Integrated Vehicle and Passenger Simulation Model Considering a Multimodal Transportation Network

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1 INTRODUCTION

Activity-based modeling (ABM) and dynamic traffic assignment (DTA) have their own domains, demand and supply respectively, and both use fairly well-developed methodologies. However, both ABM and DTA have their own internal assumptions which rely on simplifying the main characteristics of the other. For this reason, recent efforts in transportation planning have focused on how to integrate these two major domains. Integration efforts include CEMDAP-VISTA, TASHA-MATsim, and OpenAMOS-MALTA (*1, 2, 3*), and recent projects in the US such as the SHRP2 C-10 projects. From one side, ABM can be strengthened by adding detailed, time-dependent system response, according to the traffic conditions for traveler decision-making. Second, the fixed, time-dependent origin-destination demand used within DTA models can be made more flexible if it is supported by ABM, rather than using stationary origin-destination (O-D) travel demand, to capture time-dependent route choice and related traffic equilibria.

One form of integration of ABM and DTA involves simply passing outputs between models in some sort of sequential process (*1, 2, 3*). ABM supports DTA by producing the demand as an input, and DTA supports ABM by generating time-dependent travel times for daily travel decisions. To complete the integration, both interactions are necessary, perhaps using some iterative procedure. However, in this research, we are more interested in simulating the performance of the transportation system for both auto and transit modes, in a manner which is compatible with the output from the ABM. This paper contributes to research in this area by exploring how to incorporate multimodal travel directly into a large-scale transportation system simulation tool. We use transit and intermodal (auto-transit) modes in which the transit schedule, accompanied by the time-dependent travel times of vehicles, represents the real transit system. Specifically, Google's General Transit Feed Specification (GTFS) is fundamentally utilized to provide detailed information on available routes and scheduled services. The simulation allows us to capture realistic and detailed travel behavior, like missing a bus due to the late arrival of passengers, being unable to board a bus because it is already too full, or delaying the bus through from the time necessary for passenger boarding and alighting.

Comparing previous studies (*1, 2, 3*), one of critical issues for integrating ABM into DTA is the ability to capture intermodal travel with public transit through various access and egress modes, such as walk-transit-walk, auto-transit-walk, and walk-transit-auto, all under time-dependent circumstances. We want to focus on this intermodal travel more on DTA side for the main contribution of this study. For the proposed intermodal simulation, we use two main objects: vehicles, which we separate into autos and transit vehicles, and individual travelers. For the realization of the proposed architecture we introduce a mesoscopic vehicle simulation tool, **M**ulti-resolution **A**ssignment and **L**oading of **T**ransportation **A**ctivities (MALTA) (*4*). MALTA simulates auto and transit vehicles through the movement of auto and transit vehicles in a mesoscopic traffic flow model. To capture transit passenger movements, we propose a model called **F**lexible **A**ssignment and **S**imulation **T**ool for **Tr**ansit and **I**ntermodal **P**assenger**s** (FAST-TrIPs). This model essentially activates passenger movements for boarding and alighting at specific stops to accompany the realized transit vehicle movements. Passengers may choose a strategic path, called a hyperpath (*6, 7*), to travel from their origin to their destination. Also, transit vehicles, although simulated in MALTA, are governed by vehicle holding policy within FAST-TrIPs, including schedule-based holding, in which a vehicle is held until its scheduled departure time.

In addition, we propose an intermodal path model, including a hyperpath for transit passengers on the transit schedule network, and an intermodal path using the heuristic one-to-one shortest path algorithm, A*. This intermodal travel typically considers park-and-ride service in which a hyperpath is generated on the transit schedule network and then is extended to create an intermodal path from origin to destination using an elementary auto path.

This paper consists of four main sections. In Section 2, we propose the transit passenger- and intermodal-related path models. In Section 3, we describe the main simulation model appropriate for the integration with ABM, especially a tour-based model. Section 3 also includes a description of the specific vehicle and passenger simulation models. The application of the simulation model is described in Section 4, using the transportation network and demand of Rancho Cordova, CA. Section 4 also includes results, conclusions, and on-going works.

2 INTERMODAL NETWORK AND PATH ALGORITHM

Auto and Transit Schedule Network

The intermodal network is fundamentally represented by two parts: the auto network and the transit schedule network, as shown in Figure 1. The auto network is represented using a time-expanded network, typically constructed with one-minute resolution or even finer temporal detail. On the other hand, the transit network consists of a link-based expansion scheme, in which each vehicle trip (or run) between two consecutive stops is represented as one link having a departure time (t_a^{dep}), arrival time (t_a^{arr}) or a travel time ($t_a^{trv} = t_a^{arr} - t_a^{dep}$). We call such a transit network representation as a link-based time-expanded (LBTE) network (*5*). It is worth noting that the auto and transit schedule network differ in their path search methods. Specifically, the intermodal path assignment comprises a time-dependent shortest path in the auto network and a time-dependent hyperpath from the transit schedule.

