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A Multimodal Transport Network Model for Advanced Traveler Information System

Jianwei Zhang*, Theo Arentze, Harry Timmermans

Eindhoven University of Technology, Eindhoven, The Netherlands, 5612AK

Abstract

There is an application need for seamless multimodal advanced traveler information systems. Currently, no comprehensive network modeling approach exists to deal with routing queries for different private and public transport modes taking into account multiple attributes, dynamic travel times and time tables in large-scale transport networks. The goal of this paper is to develop and test a generic multimodal transport network model for ATIS applications. First, we model multimodal transport networks from an abstract point of view and categorize networks into private and public modes. Then we use a generic method to construct a multimodal transport network representation by using transfer links which is inspired by the so-called supernetwork technique. Among all modes, pedestrian networks play an important role in modeling transfer connections. We test our model and algorithm based on a case study in the Eindhoven region. The results indicate that our model and algorithms provide a suitable basis for ATIS applications. One current limitation is that much time is required for data reading and compiling. This can be solved by implementing existing computational strategies to increase efficiency.

Keywords: *Multimodal transport, traveler information system, route planning, supernetwork*

1. Introduction

As an integral important part of intelligent transport system (ITS), Advanced Travelers Information System (ATIS) will provide travelers with pre-trip information about travel options as well as real-time advice on navigating through a dynamic transportation network, where conditions may change rapidly many times in the course of a typical day. In many countries, P&R facilities are introduced, which facilitate changes between private (e.g., car) and a public transport mode (e.g., train), to alleviate congestion problems in inner city areas. Therefore, the ability to model multi-modal trips that involves both private and public transport modes is increasingly relevant. The fundamental issues behind above mentioned services are how to model properly the multimodal transport network for ATIS and how to design the corresponding algorithms for supporting queries of travelers. To the best of the authors knowledge, no general multimodal transport network models (or seamless integrated models) and algorithms are available or suitable for large-scale ATIS applications that simultaneously consider private and public transport modes.

The purpose of this study is to develop and test a generic multimodal transport network model for ATIS application that can be used for large-scale transport systems. We propose and test a supernetwork approach where the networks for different modalities are integrated in a single network [1]. Although time is the only attribute in a current test application, the framework explicitly intends to support multi-criteria evaluation of modes and routes taking into account possible considerations such as monetary costs, comfort, safety, reliability and emission as well time. The model will provide the multi-modal routing system of i-Tour – a new generation personal mobility system that is currently under development [2]. The result of a test experiment in Eindhoven region verified the validity and feasibility of our model. The paper is structured as follows: some related researches and applications will be introduced in section two; some basic concepts will be introduced in section three; our model and algorithms will be presented in section four; test results will be discussed in section five; discussion will be given in section six; the final section will summarize the major conclusions.

2. Related work

Multimodal transport models and algorithms attract many researchers' interests. In Germany, Schultes [5] and Pajor [3] did extensive research to extend networks from single mode (mainly road network) to multimodal. Liu [6] proposed a switch point approach to model multimodal transport networks. Mentz Company [7] developed a journey planner system and

* Corresponding author. Tel.: +310402473145
Fax: +9876543210; E-mail: j.zhang@tue.nl

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applied it to a regional scale with relatively high spatial resolution (e.g. 511 transit services in San Francisco, journey plan service for Transport for London). Other applications include Bahn (German national railways timetable). In the United States, Zhang [8], Li [9], Jariyasunant [10] reported applications to support mobile multimodal ATIS in California for route planning. Peng [11] proposed a distributed solution for planning of trips in a larger transport system. Companies like Trapeze, Jeppesen, Google also developed their product. In the United Kingdom, there are also many multimodal ATIS applications like Transport Direct, Journey plan and TFL. Related companies include Logica, Journeyplan and so on. In the Netherlands, Van Nes conducted an extensive [12] research for designing multimodal transport networks. Beelen [13] developed a personal intelligent travel assistant for public transport. A national service for public transport route planning in the Netherlands is 9292ov. In other countries and regions, Houda [14] proposed a public transportation ontology. Ayed [15] proposed a transfer graph approach for multimodal transport problems. Zografos [16] described an algorithm for itinerary planning based on dynamic programming. He also reported work on the design and value of online passenger information systems. Wang [17] did a study on handling times and fares in a routing algorithm for public transport. Su [18] developed a multimodal trip planning system for intercity transportation in Taiwan. Kumar [19] developed a multimodal transport system for Hyderabad city in India. All above works reflect some aspects of multimodal ATIS. However, there is no general representation solution for multimodal transport that can take into account a broad range of attributes and transport modes as well as time dependency of transport services. In many cases, the connections between different modes are not clearly described or are handled in an ad-hoc fashion. Besides that, to what extent they balance objectives of accuracy and efficiency, which is important in large-scale applications, is also unknown.

