A Multimodal Trip Planning System Incorporating the Park-and-Ride Mode and Real-time Traffic/Transit Information

Jing-Quan Li, Kun Zhou, Liping Zhang, and Wei-Bin Zhang

California PATH, University of California, Berkeley, Richmond, CA
jingquan, kzhou, lpzhang, wbzhang@path.berkeley.edu

Abstract

Most transit trip planning systems are based on static schedules and generate trips that are not dynamically responding to delays in transit operation, caused by traffic congestions or accidents. In addition, the park-and-ride travel mode is common in metropolitan areas. However, very few transit trip planners incorporate the real-time transit data and park-and-ride mode. This paper describes a multimodal trip planning system that provides multiple modes: driving, transit and park-and-ride. The system considers the real-time transit arrival time, which is estimated by a prediction model. Our preliminary cast studies show that the multimodal trip planning system works very well.

Keywords: trip planning, real-time information, shortest path, intelligent transportation systems

1 Introduction

Public transit systems play an important role in transporting travelers in metropolitan areas. Transit users generally have origin, destination and expected departure or arrival time. Based on the schedules provided by transit agencies, the transit users need to choose the routes and transfer stations that can appropriately fit their travel needs. However, finding appropriate travel routes manually is complicated mainly because it is difficult to determine proper transfer points between different routes.

Due to the advancements of computing, communication and storage technologies, automatic transit trip planners have been implemented in recent years. Transit trip planners accept the origin, destination and expected departure/arrival time inputted from users and find proper routes using available transit services. Transit trip planners are generally web based. Some notable transit trip planners in USA provided by transit agencies and companies include Bay Area 511 Transit Planner (5), Chicago RTA Transit Planner (6), Google Transit Planner (8), Houston MTA Transit Planner (9), Los Angeles Metro Transit Planner (10), New York City Transit Planner (11), and Seattle Metro Transit Planner (12). Deutsche Bahn (7), Transport Direct (13), and ENOSIS (20) are some notable planners in Europe. Google Transit Planner (8) also provides the routes outside of US if the required data is available. Some researchers have also proposed transit trip planers, including Peng and Huang (17) and Jariyasunant et al (15). Peng et al. (18) give a survey on transit trip planner software.

Most of the existing trip planners are based on static schedule data. However, transit vehicles are often delayed by traffic congestion and accidents. Especially transit buses are often late during the peak hours in metropolitan areas. The trips based on the static schedule data may make planned transfers infeasible if some transit vehicles are late. Currently, the Automatic Vehicle Location (AVL) system has been widely installed on buses by a large number of transit agencies in the USA. The real-time location data of transit vehicles (i.e., buses and trains) are sent to the transit management center. The real-time AVL data is essential for estimating the transit arrival time, thus reducing the inaccuracy of trip planning. However, the real-time AVL data is not incorporated in most trip planners.

Additionally, the transit users of metropolitan areas often drive to some transit stations, park their cars there and use the transit to travel in the morning. For example, in Bay Area, both BART (Bay Area Rapid Transit) and CalTrain provide parking lots to their customers. However, to the best of our knowledge, at this time, only Chicago RTA Transit Planner (4) considers such park-and-ride travel mode.