Path Models on an Intermodal Network

For the intermodal path in the network, we propose a path model using an A* shortest path for the auto segment and an all-to-one (from all origins or park-and-ride facilities to one destination) hyperpath for the transit segment. A walk-transit-walk trip, in this case, would only utilize a hyperpath on the transit schedule network. For the path search, we assume that travelers making a transit or intermodal trip have their own preferred arrival time (PAT) at the destination and that an intermodal trip happens through a park-and-ride facility. For a passenger, their PAT is normally set up using a specific time window, such as 30 minutes before and up to the PAT, at the destination. For example, assume a traveler wants to arrive to his/her work place at 8:30. The passenger would like to arrive earlier than 8:30, and hence may generate multiple paths in the transit schedule network to arrive at the destination between 8:00 and 8:30. According to the defined PAT and time window, an intermodal path will be generated from destination using a backwards search to the origin. If a specific trip is intermodal, then once the transit search reaches a park-and-ride facility (backward from the destination), a one-to-one A* shortest path is triggered from the park-and-ride facility (node) to the specific origin(s). At the origin, the least cost intermodal path is selected as the traveler's intermodal path. The conceptual algorithm can be explained through Figure 1 specifically as the "Intermodal A*-Hyperpath Algorithm" in Figure 3.

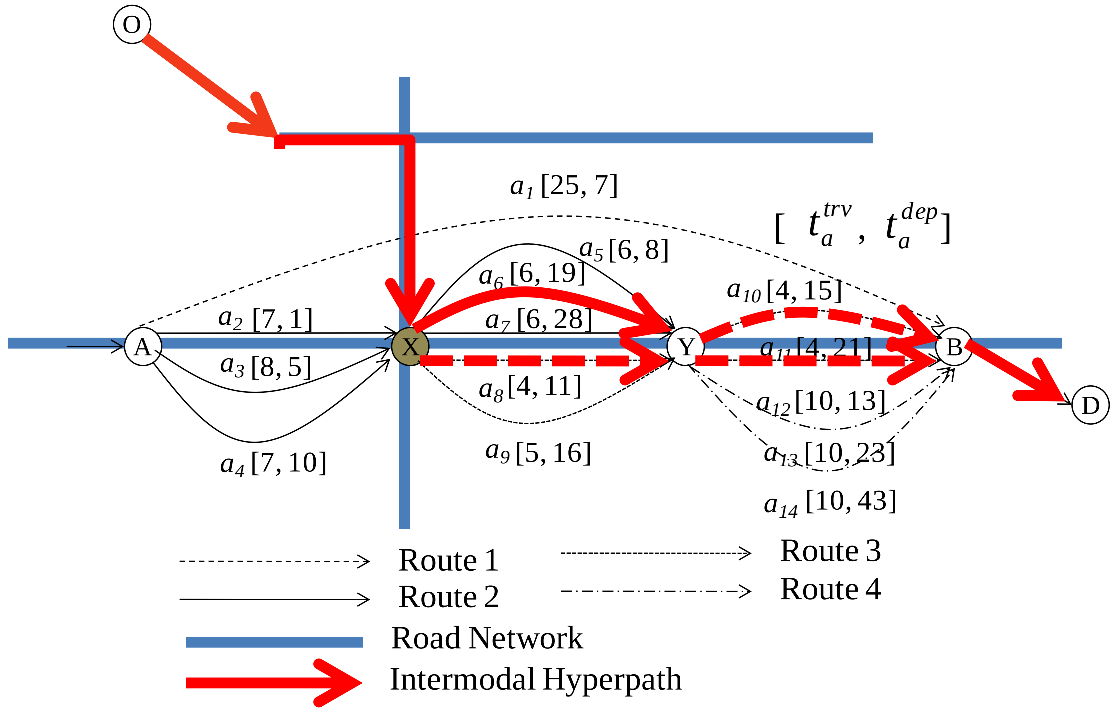


Figure 1. Example of an Intermodal Hyperpath using a Transit Schedule Network and a Time-dependent Road Network

As we assume a backward search from the destination to the origin in Figure 1, an intermodal traveler will search for the alighting stop (B) and then apply the hyperpath search backwards until the search reaches a park-and-ride facility (X). The hyperpath in the transit network is chosen to maximize the utility of the hyperpath. After the search arrives at the park-and-ride node (X), a time-dependent A* algorithm searches to the origin from the node X. More detail of the intermodal path algorithm is shown in Figure 3.

Hyperpath on a Transit Schedule Network. The concept of a hyperpath was introduced to consider a passenger path choice "strategy" in frequency-based transit assignment (*6*, *7*), and the methodology has been studied and applied for a transit schedule-based assignment as well (*8*, *9*). In a transit schedule network, each alternative is specified by each vehicle run in the schedule, and an individual traveler will consider the set of alternatives according to the cost from his/her origin stop to his/her destination. The set of alternatives in the passenger's choice set at the stop will minimize their total travel cost, represented by the following generalized cost function.