The so-called supernetwork is a network of networks for different modalities or activities This concept is first introduced by Sheffi [20] in his theory about urban transport network equilibrium analysis and then extended by Nagurney [21] to include also non-transport activities (e.g. supply chains, financial networks). Carlier, Fiorenzo-Catalano, Lindveld and Bovy show how the approach can be used to model multi-modal networks that include both public and private modes. Arentze and Timmermans [22] have developed a methodology to include also activities at locations and to specify generalized costs of links in a supernetwork as a function of an individual traveller's state which changes as execution of an activity schedule progresses. Although the supernetwork approach is not new, there is no explicit description for modeling processes and precision requirements for ATIS applications based on a supernetwork.

3. Basic concepts

To model the multimodal transport network, it is helpful to take an abstract view at first step. The multimodal network can be viewed from many aspects. From a physical point of view, it can be classified into road, rail, water and air. On the other hand, from a functional point of view, it can be classified into private modes (e.g. foot, bike and car) and public modes (e.g. bus, train, tram, metro). An advantage of the functional view is that it highlights the service provision to a traveler. Private networks offer continues service at any time associated with both physical nodes and physical links. On the other hand, public transport networks offer discrete services according to time tables whereby physical nodes (e.g. stops, stations) are visible while physical links are usually invisible. Therefore, the functional view is suitable for modeling the multimodal transport network.

A second step for modeling involves finding a general representation that supports later multi-criteria evaluation of routes. For private transport networks, the physical nodes and links can be represented as such in a model. For public transport networks, it is more complex. In these networks, the time tables of services determine the transport links; physical links may sometimes even be unknown to the routing system (e.g. metro). Therefore, the goal for modeling multi-modal transport networks is to integrate all above factors together. Two available solutions are known in the literature: one is the time dependent approach where time table events are handled as properties of links (the link costs function); the other is the time expanded approach where time table events are separately represented as event nodes (i.e., arrivals and departures) [3]. To create an integrated multi modal transport network, transfer links between different modes have to be added when all subnetworks are ready. The resulting integrated network is often referred to as a supernetwork.

The third step for modeling is elaborating the model to make it fully meet the multi-criteria measuring requirement where time, monetary cost, effort and comfort (e.g. quality of mode, transfer time) are all integrated in a generalized costs measure. For time attributes, the private network models (especially for car) can be further classified into three types of links: time independent (the costs of the link are static); time dependent (costs of link vary through time in a known way from history) or stochastic time dependent (both history and real-time information are considered). Public transport network links are always time dependent and possibly stochastic. A general solution is to allow all nodes in a multimodal network to have a timestamp and all links to have a time-depending travel time. Travel time of a next link in an evolving trip can then be determined during the search for an optimal path by keeping track of the time consumed up to the current node and retrieving the appropriate travel time depending on the current time. For monetary cost attributes, the ordinary method can be used where the total monetary costs of a trip are accumulated by money consumed in each fragment of the trip. This is correct in private networks (e.g. car network) but incorrect in some public transport cases. Given a trip composed by three linear ordered nodes A, B, C, the total monetary costs of going from A to C may not be equal to the sum of costs from A to B and from B to C. Thus, some extra measures may need to be added to handle this problem. For comfort attributes, the main factors are the quality of services or mode for the link, whereas the transfer and waiting effort should also be considered in the multimodal transport network. This means that transfer links should be explicitly represented in the network in some way (e.g. transfer node, transfer link). To integrate all these aspects in a measure of generalized costs, the key issue is how to judge the relative weights of the different attributes. In most existing approaches [4], one lets the user assign a weight value. A more advanced way is to use conjoint analysis (stated choice experiments) or estimate the weights based on observations of actual travel choices of a sample of individuals.

The final step involves selecting a proper algorithm for computing shortest paths. In the ideal case, a general shortest path algorithm (e.g. Dijkstra, A*) can be implemented directly. If this is not feasible given the network model, then

incorporating some form of restriction checking into the algorithm may provide a solution.

