validator filters out the invalid received data from GPS and saves valid GPS data to the database table. It may be possible that the GPS data sent by the GPS units gets corrupt during communication with server. Such invalid GPS data packets are filtered out by the validator. For ex- if bus is not serving on any route as it is going to fill the fuel to the fuel station or it is going to the garage for maintenance work. In such scenario,
received GPS data will be identified inaccurate or invalidate. GPS data validator monitors the received GPS data and keeps track of all active vehicles in the network.

3.2. GPS Server

Based on received validated GPS data, bus positions are mapped using geocoding process to find out the links on which the buses are moving. Valid GPS data is processed to calculate the link's speed of each active bus and inserts the link's speed to the ‘real time link speed’ database table. GPS server maintains current position, speed and other information such as bus id, route number of all active buses etc. Based on the current position and speed of the buses GPS server predicts the arrival time of buses at next bus stop.

3.3. Real Time Transit Network
Process ‘Real time network updater’ runs continuously to update the Real time transit network. Real time network updater accesses the Real time link’s speed database table to get transit link’s details such as source stop, destination stop and speed of the link. Real time transit network is updated based on current speed of active buses from real time link database. In transit link update process delay/ahead time is calculated. Delay/ahead time is propagated till the end of route transit link. Vehicles average speed is taken into account to calculate the further transit link delay/ahead time. It is assumed that the driver of vehicle will try to minimize the delay for next transit links till end of route, so during delay calculation for next transit links a damping factor (0.85) for delay is added to delay calculated based on average speed.

3.4. Trip Planner

Trip planner is responsible for searching the Real time transit network and generates the desired travel plan based on the user’s preferences. Plan search algorithm searches reachable nodes from the source node. Then, all links will be recorded in an order. After that, it will visit each of these nodes one by one. Again from these nodes, it will look for all possible reachable nodes and will record them in order. This process will be continued till the destination node is found. In case, real time information is not available due to technical reason then dynamic network is used to search the travel plans.

3.5. System input and output

A web interface has been implemented to access real-time transit trip planner system. Travelers need to give input parameters such as: source stop, destination stop of journey, departure time from source stop or arrival time at destination stop, maximum possible transit transfers, maximum walk able distance, transportation mode (can be only buses or buses and trains) and selection of preferences like; quickest, cheapest, shortest or less number of transfers etc. Suggested travel plans include the instructions to reach at destination stop from source stop along with transit service details, total covered distance and expected fare of trip. Route for each travel plan along with intermediate waypoints is displayed on map using Google map Application Programming Interface (API).

3.6. Technical Constraints

In real time scenario, a lot of vehicles will be active and will be serving the passengers on different routes. GPS data from all active vehicles will be received and processed at GPS server. It is important to update the Real time transit network quickly based on received GPS information. Multithreading feature of java is used to solve this issue by handling few bunch of routes by a single thread. Due to technical problem in GPS units, weak network or other issues such as, server does not receive GPS data from vehicle for small time period or most of the time vehicle might be moving on different route as it is going for maintenance work to garage etc. Then, it can be said that bus is not serving to the passengers in such scenarios. Therefore, it should be identified by the system to present accurate information to the users of system. Multiple users access the service via web interface. Therefore, it is important that every user of system should get results with minimal response time and system should be scalable to handle much numbers of users.

4. Plan Search Algorithm

This section will give brief detail about the plan search in the Real time transit network along with vehicle tracking and route detection in Real time updater process.
4.1. Plan search

Breath First Search (BFS) algorithm has been implemented to generate travel plans by searching real time transit network. It begins at source node and inspects all neighboring nodes which are unvisited. It visits sibling nodes before visiting child nodes. Therefore, if there is more than one solution then BFS can find the minimal one that requires less number of steps. Also if there is any solution, BFS will definitely find it out.

4.2. Real-Time Transit Network

Graphical representation for physical network and Real time transit network is in figure- 2 and 3 respectively. Many transit links are available for each physical link in the network as shown in figure- 3. Transit links for each physical link contain the transit information such as route number of transit service, arrival time at source stop, mode of transport (walk, bus and train etc.), distance and running time etc. Real time transit network is updated by updating transit links for corresponding transit service based on the real-time link's speed.