$$c'_a = \min_{\{b\}}\left[\frac{1}{\theta}\ln\sum_{b\in F_a}\exp[\theta(\hat{c}_b + \beta_{trsfTime}t_{ab} + \beta_{waitTime}w_{ab})]\right] \tag{1}$$

where $\hat{c}_a = c'_a + \beta_1 c_a$

With these basic assumptions, a link cost is updated using a two-step process in Equation (1) and Figure 2, connecting two different links b_2 and b_3. First, the cost is updated among alternatives using (1); then, its link label ($\hat{c}_{a_1}$) is updated by adding the link cost (c_{a_1}) to the log-sum. For the cost update, we utilize a log-sum function, following a stochastic user equilibrium behavioral assumption. The cost c'_{a1} at the end of link a_1 is generated by a log-sum function, including all alternatives that minimize the total cost to the passenger. For the cost update, other turn penalties, such as the transfer time t_{ab} and waiting time w_{ab}, can also be considered. After updating the cost, the link label is updated by adding the generalized link travel cost c_{a1}, in which β's are the parameters (weights) on different components in the generalized cost. Finally, following the hyperpath concept, we propose a label-setting hyperpath algorithm on the transit schedule network. More details on the transit hyperpath algorithm are given in Noh et al. (*5*).

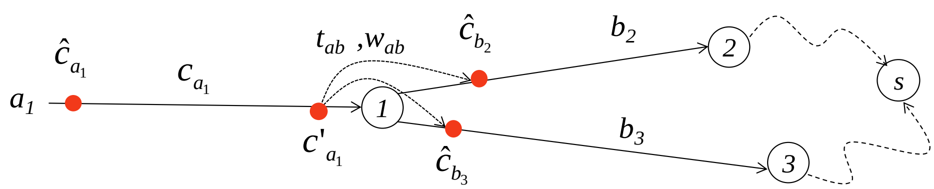


Figure 2. Cost Update of Weight Function on a Hyperpath

Intermodal A-Hyperpath on a Multimodal Network*. For the intermodal path, we utilize the one-to-one shortest path, namely the time-dependent shortest path (TDSP) A* proposed in (*10*), for the auto portion of the intermodal path. As in Figure 3, C_i is the label giving the minimum (cumulative) travel time from the origin start time τ_r, and $\hat{C}_i$ is the temporary label providing the estimated minimum cost from origin r to destination s when passing through node i. To estimate $\hat{C}_i$, the lower bound of the travel time from node i to destination s, e_{is}, is estimated. For a better performance, the lower bound can be updated by e_{ij} / *speed*, where *speed* is a factor determining the search area.

The intermodal hyperpath is built by combining the transit hyperpath and the one-to-one shortest path in the auto network. Similar models were applied on a frequency-based transit network (*11,12*). As the contribution of this research, we define an intermodal path using a transit schedule network, enhancing the resolution of time and describing the temporal travel behavior in the transit network. The intermodal hyperpath is searched backward from the destination to all origins, according to the PAT at the destination. Typically, a PAT is generated according to the estimated arrival time at the destination from an ABM model, since each traveler has an activity start time and an activity duration (or end time). Here again, a time window is set between the PAT (from the activity start time) and a safety buffer such as arriving up to 30 minutes before the start of the activity. In more detail, an auto-transit-walk trip is searched backwards, beginning from the egress (walk), directly transferred to the transit mode; and, once arriving (backward) at any park-and-ride facility, the auto mode is searched back to the origin.

The intermodal hyperpath algorithm is shown in Figure 3. For this, a small modification of the traditional hyperpath algorithm is required, especially for creating the auto access link on the intermodal network. From step 01 to step 04 in the algorithm, access links $e_{access}(i,j)$ and egress links $e_{egress}(i,j)$ are created. Fundamentally, access links are only created between the origin node i_{od} and park-and-ride node j_{pandr}.

For other stops j_{stop}, an egress link is created, but satisfying a walking distance upper bound $\bar{d}$. From Step 05 to 09, the multimodal adjacency list is created. When the algorithm searches an auto access link, that access link cost will be updated by the path cost from the TDSP A* algorithm, from the origin to the park-and-ride facility.

// Hyperpath Algorithm --

01: **for** $((a,b))$

02: $F_a = \{b \in L \setminus a \,|\, t_a^{arr} + t_{ab}^{trsf} < t_b^{dep}\}$; $B_b = \{a \in L \setminus b \,|\, t_a^{arr} + t_{ab}^{trsf} < t_b^{dep}\}$; $\hat{c}_a := \infty$;

03: $\hat{c}_s := 0$; $Q := \emptyset$;

04: **for** ($a \in B_s$) $Q := Q \cup \{ a \}$;

05: **while** $(Q \neq \emptyset)$

06: Retrieve $a \in Q$ and $Q := Q - \{ a \}$;

07: **for** ($e \in B_a$)

08: **if** $(\{ e \} \cap Q = \emptyset)$ **then** $Q := Q \cup \{ e \}$

09: **for** ($b \in F_a$)

10: $\hat{c}_a^{new}$:= ***set_optimal_set***(a , b);

11: **if** ($\hat{c}_a^{new} < \hat{c}_a$) $\hat{c}_a := \hat{c}_a^{new}$;