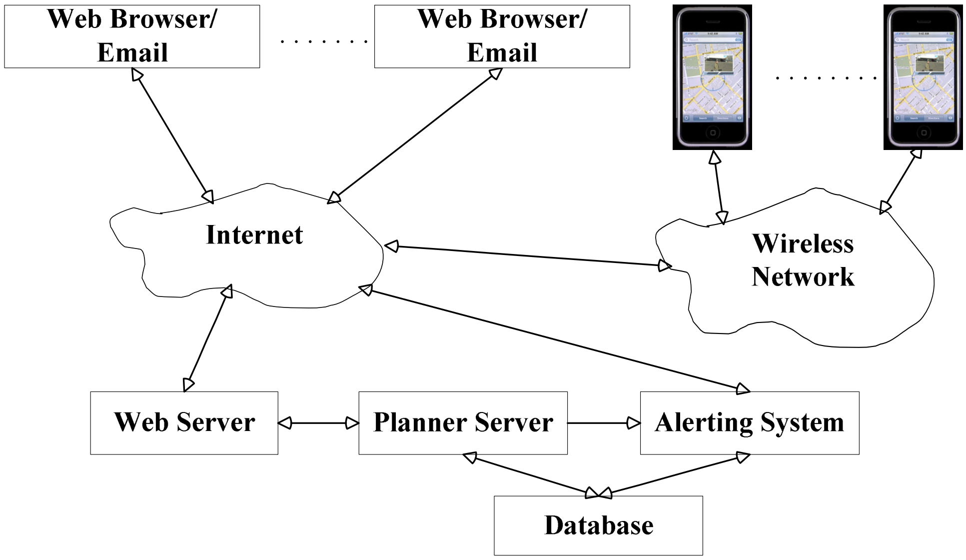

Figure 1: The architecture of the multi-modal trip planning system

We design and implement a multimodal trip planning system (see Figure 1 for the system architecture) as part of the SafeTrip 21 program. This development is to support the field testing of real-time traveler information with a goal to evaluate whether real-time multimodal information would encourage mode shift. To achieve this goal, a trip planning system is needed to provide the following features: (1) supporting multiple travel modes, including driving only, transit only, and park-and-ride; (2) incorporating the real-time estimation of transit arrival time in order to reduce the planning inaccuracy; and (3) accessible by web and cell phone.

2. Design of the Trip Planning Server

Figure 2 presents the architecture of the trip planning server. While the essence of most multi-modal trip planners is to seek good travel routes for given origin, destination and starting/arrival time, finding good routes is far more complicated than solving a simple shortest path problem. First, different users may have different preferences. For example, some users prefer trains to buses. In addition, it is difficult to model these preferences using some quantitative weights. Assume that there are two routes, where one route requires a slightly longer walking distance, while the other one requires a slightly longer time staying in the bus. Different users may have different opinions on which route is better. Therefore, multi-modal planners generally provide several good routes to users so that the users can choose the best one from these routes by themselves.