4. Method

First, from the abstract view, we would like to model the multimodal transport network distinguishing two types of networks: the private and the public. In the private transport network, only physical nodes are contained whereas in public transport network, both physical nodes and event nodes are included to account for time tables of public transport services. An abstract fragment of a private transport network is represented in figure 1. All nodes and links in a private transport network are physical links (road segments).

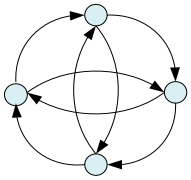

Fig. 1. Representation of a private network

An abstract fragment of a public transport network is represented in figure 2 which includes a stop (e.g., a bus stop or train station) and related events [3]. The top-level node is a physical node (the stop) while the other nodes are event nodes (arrivals or departures). Each event node has a link to the stop node and the direction is decided by event type. If the event type is arrival then the direction is from event node to stop node (alighting). If event type is departure, then the direction is reversed (waiting and boarding). Besides that, all event nodes are ordered in the way that a higher-level node refers to an earlier event. The directions of links between event nodes related to a same stop are from an earlier event to a later event. The latter links refer to either waiting or transferring. Another type of link is a trip sequence link which connects event nodes between stops from an earlier event to later event. These links represent movement of a public vehicle from one stop to another stop.

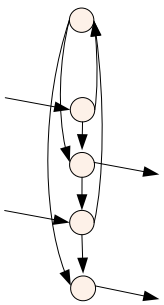

Fig. 2. Representation of a public transport network

Second, from the general view, we would like to have a general representation of a multimodal transport network where the basic elements are just nodes and links. This is described in figure 3. As we mentioned before, there are two kinds of nodes in a supernetwork: physical nodes which represents locations and have X, Y coordinates as necessary attributes, and event nodes which represent the arrival and departure events at certain stops or stations. The latter nodes have event type, event time and service related factors (e.g. bus stop sequence) as necessary attributes. Only physical links have distance, time, speed, monetary costs, emission, quality and generalized cost as necessary or possible attributes.

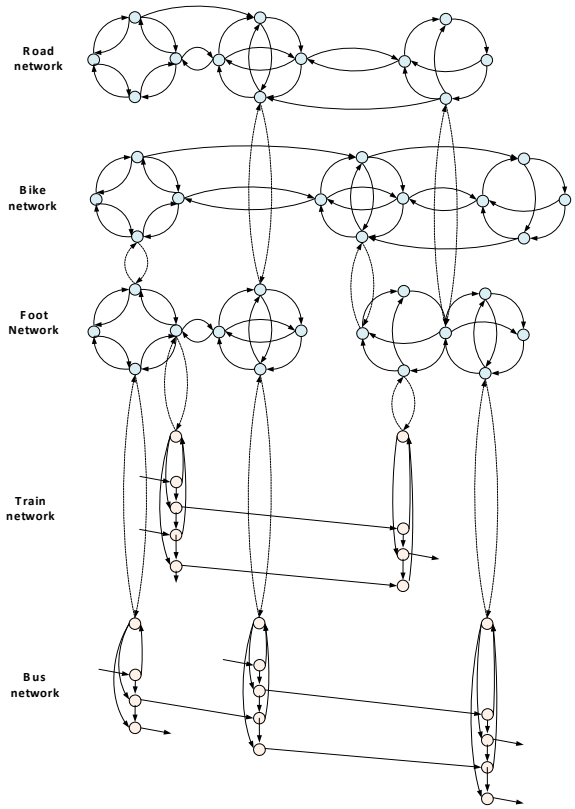

Fig. 3. Representation of a multimodal transport network

It should be noticed that there are two kinds of transfers: one is within a same mode (e.g. transfer from one bus line to another), the other is between different modes (e.g., transfer from bus to train) which are represented by dashed lines in figure 3. The foot (pedestrian) network plays a key role in mode transfers: all transfer links are connected to this network, as walking is always involved in such transfers. There are several solutions for adding transfer links. A simple solution is that each node in a particular layer is linked to the nearest node in the foot network. Another possible solution is to find the nearest link in the foot network and insert a transfer node at the intercept point. The latter one is more realistic, but requires more operations.

Different degrees of elaboration of a network exist. It is important to check whether a model meets the requirements for measuring and calculating all performance characteristics of routes that are considered important. If not, one has to modify or elaborate. In this study, we mainly focus on travel time. The model displayed in figure 3 is adequate for accurate time calculations in a multimodal transport network. This model may not be appropriate, however, for complex fare computations. Required extensions will be considered in future research.