12: **if** $(\{ a \} \cap Q = \emptyset)$ **then** $Q := Q \cup \{ a \}$

// TDSP A* algorithm --

01: **for** ($j \in N$) $C_j := \infty$, $\hat{C}_j := \infty$

02: $C_r := \tau_r$, $\hat{C}_r := e_{rs}$; $Q := \{r\}$; $i = r$;

03: **while** $(i \neq s)$

04: Retrieve $i = \arg\min_{j \in Q} [\hat{C}_j]$ $Q := Q - \{i\}$;

05: **for** ($j \in F_i$)

06: **if** ($C_i + t_{ij}^{C_i} + e_{js} < \hat{C}_j$) **then**

07: $C_j = C_i + t_{ij}^{C_i}$; $\hat{C}_j = C_i + t_{ij}^{C_i} + e_{js}$;

08: **if** $(\{ j \} \cap Q = \emptyset)$ **then** $Q := Q \cup \{ j \}$;

// Intermodal A*-Hyperpath Algorithm--

01: **for** (i_{od}, j)

02: **if** $(j_{type} = pandr)$ **then** generate $e_{access}(i,j)$;

03: **else** $(j_{type} = stop)$ **then**

04: **if** $(d_{ij} < \bar{d}\,)$ **then** generate $e_{egress}(i,j)$;

05: **for** ($(a,b) \in M$)

06: **if** ($a_{type} = transit$ and $b_{type} = transit$) **then**

07: $F_a = \{b \in L \setminus a \,|\, t_a^{arr} + t_{ab}^{trsf} < t_b^{dep}\}$; $B_b = \{a \in L \setminus b \,|\, t_a^{arr} + t_{ab}^{trsf} < t_b^{dep}\}$; $\hat{c}_a := \infty$;

08: **else then**

09: $F_a = \{b \in L \setminus a\}$; $B_b = \{a \in L \setminus b\}$; $\hat{c}_a := \infty$;

10: // Hyperpath Algorithm: Step 03 ~ 09

11: // Hyperpath Algorithm: Step 10

12: **if** $(a_{type} = access)$ **then** // TDSP A* algorithm and update c_a

13: // Hyperpath Algorithm: Step 11 ~ 13

Figure 3 Intermodal A*-Hyperpath Algorithm

3 INTEGRATED VEHICLE AND PASSENGER SIMULATION

Premise for ABM and Its Output

Activity-based models can be separated to two streams: tour-based models like DaySim (*13*) and sequential activity choice models like OpenAMOS (*14*). First, the tour-based model creates the whole demand or schedule for each traveler for a given day, which then can be used to generate origin-destination (OD) or tour-based inputs to the DTA model. Second, the sequential activity choice model behaves in a similar way, but the model generates *discretionary* trips in the daily schedule only according to a possible set of activity destinations within the traveler's time-space prism (TSP) constraints. In this case, the discretionary travel depends on the actual traffic conditions and any TSP constraints that come up *during* the day, and these are not pre-specified. When we consider an integrated model, this latter (sequential) treatment of discretionary travel is reasonable, but it may generate unstable DTA results because the trip timing, destination, and route are not known in advance. For the integration, the sequential activity choice model also requires a within-day loop, especially for the discretionary trips that must be communicated between the ABM and DTA, as well as the day-to-day (outer loop) integration.

Considering this background, to integrate a DTA system with an activity-based model, we assume for now that the demand from a tour-based model is provided, in the form of an input file to the DTA model for handling intermodal travel simply. In this case, the sequence and location of activities for each individual will not change. After the assignment of the travel demand in the DTA model, the skim matrix for the next iteration will be fed back into the tour-based model. We make this assumption here because we are focusing more specifically on the proposed integration between the traffic and transit models (MALTA and FAST-TrIPs), specially incorporating an intermodal travel capability with the tour-based demand. However, it is worth noting that the proposed traffic and transit models can be applied to a sequential ABM model as well.

Vehicle and Individual Traveler Simulation

Auto and Transit Vehicle Simulation. One of the main contributions of this study is the integration of dynamic traffic and transit assignment and simulation. In our study, we utilize MALTA communicating with FAST-TrIPs. The vehicle objects in MALTA are mainly divided to two types, auto and transit vehicles, which follow the anisotropic mesoscopic simulation (AMS) model (*15, 16, 17*) for traffic flow. To represent reasonable transit vehicle runs, each transit vehicle follows a detailed movement module in FAST-TrIPs, allowing the dwell time to vary by the number of passengers boarding and alighting and allowing a schedule-based holding policy. As shown in Figure 5, for the transit vehicle movements, a transit vehicle object will receive the information in advance about the potential number of boardings and alightings at the next stop. If there are no passengers boarding or alighting, the vehicle may pass by the stop; otherwise, it will stop and a dwell time is estimated based on the number of passengers boarding and alighting. Also, the vehicle object will check its departure time at the stop with a holding flag. If the dwell time or holding status is turned on, the transit vehicle will not leave the stop until the next simulation time interval Δt.