4.3. Vehicle Tracking and Route Detection

GPS server tracks movements of all active buses in network as shown in figure 4. GPS server's components include vehicle activity monitor which keeps track of all active buses in the system. As soon as server stops receiving GPS data from particular vehicle in network then vehicle activity monitor removes such vehicle from the system. Location Mapper locates position of tracked vehicle on the route and tracks movement of a vehicle.

4.3.1. Vehicle Activity Monitor

Vehicle activity monitor thread keeps track of all active buses in the network. It continuously monitors that the GPS data for each listed vehicle in ‘active vehicle data’ table is being received by server or not. If any particular vehicle's data is not being received by the system for specific time duration (i.e. 3 minutes) then it removes the bus instance from the system and from ‘active vehicle data’ table.

4.3.2. Location Mapper
Location Mapper provides the method to track the vehicle location and movement using received GPS data. Vehicle location should be mapped with the particular node of the augmented route present in the system database. Using vehicle's latest location information, system checks vehicle's direction and decide whether vehicle is following correct route or not. Location Mapper provides the way to find position of a vehicle in the augmented route and return the position which includes previous stop id, next stop id and time at previous stop id in seconds. It maps the current position of vehicle with virtual node of augmented route and returns the mapped virtual node.

![Diagram of Vehicle Tracker](image)

Fig.4: Vehicle Tracker

Location Mapper also ensures if vehicle is following correct route or not. It tracks the movement of vehicle by monitoring the real time GPS positions of a vehicle. Augmented route for each route of public transport is created to locate vehicle position on route in the system. Augmented route contains all intermediate stops of a route along with virtual nodes. For each 50 meter (can be changed for more efficient position mapping) distance a virtual node has been created on route.

4.4. Real Time Network Updater

Real time network updater process continuously updates the real time transit network based on real time link's speed data. GPS server updates the link's speed data into the database table based on received GPS data. Real time network updater accesses the link's speed data and updates the transit links information into the real time network. Real time network updater process flow chart has been shown below in figure 5.
5. Experimental Setup

Real time transit trip planner system for Mumbai has been deployed on IBM X 3500M server having Intel(R) Xeon(R) CPU E5-2620 processor with 2.00 GHz of processing power, 8 GB of RAM and 12 MB of cache.

![Real Time Network Updater Flow Chart](image)

Real time transit trip planner system has been deployed for two bidirectional routes of Mumbai public transport BEST authority. In Mumbai public transport service, there are total 999 routes includes 872 bus routes and 127 train routes covering whole Mumbai city and 4310 total stops are present in the city. We have collected all route information includes route intermediate stops from source stop to destination stop, distance and fare details of route. Also, spatial information i.e. latitude and longitude of all stops of Mumbai is collected. Transit network for Mumbai have total 14184 physical links available. The two bidirectional routes are C-52 EXP and 440Ltd. Route C-52 EXP runs from stop “Wadala Depot, Wadala” to the stop “Kalamboli bus station” and route 440Ltd runs from stop “Wadala Depot, Wadala” to the stop “Borivali station-east”. Route C-52 EXP contains 28 intermediate stops and route 440Ltd contains 30 intermediate stops. 22 buses are serving on the route C-52 EXP and 14 buses are serving on the route 440Ltd.

Received GPS data include bus Id to identify vehicle uniquely, route number on which bus is moving, latitude, longitude of vehicle and log time for GPS data from vehicle. Sample GPS data received at IIT-Bombay server is:

```
BusId=9999  RouteNo=440Ltd  LatPosition=18.9636754000  LongPosition=72.816189899  LogTime=12/11/2012 8:29:58 AM 03:38:38:905 PM
```

Moving GPS installed buses on specified routes has been shown in figure 7 and many trip plans were generated to test the system shown in figure 6. Plans generated by dynamic transit trip planner are used as a baseline for verification of results suggested by real time transit trip
planner system. Whenever user visits the website of system information such as time of visiting, user's inputs to search travel plan and generated results for user are logged on to the server to understand and track the searching behavior of users.

**Fig. 6. Real time plan from “Vashi Village” to “Kalamboli Bus Station”**

**Fig. 7: Track the bus online**

6. **System Evaluation**

Load testing of a system has been done to evaluate response time and scalability of system. Load testing of a system is carried out using Apache Jmeter performance testing tool. The number of concurrent users had been increased from 50 to 200 by having same testing time. Then, load testing results were generated. It has been shown in table-1. It incurred that system can handle 200 concurrent users with average response time of 43 second and its throughput is 11.8 which shows 11.8 requests can be processed per second by system.