To test whether this conceptual model works well, we program the algorithms to generate the structures using data of real networks and transport services. Thus, the algorithms needed are twofold: an algorithm for compiling the multimodal transport network based on data about road networks and

public transport services and a routing algorithm that is able to find multi-modal routes as shortest paths through the network. Figure 4 shows a flow diagram of the compiling algorithm part.

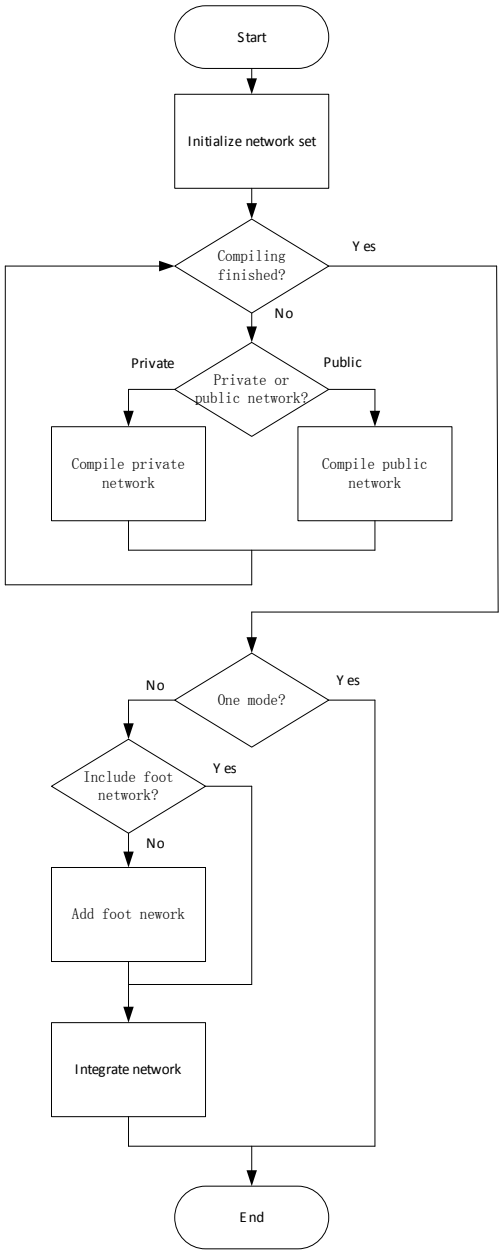

Fig. 4 Flow diagram of the algorithm for compiling multimodal transport networks

The algorithm consists of three steps: 1) initialize individual networks; 2) compile each individual network and 3) integrate the individual networks into a single multimodal transport network. In the compilation step, there are two compilers corresponding to two kinds of abstract networks – private and public. In the integration step, which is relevant only if there is more than one mode, the foot network is crucial for determining transfer links. The foot network needs to be added and compiled also when it is not in the network mode set because this mode is always involved in transfers. In the integration step, for simplification, we choose to add transfer links through searching nearest nodes in the foot network. When a full multimodal transport network has been constructed in this way, we can use routing algorithms to check the consistency of the model. Commonly used algorithms include the Dijkstra algorithm and A*. In terms of calculating the time between two nodes, we distinguish four link cases: location node to location node; location node to event node; event node to location and event node to event node (figure 5).

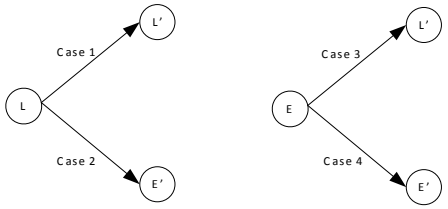

Fig. 5 Flow diagram of the algorithm for compiling multimodal transport networks

In figure 5, L means location node and E means event node. To calculate the time spent on the link, the following rules can be used. If the origin node is a location node and the target node is also a location node, then time on the link equals the length of the link divided by speed (case 1). If the origin node is a location node and the target node is an event node, there are two cases. If the time stamp of the event node is later than the current time at the location node then the time on the link equals the difference, else it equals positive infinity (the node cannot be reached) (case 2). If the origin node is an event node and the target node is a location node, then the time on the link equals the length of the link divided by speed (case 3). If the origin node is an event node and the target node is also an event node, then time on the link equals the difference between their timestamps (waiting time) (case 4). Given the way we compile the whole network (as explained before), the timestamp of the target node will always be later than the origin node. In summary, we define the time on a link as follows:

$$Time\ on\ link = \begin{cases} length / speed & case\ 1 \\ E'.timestamp - L.timestamp & case\ 2a \\ +\infty & case\ 2b \\ length / speed & case\ 3 \\ E'.timestamp - E.timestamp & case\ 4 \end{cases}$$