Integrated Traveler-Vehicle Simulation. The proposed integrated simulation model between individual travelers and vehicles is as follows (see Figure 4). Initially, demand from an ABM, and transit GTFS data, are fed into the MALTA and FAST-TrIPs models. After the intermodal hyperpath generation in FAST-TrIPs, the auto path segment is transferred to MALTA for vehicle simulation. When the auto vehicle arrives at a park-and-ride node, a passenger object will then be given a transit departure time and assigned to a transit route. If the individual traveler is assigned the walk-transit-walk mode, the traveler object will be placed directly on the transit route. Each individual traveler on a transit route is then assigned to an elementary path, sampled from their assigned hyperpath. The elementary path consists of an initial boarding time, a series of boarding stops, vehicle trip IDs, alighting stops, and walking times including access/egress time and transfer times.

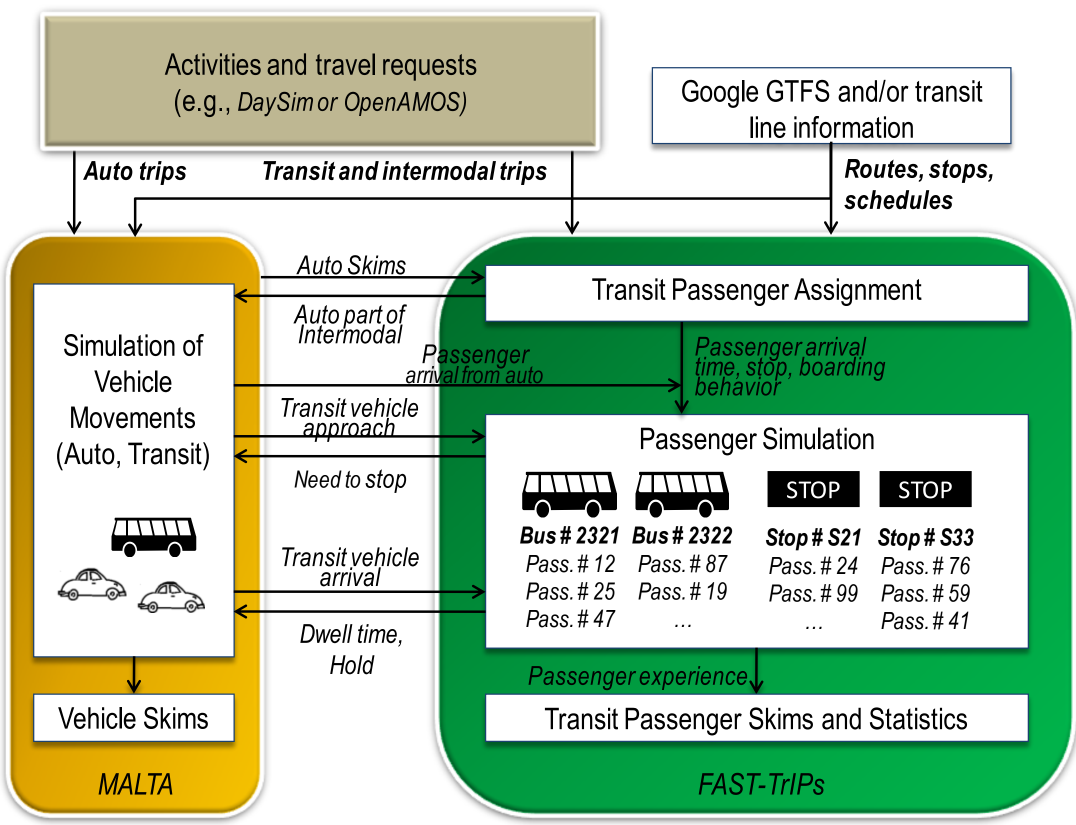


Figure 4. MALTA – FAST-TrIPs Integrated Simulation Model

The passenger movement is simulated by two major functions, which are the boarding/alighting and the transfer functions. Whenever a transit vehicle arrives to a stop and its status changes to “dwelling”, the first function is called and all boarding and alighting of passengers happens, as shown in Figure 5. At this time, the dwell time is calculated using the actual number of boarding and alighting actions, and this dwell time is assigned to the vehicle. Transit vehicles and stops have passenger containers to keep the passenger ID’s at the associated locations. In the boarding actions, passengers are removed from a stop’s container and added to the vehicle’s container, and vice-versa for the alighting actions. Considering the walking times for access, egress, and transfers, passengers are moved to the new location when required.

The experienced times, including arrival to the stop, boarding, and alighting are stored in the passenger object for post-processing. In general, the passenger simulation is a mixed approach, including both event-based and time-based simulation. Whenever a passenger is on board or loaded to a transit stop, it is not required to be processed until the next event, while those passengers who are walking and transferring between stops are scanned in each time interval until they are loaded to either a stop or to a vehicle, as appropriate.

