TRB Paper No. 01-3108

TITLE: DYNAMIC VEHICLE DISPATCHING AT INTERMODAL TRANSFER STATION

by

Md. Shoaib Chowdhury, Ph.D.

(Corresponding Author)
Transportation Engineer
Parsons Brinckerhoff Quade & Douglas, Inc.
Department of Traffic
One Penn Plaza, New York, NY 10119
TEL: (212) 465-5672
FAX: (212)-465-5584
E-MAIL: chowdhury@pbworld.com

Steven I-Jy Chien, Ph.D.

Assistant Professor
Department of Civil and Environmental Engineering
New Jersey Institute of Technology
Newark, NJ 07102-1982
TEL: (973) 596-6083
FAX: (973) 596-6454
E-MAIL: chien@njit.edu

Word Count: 174 (abstract)+4214 (text) +7*250 (7 figures) +4*250 (4 tables) =7138 words

Submitted to the Journal of Transportation Research Board

ABSTRACT

Transfer time is one of the most important service quality indicators for evaluating intermodal transit systems. In the advent of Advanced Public Transportation System, vehicle arrival times and transfer demand can be obtained in real time. Thus, the decision of dispatching vehicles at transfer stations can be optimized to reduce the transfer cost. A time varying total cost function, including connection delay and missed connection costs incurred by transfer passengers, and vehicle holding cost is formulated as a function of holding times for vehicles that are ready to be dispatched at transfer stations. A procedure is developed to dynamically optimize the dispatching time for each ready vehicle by minimizing the time varying objective function. A transit network consisting of four routes connecting at a transfer terminal is designed in this study to demonstrate the application of the dispatching model. It is found that the proposed method can be used to advance transit vehicle dispatching strategies and reducing the transfer time.

Keywords: Transit, Vehicle Dispatching, Transfer, Optimization, APTS.

1. INTRODUCTION

Transfer time is one of the most important service quality indicators for evaluating intermodal transit systems. Efficient transfer connection among vehicles may significantly improve the service quality, stimulate demand and increase productivity. Due to stochastic headway variations, synchronization of vehicle arrivals among connecting routes at transfer stations cannot significantly reduce transfer time (*1*). In the advent of Advanced Public Transportation System (APTS) [e.g. Automatic Passenger Counter Systems (APCS), Advanced Vehicle Location Systems (AVLS) and Advanced Traveler Information Systems (ATIS)], it is possible to estimate vehicle arrival times and demand in real time (*2*). Thus, the dispatching of vehicles at transfer stations can be optimized in a dynamic way to improve the transfer efficiency.

Many previous studies have discussed the applications of controlling transit vehicles for improving service reliability. Abkowitz and Tozzi (*3*) examined the impact of ridership profiles on the effectiveness of headway control. Five passenger boarding and alighting profiles were examined: boarding at the beginning of the route and alighting at the end of the route; boarding at the beginning of the route and alighting at the middle and end of the route; boarding at the beginning of the route and alighting at the middle of the route; boarding and alighting uniformly along the route; and boarding at the middle of the route and alighting at the end of the route. They found that the implementation of headway control achieved the greatest reduction of wait time.

Abkowitz, Josef, and Driscoll (*4*) developed a computer simulation model to evaluate four timed transfer strategies: unscheduled transfers; scheduled transfers (without vehicle holding); scheduled transfers (holding vehicles operating on a low frequency route until vehicle operating on a higher frequency route arrive); and scheduled transfers (always holding the early arriving vehicle). They simulated a network consisting of two routes with a single transfer point and found that route characteristics including scheduled headway, percentage of transferring and through passengers at the transfer point and distance from the route origin to the transfer point significantly affected the determination of a preferable transfer strategy. Results showed that the double holding strategy was preferable when headways of both transit routes were equal, while the scheduled strategy was preferable for both routes with long headways.

Dessouky, Hall, Nowroozi, and Mouriks (*5*) developed a simulation model for assessing various bus holding strategies at timed transfer stations. Several holding strategies were examined: holding a vehicle until all coordinated vehicles arrive; dispatching a vehicle at its scheduled departure time; holding a vehicle until predefined fixed period; and holding a vehicle until predefined fixed period if at least one late vehicle is predicted to arrive during the holding period. Simulation results showed that accurate real time vehicle arrival information significantly reduce vehicle departure delay and the number of passengers missing their connections.

Lee and Schonfeld (*6*) formulated a model for optimizing dispatching decision of coordinated vehicles at a transfer terminal. Holding times were optimized by minimizing the total cost that includes vehicle holding cost, holding cost incurred by onboard passengers and missed connection cost incurred by passengers transferring from late connecting vehicles. In that model, the missed connection delay time was assumed to be equal to scheduled headway, while connection delay cost of passengers from late incoming vehicles were neglected.