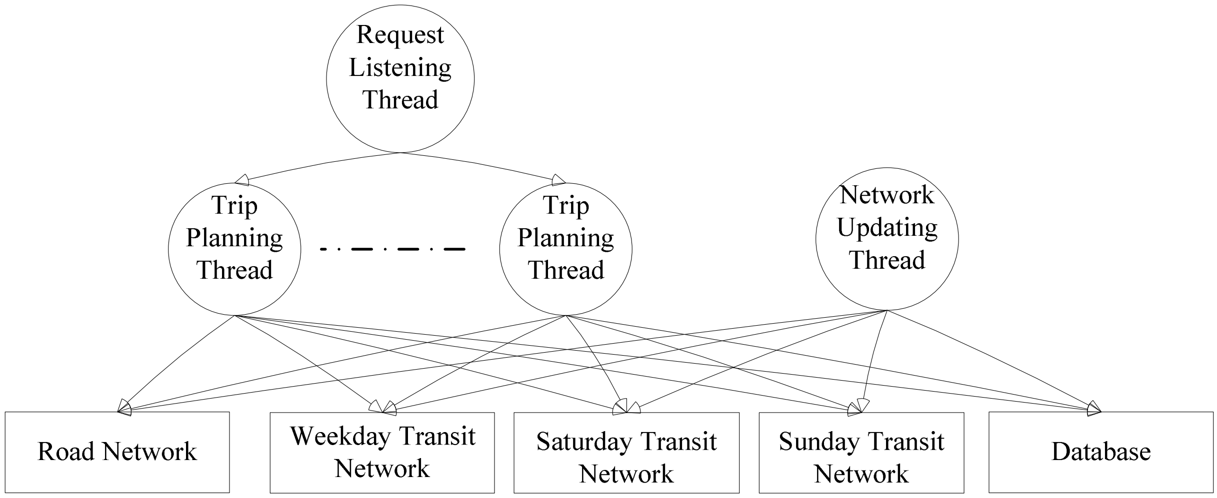

Figure 2: The architecture of the trip planning server

When users choose to drive from a given origin to a destination, the quickest route is returned and a Dijkstra algorithm is applied. If users choose the mode of transit only or park-and-ride, we first select the transit stops or parking lots that are near the origin. Then, the transit stops nearby the destination are determined. In summary, we solve three kinds of shortest path problems: (i) from the origin to the nearby transit stops or parking lots; (ii) from the destination to the nearby transit stops; and (iii) from the transit stops or parking lots that are close to the origin to the transit stops that are close to the destination. These routes will be combined together to yield an overall route.

2.1 Underlying Network Construction

Due to the nature of multi-modal transportation, our underlying network consists of different types of nodes, including intersections, bus stops, train stations, parking lots, and transit time points. First, we construct two types of networks: road network and transit networks. The road network consists of intersections, transit stops and parking lots. The time points are excluded in the road network. The road network includes arcs between intersections, arcs between intersections and transit stops, and arcs between intersections and parking lots. The shortest paths from the origin to nearby stops or parking lots and from the destination to nearby stops are based on the road network.

The transit networks include transit stops, parking lots, and time points. The arc types are: a stop to related time points, a paring lot to related time points, time points to time points of the same route, the time points to time points of different routes, time points to stops and time points to parking lots. Transfer between different routes is very important in underlying network construction. First, we examine the possible transfers based on the static schedule data and minimum transfer time. Then, the planning server periodically queries the estimated transit arrival time from the database. If a transit vehicle arrives to a stop late and the original transfer is infeasible, the corresponding arc is disabled in underlying networks.

Since most transit agencies have different services on weekday and weekends, three transit networks, weekday transit network, Saturday transit network, and Sunday transit network are constructed, each of which contains the time points for that day. It is worthy to note that all the networks are shared by the trip planning threads (see Figure 2) for saving the memory. Due to a large number of intersections and time points, the road network and transit networks are very large. It is critical for planning threads to share the data.

When real-time passenger information is available, the real-time transit arrival and traffic time is updated periodically in the database. A thread is implemented to query the real-time data from the database and to update corresponding networks. Some lock mechanisms are used in the programs for mutual exclusion between different threads.

2.2 Trip Planning Algorithms

First, we need to determine the shortest paths from the origin to its nearby transit stops or parking lots. For the origin to each nearby stop or parking lot, we apply the bi-directional Dijkstra algorithm to solve it. The bi-directional Dijkstra algorithm is expected to have a better performance for the node-to-node shortest path problem (1). The same procedure is employed for the shortest paths from the destination to its nearby stops.

Note that the users may provide the expected departure time or arrival time. Some arcs may not be valid with the specified time. For example, if a user expects to depart at 7:00, the arc from the transit stop to a trip starting at 6:40 is invalid. Therefore, finding paths between two transit stops is a time-dependent shortest path problem. As mentioned earlier, it is desirable to provide several routes between two transit nodes since users may have different preferences. We first solve a one-to-many time-dependent shortest path problem. Then, a time-dependent K shortest path algorithm is run to obtain more paths.

The time-dependent shortest path problem has been investigated by forward/backward search (14) and dynamic programming (19). In this paper, $GOR1$ algorithm (4) and K shortest path algorithm by Jimenez and Marzal (16) were adapted to solve the time-dependent shortest path and K shortest path problem respectively.

2.3 Case Studies

Our trip planning server is implemented in C++ on a Lenovo Thinkstation with 4 Intel processors at 2GHZ, 4GB of RAM and a Linux operating system. We conduct preliminary case studies on the South Bay of San Francisco Bay Area. Our case studies considering driving, transit and park-and-ride. The trip planning for driving mode is based on the road network data provided by NavTeq. The transit services include CalTrain, CalTrain shuttles and some routes of San Mateo County Transit District (SamTrans). Several CalTrain parking lots are used to provide park-and-ride mode. The weekday underlying network includes 34065 nodes and 109318 arcs. Our tests show that the trip planning runs very fast and returns results in a few seconds. More services from various transit agencies will be included into our system in future filed tests.