To accelerate the speed of compiling, optimize database indexing and omitting unnecessary data are possible options. To accelerate the speed of path-search algorithms, in addition strategies such as making use of the hierarchical structure of road networks, data pre-processing (caching data into memory), bidirectional search and heuristic search can also be incorporated. However, in the present study, we use the classic Dijkstra algorithm without any accelerating strategy.

Table 1. Collected multi transport data

Mode	Num. node	Num. link	Num. records
Foot	4654	6819	
Bike	4646	6781	
Car	4755	6957	
Bus	1736		121584
Train	13		3009

5. Test and illustration

We collected road network data and public transport data in Eindhoven region (The Netherlands, approx. 200,000 inhabitants) to test and illustrate the algorithms. The data include six modes which are foot, bike, car, bus and train. For public transport, time-table and route information is included in records of events and bus stops. The foot network includes 4,654 nodes and 6,819 links. The bike network includes 4,646 nodes and 6781links. The car network includes 4,755 nodes and 6,957 links. For the bus network, there are 1,736 bus stations and 121,584 arrival/ departure events for one day. In terms of the train network, there are 13 train stations and 3,008 arrival/departure events for one day, given the time tables of the bus lines in the region. We assumed that the speed of walking is 5 km/h, the speed of cycling is 15 km/h, and the speed of car follows the maximum speed limitation for the road concerned.

Table 2. Parameter setting

Parameter name	Parameter value
Start place	Salderes, Best
End place	Mackenzie Street, Geldrop
Start time	09:20
Preference	Fastest
Mode set	Foot, Bike, Car, Bus, Train

We consider a trip from Salderes, Best to Mackenzie Street, Geldrop in Eindhoven region. The start time of the trip is set as 09:20:00. The travel preference is set as fastest. Each transport mode is considered to be available for the traveler. As a test, we only select: foot + bike + train. The details of the computer environment are as follows: CPU: Intel E8400 RAM: 2G (shared with graphic card); operation system: Windows XP SP3; programming language: JAVA; algorithm: basic Dijkstra. As table 3 shows, the network compilation time is very short for private modes and very long for public modes; the route calculation time is very short (< 0.1s) for private modes, and also very long for public modes when there are a lot of arrival and departure events.

Table 3. Computation times

Mode	Netwrok compilation time(s)	Route calculation time(s)
Foot	0.329	0.031
Bike	0.328	0.031
Car	0.328	0.031
Bus	7.391	1.25
Train	0.334	0.265
Foot bike train	8.062	0.46955

Figures 6- 11 show the route planning results of different mode sets graphically. As expected, the foot route in figure 6 is similar to the bike route in figure 7 whereas the car route in figure 7 is quite different because of availability of high ways. In figures 9and 10, the red dots represent the stations passed on the route; the light-blue dots stand for transfer stations where traveler has to get off from one vehicle and can board on another. In figures 10 and figure 11, the green line means bike route; yellow line means train route. In multimodal route (Fig. 11), foot mode are replaced by bike, this is due to bike is faster than foot.