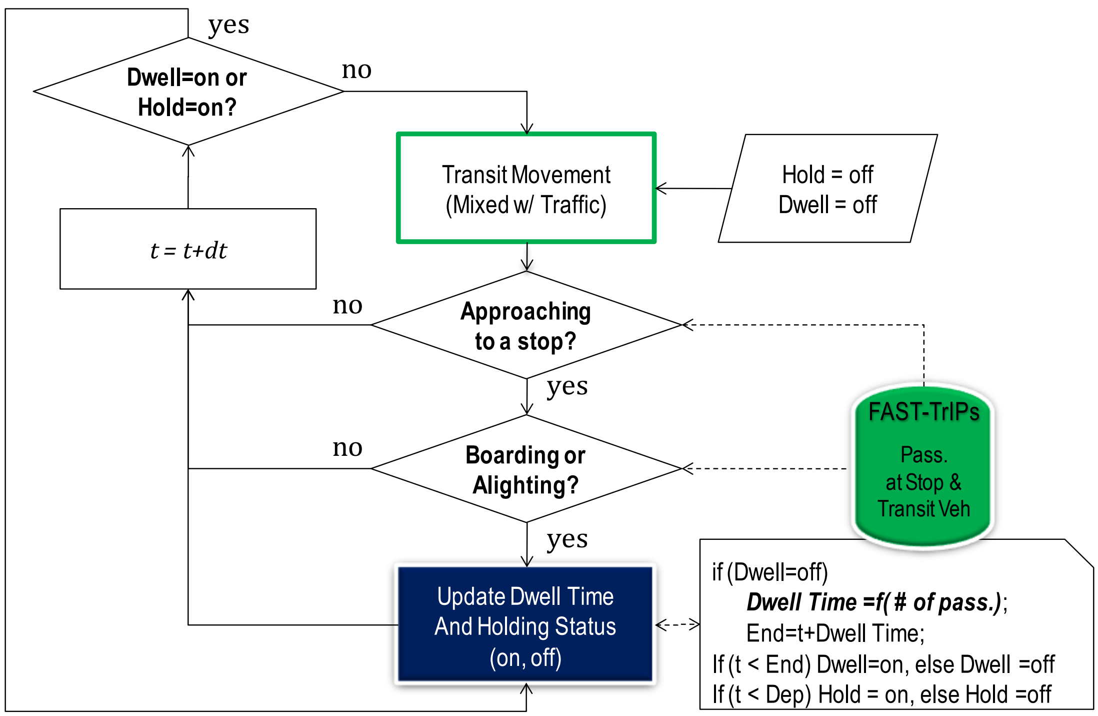


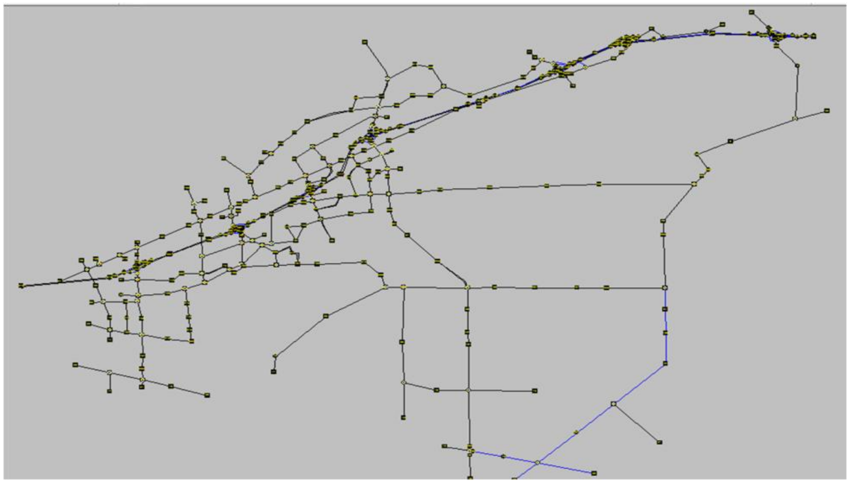
Figure 5. Transit Dwell Time and Holding Status Update

4 APPLICATION AND RESULTS

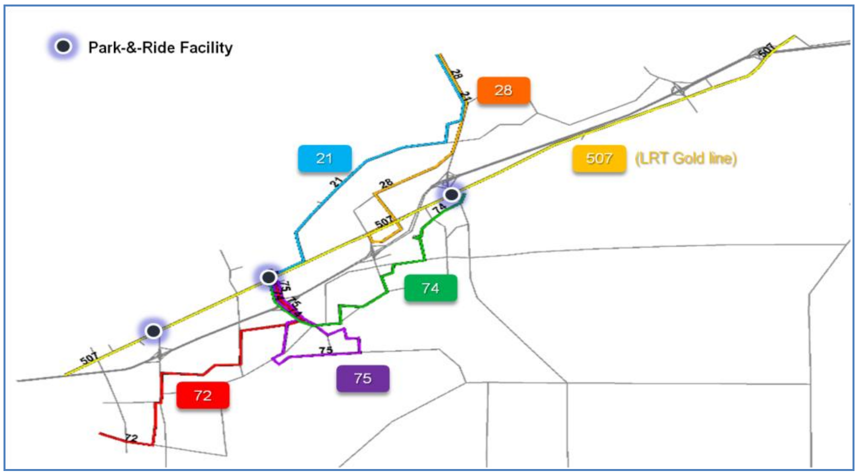
Multimodal Network and Demand

For the application, the Rancho Cordova area in California (near Sacramento) is chosen. The area is illustrated in Figure 6. Fundamentally, the auto network contains 448 nodes and 850 links. For this application, we consider a 200-minute time period, from 6:00 am to 9:20 am (minutes 300 to 500 in the day), is simulated using time-dependent travel times in the road network. For the simulation, 55,844 background autos and trucks are generated during the time period. On the demand side, 90 drive-transit-walk trips are generated, which are created randomly but based on the DaySim transit demand for the area. For the transit network, 163 stops, 4,601 stop times, and 205 trips are generated for five bus route (Routes 21, 28, 72, 74, and 75). In the Rancho Cordova area, there are three park-and-ride facilities, at Folsom Blvd. and Mather Field Rd., Trade Center Dr. and Sunrise Blvd., and Butterfield Way and Folsom Blvd.