3. Uncertain Traffic and Transit Travel Time and Real-time Estimation

A critical element of the real-time multimodal trip planning tool is transit arrival time information. A typical transit trip involves travelers waiting at stop (bus) or station (rail) for the next transit vehicle, moving to a new stop/station, transferring to another transit vehicle or/and walking to the destination. Transit travelers' perceptions and satisfaction of waits, transfers and transit travel times contribute greatly to their decisions whether or not to take transit in future.

Accurate prediction of the expected arrival time at individual downstream stops/stations is of significant value to both transit operators and customers. There are a wide range of uncertainties in predicting bus travel time/arrival time, including the uncertainties in traffic condition, passenger boarding and alighting activities, and errors in transit vehicle positioning, among others. Some algorithms based on the Kalman filter have been proposed to predict the bus arrival time (2, 3). As a case study, we collected bus operations data, examined operation characteristics, and assessed how real-time prediction can reduce the uncertainties in bus arrival times.

Route 390 is one of the most heavily used bus routes operated by SamTrans. It provides schedule-based bus services between Palo Alto transit center and Daly City BART along California State Highway 82 - also known as El Camino Real. The route is about 27 miles long, with 2-hour schedule travel time for most time of day. It connects 6 CalTrain stations between Palo Alto and Hillsdale and 3 BART stations at Millbrae, South San Francisco and Daly City. Route 390 has 97 bus stops on northbound direction and 100 stops on southbound direction. Of those, 11 are time points, where SamTrans has posted its schedule. The connection points to CalTrain and BART stations are all time points.

Portable GPS/GPRS devices were installed on 15 SamTrans buses to collect second-by-second bus movement data. The collected data were then processed to be projected onto the route, matched with schedule runs, and grouped in terms of run numbers. Figure 3 plots trajectories of 102 bus trips in the time-space diagram. These bus trips are for weekday northbound service, which is scheduled to leave Palo Alto transit center at 2:18pm and arrive at the destination – Daly City BART, at 4:27pm. The circles on the plot pinpoint the locations and schedules at the 11 time points.

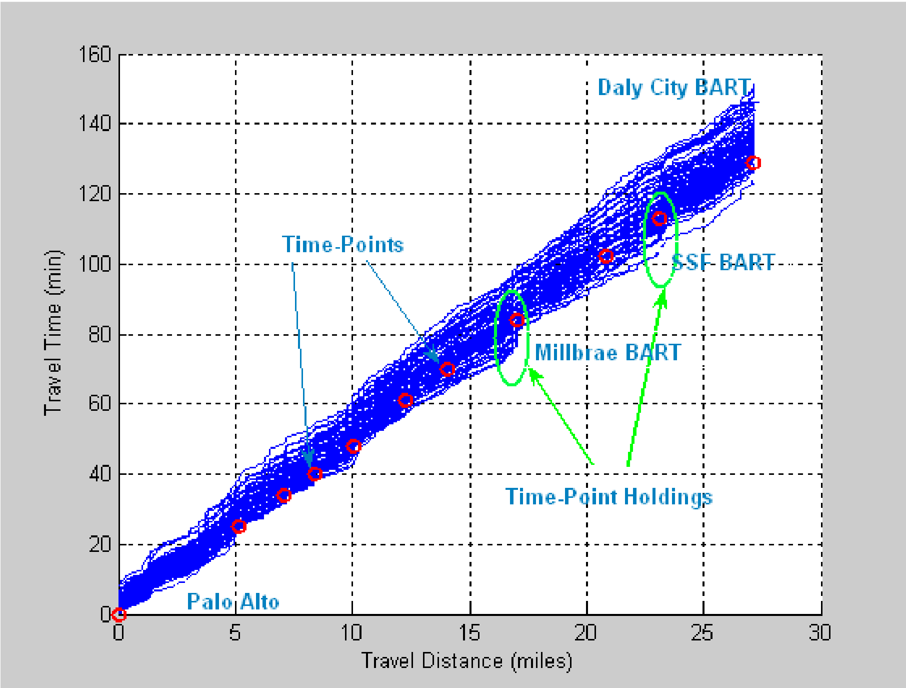

Figure 3: Bus Trajectories

Figure 3 shows several interesting bus operation characteristics. The variance of bus travel time becomes larger when bus is further into the trip. Bus is likely running behind the schedule.