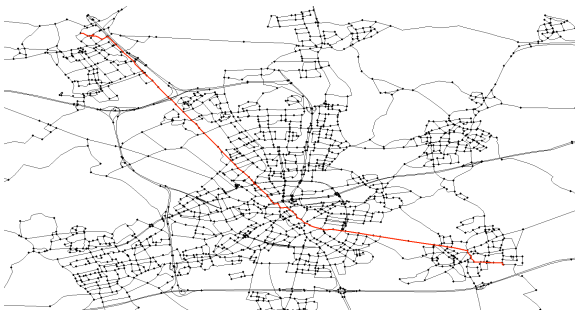

Fig. 6 Foot route fastest

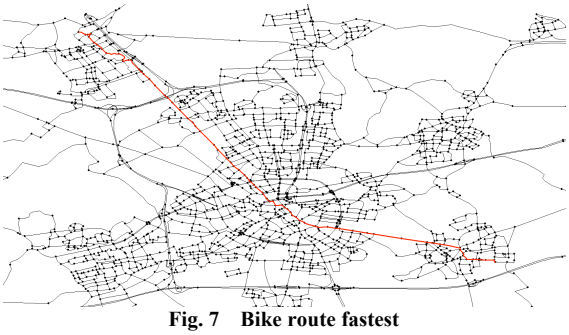

Fig. 7 Bike route fastest

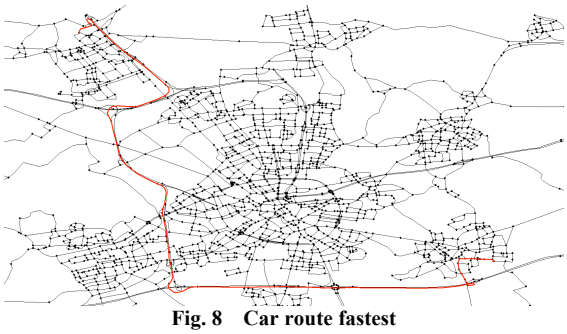

Fig. 8 Car route fastest

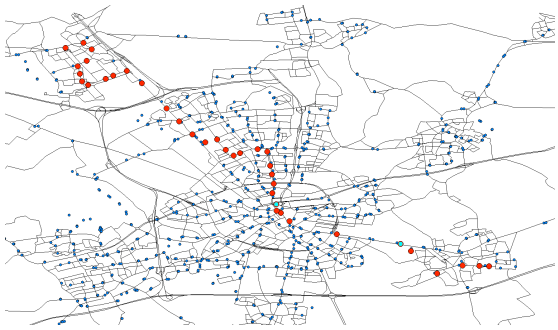

Fig. 9 Bus route fastest

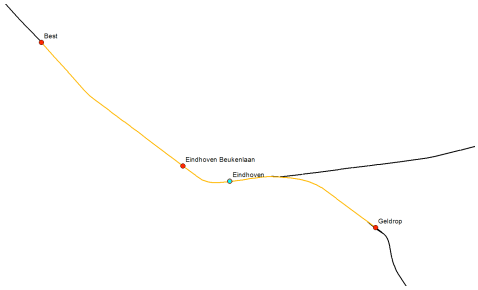

Fig. 10 Train route fastest

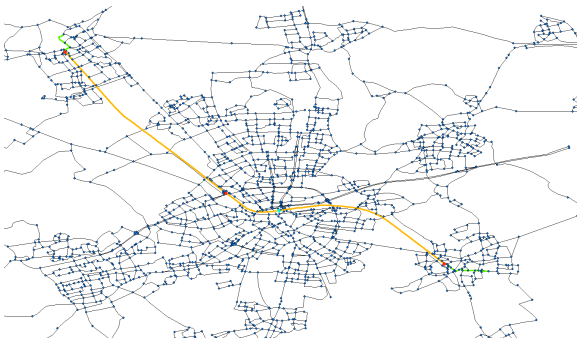

Fig. 11 Multi modal route fastest

6. Discussion

From the aspect of time cost (table 3), we can see both network compilation time and route calculation time increase dramatically when large size public transport data are added. For the compilation time, cache technology normally can greatly reduce the time because the server only needs to compile once, when the server starts. For the route calculation time, the classic Dijkstra seems not fast enough when large data sets of public transport time tables are involved. Two approaches can be implemented to improve the calculation performance. The first one is to use an accelerating strategy, such as bi-direction search or heuristic method like A*.The second one is to restrict the search space by data preprocessing.

From the aspect of quality, the routing result is good in general. The fastest route of foot and bike equals the shortest one. While the fastest car route very often is not equal to the shortest one. The route of public transport may vary due to different start times. For multimodal transport route, it is very close to the realistic route selection.

The test algorithm and results verified the validity and feasibility of our proposed integrated multimodal transport network model. The test results indicate that even the basic Dijkstra algorithm could be used to find high quality routes in short computation time for realistic networks. However, a limitation of the current model is that long computation time is needed to read and compile the integrated network. We will test several accelerating strategies in future research. Furthermore, we will extend the set of attributes included in generalized costs functions for links.

7. Conclusions

There is no generic multimodal transport network model existing for ATIS applications. In this study, we proposed an approach that is based on an abstract modeling view (private network and public transport) and is inspired by the supernetwork technique (a general way to construct an integrated multimodal transport network). Results of a test experiment in the Eindhoven region indicate that our model and algorithms provide a suitable basis for ATIS applications.