However, this last park-and-ride facility was omitted since the GTFS does not connect this location with any of the five bus routes.



(a) Auto Network



(b) Transit Network

Figure 6. Test Network (Rancho Cordova, CA)

Results and Analysis

For the results, first we examine the results of the intermodal path assignment. An example of the path assignment is shown in Figure 7. The searched path in Figure 7(a) is given by the proposed intermodal hyperpath model, in which the transit path is an elementary path selected from within the hyperpath. The auto path shows a sequence of nodes and the estimated travel times. On the other hand, the transit path shows that passenger 101 from origin TAZ 47 to destination TAZ 69 starts his/her trip at 431 minutes (7:11 am), by boarding bus run 342185 at stop 319 and alighting at stop 2779 with egress time 3.58 minutes. The access time by auto to a park-and-ride facility is 9.79 minutes. The simulated path is shown in Figure 7(b). MALTA basically gives the vehicle trajectory for each different mode (vehType 1 = auto; 2 = truck; 3 = bus; 4 = LRT), noting that the auto and bus trajectories are separated to two different tables

(Figure 7(b)). The results give a coarse one-minute resolution on the vehicle trajectories. At each one-minute interval, the vehicle position (vehPos) is also recorded, giving the distance (ft) from the downstream node (toNode) at that particular instant in time. In MALTA, each transit vehicle follows its given route (a series of nodes), and transit stop information is listed separately. In the example, the passenger arrives at a park-and-ride facility (node 77) at 439 minutes (26340 sec) and the passenger will take the transit vehicle with vehID 342185 which leaves at the park-and-ride stop at 443 minutes (26580 sec). The passenger will reach the destination stop at around 453 minutes (27180 sec). The exact arrival time at the stop 2779 is recorded as 453.2 minutes in the FAST-TrIPs simulation model. An additional egress time (3.59 minutes) is added for the passenger to arrive at his/her final destination.

Auto path	278,33,117,276,116,127,111,275,120,114,274,99,263,100,262,98,147,77
Transit path	101 47 69 431 319 342185 2779 9.78596, 3.58535

(a) Searched Path

Auto VehID	currTime (Sec)	fromNode	toNode	vehType	vehPos(ft)	vehLane
15569	25860	278	33	1	87	1
15569	25920	33	117	1	63	1
15569	25980	276	116	1	92	1
15569	26040	276	116	1	0	1
15569	26100	127	111	1	29	1
15569	26160	275	12	1	11	1
15569	26220	274	99	1	80	1
15569	26280	263	100	1	1	1
15569	26340	147	77	1	2	1

Transit VehID	currTimeSec	fromNode	toNode	vehType	vehPos(ft)	vehLane	Stops on link
342185	26580	77	147	3	52	1	319
342185	26640	100	263	3	41	1	-
342185	26700	263	99	3	82	1	2770
342185	26760	274	114	3	89	1	2771
342185	26820	274	114	3	89	1	2771
342185	26880	114	120	3	74	1	2772
342185	26940	120	275	3	77	1	2773
342185	27000	275	111	3	89	1	2774,2775
342185	27060	111	127	3	48	1	2776
342185	27120	127	116	3	87	1	2778,2779,2780

342185	27180	127	116	3	87	1	2778,2779,2780
342185	27240	116	550	3	42	1	2781,2782
342185	27300	117	33	3	72	1	2784, 3027
342185	27360	33	32	3	74	1	3028
342185	27420	33	32	3	1	1	3028

(b) Realized Path

Figure 7. Example of (a) Intermodal Hyperpath Result (searched path) and (b) Simulation Result (realized path)

In addition, the searched paths are also compared to the realized paths from the vehicle and traveler simulation, comparing the travel times. The basic travel time results are shown in Table 1. The realized average auto access travel time is 5.87 minutes, with a minimum of 2.10 minutes and a maximum of 9.40 minutes. Also, the average transit in-vehicle travel time is 13.91 minutes. The average intermodal travel time is 19.78 minutes, with a minimum time of 7 minutes and maximum time of 56 minutes. The difference between the searched (or planned) and simulated (or realized) paths are shown in the last two columns in Table 1. The average difference of the access time is 2.17 minutes. This access time difference is affected by the accuracy of the given backward A* model. Also, the passenger may choose the earliest possible access link. To maximize the utility of the transit hyperpath, each passenger will try to have the earliest arrival time at the stop, to obtain the full set of alternatives in the chosen hyperpath. And the average difference of the total traveled time between planned and realized travel time is 1.07 minutes and 1.0 minute difference is detected for both, a minimum and a maximum differences.