When arriving earlier at a time point, the bus will wait at the time point until the stated time in the route schedule – so called time point holding phenomenon. This time point holding phenomenon is most observable at Millbrae BART stop and South San Francisco stop. The longest holding time observed at these two time points is 6 and 8 minutes, respectively.

Correlation analysis showed that schedule deviation at downstream time points is strongly correlated with the schedule deviation at the last time point and the dwelling time at time point is not correlated with the experience delay. Inspired by these findings, we examined the performance of the following regression based model in dynamical estimation of bus arrival and departure time.

Let $s_i, i = 1,2,...,n$ denote the schedule departure time at n time points, τ_k denote the schedule deviation at the last time point, $k = 1,2,...,n-1$, e_j and d_j denote the estimates of arrival time and departure time at time point $j = k+1,...,n$. The prediction model is formed as

$$\hat{\tau}_j = \alpha\hat{\tau}_{j-1} + \beta(s_j - s_{j-1})$$

$$d_j = s_j + \hat{\tau}_j \qquad j = k+1,...,n$$

$$a_j = d_j - w_j$$

with $\hat{\tau}_k = \tau_k$. The underline meaning of this model is that, given the observed schedule deviation at the last time point (k), the expected schedule deviation at individual downstream time point (j) is a weighted combination of two elements: the schedule travel time from time point k to time point j and the experience delay at time point k. The weightings α and β are model parameters which can be estimated with historical trip data. w_j is the dwelling time at time point j and can also be estimated from trip information. The performance of this model is shown in Figure 4. As a comparison, Figure 4 also shows the performance of using schedule as the estimation.