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References

[1] Nagurney, A, Dong, J., Mokhtarian, P. L.. Teleshopping versus shopping: a multicriteria network equilibrium framework. Mathematical and Computer Modelling, 34 (7-8), 2001, 783–798. http://dx.doi.org/10.1016/S0895-7177(01)00099-1

[2] http://www.itourproject.com/web/, 2011, June,.

[3] Pajor, T.. Multi-modal route planning. Master thesis of Karlsruhe Institute of Technology, 2009.

[4] Andre, P., Wilson, M. L., Owens, A. & Smith, D. A.. Journey planning based on user needs. Computer/ Human Interaction 2007 Conference, San Jose.

[5] Schultes, D.. Route planning in road networks. Ph.D Thesis of Karlsruhe Institute of Technology, 2008.

[6] Liu, L., Meng, L. Algorithms of multi-modal route planning based on the concept of switch point. 6th International Symposium on LBS & TeleCartography, Nottingham, UK, 2009.

[7] Rehrl, K., Bruntsch, S., Mentz, H. J.. Assisting multimodal travelers: design and prototypical implementation of a personal travel companion. IEEE Transactions on Intelligent Transportation Systems, 8(1), 2007, 31-41. http://dx.doi.org/10.1109/TITS.2006.890077

[8] Zhang, L., Li, J.Q., & Zhou, K... Design and implementation of a traveler information tool with integrated real-time transit information and multi-modal trip planning. Transportation Research Board Annual Meeting, Washington, D. C, 2011.

[9] Li, J. Q., Zhou, K., Zhang, L. & P. Zhang, W. B., A multimodal trip planning system incorporating the park-and-ride mode and real-time traffic/transit information. Transportation Research Board Annual Meeting, Washington, D. C., 2010.

[10] Jariyasunant, J.. Mobile transit trip planning with real–time data. Transportation Research Board Annual Meeting, Washington, D. C. 2010.

[11] Peng, Z. R., Kim, E.. A standard-based integration framework of distributed transit trip planning systems. Journal of the Intelligent Transportation Systems, 12(1), 2008 13-19. http://dx.doi.org/10.1080/15472450701849642

[12] Zhang, L., Li, J.Q., & Zhou, K.. Design and implementation of a traveler information tool with integrated real-time transit information and multi-modal trip planning. Transportation Research Board Annual Meeting, Washington, D. C, 2011.

[13] Beele, M. Personal intelligent travel assistant: a distributed approach. Masterís thesis of Delft University of Technology, 2004.

[14] A public transportation ontology to support user travel planning. IEEE International Conference on Research Challenges in Information Science, Nice, France. 2010.

[15] Ayed, H., & Khadraoui, D.. Transfer graph approach for multimodal transport problems. Second International Conference MCO, Metz, France – Luxembourg, 2008.

[16] Zografos, K. G., & Androutsopoulos, K.N.. Algorithms for itinerary planning in multimodal transportation networks. IEEE Transactions on Intelligent Transportation. Systems, 9 (1), 2008, 175-184. http://dx.doi.org/10.1109/TITS.2008.915650

[17] Wang, M..Optimal paths based on Time and fare in transit network. Master thesis of National Cheng Kung University. 2008.

[18] L Su, J.M. Chang, C.H., Ho, W.C., Development of trip planning systems on public transit in Taiwan, IEEE International Conference on Networking, Sensing and Control, Hainan, China.. Transportation Research Board Annual Meeting, Washington, D. C. 2008

[19] J Kumar, P, Singh, V, Reddy, D.. Advanced traveller informantion system for hyderabad city. IEEE Transactions on Intelligent Transportation Systems, 6(1), 2005, 26-37. http://dx.doi.org/10.1109/TITS.2004.838179

[20] Sheffi, Y. Urban transportation networks: equilibrium analysis with mathematical programming methods, Prentice-Hall, 1985.

[21] Nagurney, A, Dong, J., Supernetworks: decision-making for the information age. Edward Elgar Publishing. 2002.

[22] Arentze, T., & Timmermans, H. J. P.. Multistate supernetwork approach to modeling multi-activity, multimodal trip chains. International Journal of Geographic Information Science, 18(7), 2004, 631–651. http://dx.doi.org/10.1080/13658810410001701978