**Table 1: Load testing result for real time transit trip planner**

| No Of Users | Median Response Time (in ms) | Average Response Time per user (in ms) | Throughput (Request processed Per Second) |
|-------------|-----------------------------|----------------------------------------|-------------------------------------------|
| 50          | 8250                        | 9535                                   | 11.6                                      |
7. Conclusion

The paper describes implementation of real time transit trip planner system. Real time transit trip planner system includes tracking of GPS unit installed vehicle and based on real time data generating a travel plan for user of system, implementing BFS algorithm to search travel plan, GPS server to manage and track all vehicles installed with GPS unit and web interface to access system. With the help of real time information of vehicle position, trip planner system can predict accurate time delay for vehicle and assists the user to plan trip. Using real time data in system provides an accurate travel time prediction, estimation of bus arrival for real time scenarios such as traffic congestion. The study incurred that, increasing use of GPS based tracking system in the transportation will help the traveller to choose faster and convenient travel path and travel options according to his preferences. It is expected that large numbers of bus transit users shall prefer to plan their journey trip in advance through interactive trip planner, which will save their waiting time and also make their journey comfortable. This intelligent trip planner will attract more passengers to the transit system.

Future work will be to get more bus route’s GPS data. In this paper we are presenting results based on 2 routes GPS data only for testing our algorithm. If we get more routes’ GPS data, the algorithm can be enhanced more and better results can be produced. Also, we are using average for estimating link’s speed. A mathematical model can be suggested to predict accurate arrival/departure time for each link.

References

Bast, H., Carlsson, E., Eigenwillig, A., Geisberger, R., Harrelson, C., Raychev, V., & Viger, F. (2010). Fast Routing in Very Large Public Transportation Networks using Transfer Patterns. European Symposium on Algorithms, Lecture Notes in Computer Science, 6346, 290-301.

Chen, C., Kitamura, R., & Chen, J. (1999). Multimodal daily itinerary planner interactive programming approach. Transportation Research Board, 1676, 37-43.

Jau-ming Su, & Chih-hung Chang (2010). The multimodal trip planning system of intercity transportation in Taiwan. Expert Systems with Applications, 37, 6850-6861.

Jerald Jariyasunant, Daniel B. Work, Branko Kerkez, Raja Sengupta, Steven Glaser, & Alexandre Bayen (2010). Mobile Transit Trip Planning with Real-Time Data, Transportation Research Board 89th Annual Meeting, 2, 139-146.

Jerald Jariyasunant, Eric Mai, & Raja Sengupta (2011). Algorithm for Finding Optimal Paths in a Public Transit Network with Real-Time Data. Transportation Research Record: Journal of the Transportation Research Board, 2256, 34-42.

Jing-Quan Li, J.-Q., Zhou, K., Zhang, L., & Zhang, W.-B. (2010). A Multimodal Trip Planning System Incorporating the Park-and-Ride Mode and Real-Time Traffic and Transit Information, Proceedings ITS World Congress, 25, 65-76.

Jing-Quan Li, Kum Zhou, Liping Zhang, & Wei-Bin Zhang (2012). A multimodal trip planning system with real-time traffic and transit information. Journal of Intelligent Transportation Systems, 16(2), 60-69.

Ranade, A., Srikrishna, M., Tilak, K., & Datar, M. (2005). Mumbai Navigator. Indian Journal of Transport Management.

Sanders, P., & Schultes, D. (2007). Engineering fast route planning algorithms. Experimental Algorithms, Lecture Notes in Computer Science, 4525, 23-36.

Transit Google, http://www.google.com/intl/en/landing/transit.

Walsh, T., & Antsfeld, L. (2012). Finding multi-criteria optimal paths in multi-modal public transportation networks using transit algorithm. 19th world Congress on Intelligent Transport Systems

Xu, W., He, S., Song, R., & Chaudhry, S.S. (2012). Finding the k Shortest Paths in a Schedule-Based Transit Network. Computer and Operations Research, 39, 1812-1826.

Yang, Z., & Yu, B. (2007). A Parallel Ant Colony Algorithm for Bus Network Optimization. Computer-Aided Civil and Infrastructure Engineering, 22, 44-55.