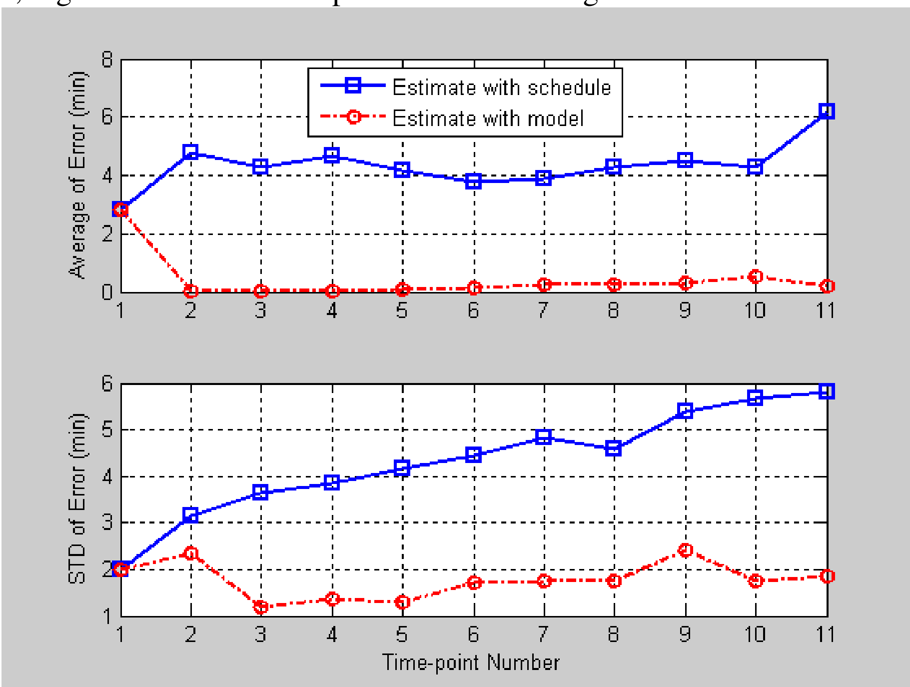

Figure 4: Performance comparison

We note here that this case study serving as an example to demonstrate that real-time estimation of transit vehicle's arrival and departure time can significant reduce planning inaccuracy. There is no "one size fit all" solution for different types of transit operation modes, e.g., scheduled-based versus headway-based, bus versus rail, fixed-route versus demand-responsive transit, as the operating environments and characteristics are very different.

4 Design of the Trip Planning User Interface

A web-based trip planning interface is implemented so that users can use a web browser to access the trip planner. The users can input the origin and destination addresses, travel mode (i.e., driving only, transit only and park-and-ride), expected departure or arrival time, and optional preference (i.e., shortest time, less transfer or less walking). Figure 5 presents a screen capture for the web-based client.

The corresponding latitudes and longitudes of the addresses are obtained by using Google's geocoding service. The web-based interface is implemented in Javascript. The user inputs will be sent to the trip planner server, which will return an XML file including the trip information. The trip information is displayed in the web browser. Google Map API is used to display the trip graphically in the web browser.

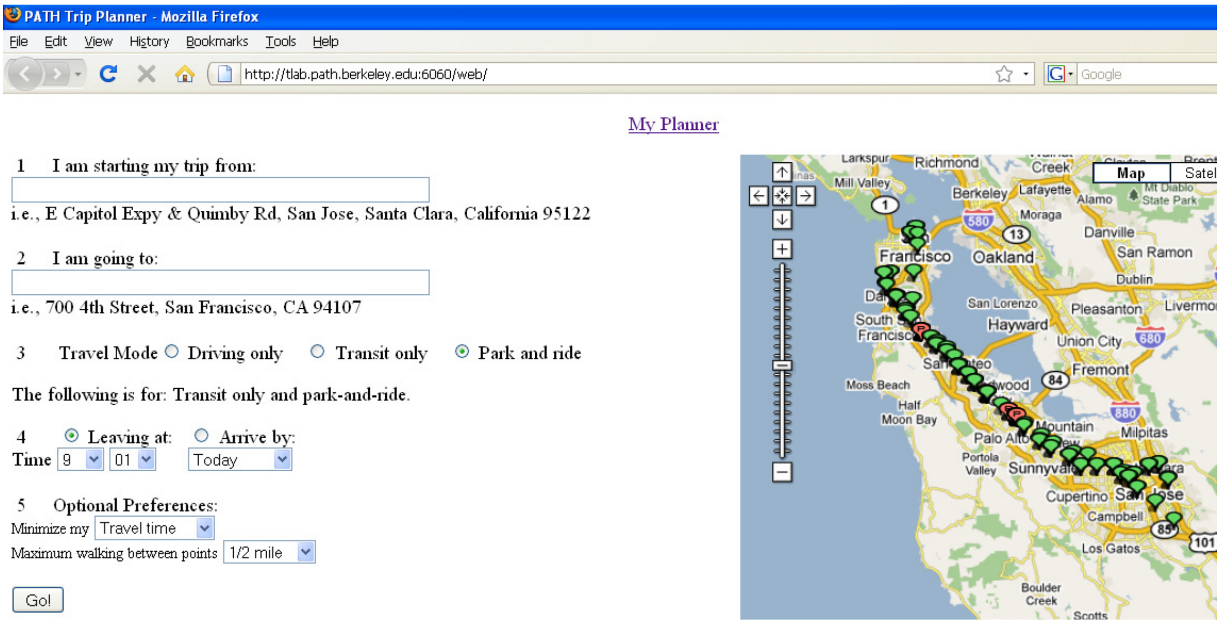

Figure 5: A Screen Capture of the Web-based Planner Client

We are also designing a cell phone based interface. The work is still in progress.