Table 1. Searched and Realized Path Results

	(a) Realized Auto Access Time (min)	Realized Transit travel Time (min)	(b) Realized Total Travel Time (min)	(c) Planned Auto Access Time (min)	(d) Planned Total Travel Time (min)	Difference [(c)-(a)] (min)	Difference [(d)-(b)] (min)
average	5.87	13.91	19.78	8.03	20.85	2.17	1.07
min	2.10	3.90	7.00	3.04	8.00	0.06	1.00
max	9.40	47.90	56.00	13.16	57.00	6.76	1.00

CONCLUSION

In ABM-DTA integration, intermodal trips like drive-transit-walk or walk-transit-drive are critical to provide the more refined results. This study mainly proposed the integration of two models, MALTA and FAST-TrIPs, focusing on the extension of schedule-based transit behavior using a hyperpath model, and an A* algorithm for the auto access segments, to describe intermodal travel. The proposed model was tested on a real transportation network in Rancho Cordova, CA. The proposed model will be tested on a larger transportation network and extended to the integration with a sequential activity choice model, in related on-going studies.

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REFERENCES

1.Lin, D., N. Eluru, S. Waller, and C. Bhat. Integration of Activity-Based Modeling and Dynamic Traffic Assignment. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2076, No. -1, 2008, pp. 52-61.

2. Hao, J., M. Hatzopoulou, and E. Miller. Integrating an Activity-Based Travel Demand Model with Dynamic Traffic Assignment and Emission Models. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2176, No. -1, 2010, pp. 1-13.

3. Pendyala, R. M., K. C. Konduri, Y.-C. Chiu, M. D. Hickman, H. Noh, P. Waddell, L. Wang, D. You, and B. Gardner. Integrated Land Use–Transport Model System with Dynamic Time-Dependent Activity-Travel Microsimulation. Presented at 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.

4. Villalobos, J. *Development and Implementation of the Multi-Resolution And Loading of Transportation Activities (MALTA) Simulation Based Dynamic Traffic Assignment System, Recursive On-Line Load Balance Framework (ROLB).* Ph.D. Dissertation. The University of Arizona, Tucson, 2012.

5. Noh, H, M. D. Hickman, and A. Khani, Hyperpaths in a Transit Schedule-Based Network. Presented at 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.

6. Nguyen, S., and S. Pallottino. Equilibrium Traffic Assignment for Large Scale Transit Networks. *European Journal of Operational Research*, Vol. 37, No. 2, 1988, pp. 176-186.

7. Spiess, H., and M. Florian. Optimal Strategies: A New Assignment Model for Transit Networks. *Transportation Research Part B: Methodological*, Vol. 23, No. 2, 1989, pp. 83-102.

8. Hamdouch, Y., and S. Lawphongpanich. Schedule-Based Transit Assignment Model with Travel Strategies and Capacity Constraints. *Transportation Research Part B: Methodological*, Vol. 42, No. 7-8, 2008, pp. 663-684.

9. Hamdouch, Y., and S. Lawphongpanich. Congestion Pricing for Schedule-Based Transit Networks. *Transportation Science*, Vol. 44, No. 3, 2010, pp. 350-366.

10. Chabini, I., and Shan Lan. Adaptations of the A* Algorithm for the Computation of Fastest Paths in Deterministic Discrete-Time Dynamic Networks. *Intelligent Transportation Systems, IEEE Transactions on*, Vol. 3, No. 1, 2002, pp. 60-74.

11. García, R., and A. Marín. Network Equilibrium with Combined Modes: Models and Solution Algorithms. *Transportation Research Part B: Methodological*, Vol. 39, No. 3, 2005, pp. 223-254.

12. Lozano, A., and G. Storchi. Shortest Viable Hyperpath in Multimodal Networks. *Transportation Research Part B: Methodological*, Vol. 36, No. 10, 2002, pp. 853-874.

13. DaySim (http://jbowman.net/#Sacramento) accessed by October, 15, 2011.

14. OpenAMOS (http://simtravel.wikispaces.asu.edu/OpenAMOS+Modeling+Framework) accessed by October, 15, 2011.

15. Y.-C. Chiu and L. Zhou, An Anisotropic Mesoscopic Traffic Simulation Model: Basic Properties and Numerical Analysis. Presented at the 85th Annual Meeting of Transportation Research Board, Washington, D. C., 2006.

16. Y.-C. Chiu and H. Song, The Development and Calibration of the Anisotropic Mesoscopic Simulation Model on Uninterrupted Flow Facilities. Presented at the 86th Annual Meeting of TRB, Washington, D.C., 2007.

17. Y.-C. Chiu, An Anisotropic Mesoscopic Traffic Simulation Model for Uninterrupted Flow Facilities: Part I: Basic Properties and Numerical Analysis. *Transportation Research Part B* (under review), 2008.

18. GTFS Data Exchange. www.gtfs-data-exchange.com. Accessed June, 2011.