Section 5: Conclusion and Future Research

Most transit trip planning systems are based on static schedules and generate less accurate trips if traffic congestions or accidents delay transit vehicles. In addition, the park-and-ride travel mode is common in metropolitan areas. This paper describes a multimodal trip planning system that provides the park-and-ride travel mode and incorporates real-time traffic and transit information.

The overall system consists of a trip planning server, web and cell-based clients, transit vehicle arrival time estimation, customized altering sub-system, and database. Since our system provides multimodal transportation systems, the nodes of underlying networks include intersections, transit stops and stations, parking lots, and time points. The trip planning algorithms are composed of the time-dependent shortest path and K shortest path. The transit arrival prediction model is based on the regression analysis and historical data. In addition, an altering service is implemented to provide customers real-time trip solutions by email or cell message.

We conduct preliminary case studies on the South Bay of San Francisco Bay Area. The results show that our trip planning system works satisfactorily. Our future work includes the field testing of the planning system and the implementation of cell phone based clients.

Reference

1. Ahuja, R. K., T. L. Magnanti, and J. B. Orlin. Network Flows: Theory, Algorithms, and Applications. Prentice Hall, 1993.
2. Cathey, F.W., and D.J. Dailey. A prescription for transit arrival/departure prediction using AVL data. *Transportation Research Part C*, Vol. 11, 2003, pp. 241-264.
3. Chen, M., X. B. Liu, and J. X. Xia. Dynamic prediction method with schedule recovery impact for bus arrival time. *Transportation Research Record*, No. 1923, 2005, pp. 208-217.
4. Cherkassky, B. V., A. V. Goldberg, and T. Radzik. Shortest paths algorithms: theory and experimental evaluation. *Mathematical Programming*, Vol. 73, 1996, pp. 129–174.
5. Homepage of Bay Area 511 Transit Planner. http://www.511.org
6. Homepage of Chicago RTA Transit Planner. http://www.rtachicago.com
7. Homepage of Deutsche Bahn. http://www.deutschebahn.com/site/bahn/en/start.html
8. Homepage of Google Transit Planner. http://www.google.com/transit
9. Homepage of Houston MTA Transit Planner. http://tripplanner.ridemetro.org
10. Homepage of Los Angeles Metro Transit Planner http://www.metro.net/index.asp
11. Homepage of New York City Transit Planner. http://tripplanner.mta.info
12. Homepage of Seattle Metro Transit Planner. http://tripplanner.kingcounty.gov/cgi-bin/itin_page.pl?resptype=U
13. Homepage of Transport Direct. http://www.transportdirect.info/web2/home.aspx
14. Huang, R., and Z.-R. Peng. Schedule-based path-finding algorithms for transit trip-planning systems. Transportation Research Record, No. 1783, 2002, pp. 142-148.
15. Jariyasunant, J., B. Kerkez, and D. Work. Mobile Transit Planning with Real Time Data. Presented at California PATH, University of California, Berkeley, June 2009.
16. Jimenez, V. M., and A. Marzal. Computing the k shortest paths: A new algorithm and an experimental comparison. *Lecture Notes in Computer Science 1668*, 1999, pp.15–29.
17. Peng, Z. R., and R. Huang. Design and development of interactive trip planning for web-based transit information systems. *Transportation Research Part C*, Vol. 8, 2000, pp. 409–425.
18. Peng, Z.-R., S. Hawks, and K. West. Use of planning support software in transit services a state-of-practice survey. *Transportation Research Record*, No. 1927, 2005, pp. 128-136.
19. Zografos, K. G., and K. N. Androutsopoulos. Algorithms for itinerary planning in multimodal transportation networks. *IEEE Transactions on Intelligent Transportation Systems,* Vol. 9, 2008, pp. 175–184.

20. Zografos, K. G., K. N. Androutsopoulos, and Spitadakis, V. Design and assessment of an online passenger information system for integrated multimodal trip planning. *IEEE Transactions on Intelligent Transportation Systems,* Vol. 10, 2009, pp. 311–323.