Intelligent Transportation Systems (ITS) technologies can significantly improve passenger intermodal operations and services (*7*). Computer-aided bus dispatching systems have been in practice or recently implemented in many transit industries (*2*). Tri-Met (*8*), the transit provider in Portland, has implemented satellite-based Global Positioning Systems (GPS) to track vehicle locations. Bused can be dispatched based on the real time information of bus locations and travel time variation. In Michigan, Ann Arbor Transportation Authority (AATA) deployed an APTS technology on their bus transit routes (*9*), called "Advanced Operating System" (AOS) that enabled digital bus-to-bus communication to improve transfer service between buses. Buses among coordinated routes can locate other vehicle positions through the digital communication system and request for holding earlier arrived vehicles to ensure successful connection of passengers from the late vehicles. The system did not optimize holding time, but a preset maximum (up to five minutes) holding time is executed. It was reported that the system is capable of improving transfer efficiency.

The purpose of this study is to improve transit service quality by reducing transfer time that can be achieved through dynamic dispatching vehicles operating on a number of routes connecting at a transfer station (See Figure 1). The dynamic total cost function, including the connection delay and missed connection costs incurred by transfer passengers, and vehicle holding cost, is formulated and discussed in this paper. The vehicle holding time is optimized by minimizing the total cost function, while a procedure is developed to evaluate the benefit of the dynamic dispatching model. The review of previous studies gives an overview of the past efforts on vehicle holding strategies in transit services and signifies that there is a need for the development of dynamic dispatching model in order to gain maximum benefits from APTS technologies and to improve the transfer efficiency in the intermodal transit services.

2. METHODOLOGY

The objective total cost function is defined by the sum of vehicle holding cost, connection delay cost, and missed connection cost. The dispatching decision for each ready vehicle to be dispatched is evaluated at the time before dispatching the vehicle. If the vehicle is held for connecting a late vehicle, its dispatching time will be re-evaluated periodically (e.g., every 30 seconds in this study) until the holding vehicle is dispatched. While evaluating the dispatching decision, the cost associated with holding the vehicle is independent on the dispatching decision of other vehicles those have arrived at the transfer station. Thus, each ready vehicle has its identical total cost function. Hence, the optimal dispatching time of the vehicle can be obtained and that minimizes the total cost function.

Two major assumptions are made for developing the cost functions. First, it is assumed that the time and location dependent vehicle arrival distributions are available to transit operators. In real world, vehicle arrivals at a transfer station deviate from their scheduled arrival times due to traffic congestion and the numbers of boarding and alighting at stations/stops along the service route. Thus, vehicle arrival distributions at transfer stations will be highly location and time dependent. For instance, normal and lognormal vehicle arrival distributions were observed in different systems discussed in previous studies *(10, 11)*. The second assumption is that the transfer demand from one vehicle to another is known or predictable. For the purpose of long-term demand estimation, historic ridership information is required for developing a prediction model. However, for short term estimation, APCS can be applied to provide time varying demand information.

To estimate late vehicles arrival time, a number of checkpoints are suggested to be located at any bus stops along the route. With the use of AVLS and the historic travel time information, the travel time variation from any checkpoint to the transfer station can be estimated by arrival time prediction models, such as an artificial neural network model developed by Chien and Ding (*12*), multivariate regression models developed by Abdelfattah et. al. (*13*) and Zeng et. al. (*14*), and a Kalman filtering model developed by Wall and Dailey (*15*). To retrieve the vehicle arrival/departure times and the transfer demand information as input of the proposed dispatching model, a database will be accessed and updated dynamically. A general procedure is developed in this study for dispatching ready vehicles at transfer stations and discussed next.

Procedure for Dynamic Vehicle Dispatching

The procedure for dynamic dispatching is activated when the ready vehicle *v* arrives at the transfer station. The configuration of the procedure illustrated in Figure 2 is summarized below.

Step 1: Begin the dynamic vehicle dispatching procedure for vehicle *v*.

Step 2: Go to Step 3, if vehicle *v* has not arrived at the transfer station; otherwise, Step 4.

Step 3: Move to the next time step and go to Step 2 (the duration of the time step can be determined according to the duration of re-evaluation time period)

Step 4: Estimate the number of passengers waiting for vehicle *v* at the transfer station.

Step 5: Estimate coordinated vehicles arrival times at the transfer station and transfer demand to vehicle *v*.

Step 6: Go to Step 8, if the coordinated vehicles will be late; otherwise, Step 7.

Step 7: Dispatch vehicle *v* and stop the procedure.

Step 8: Go to Step 9, if there are passengers transferring from the late vehicles to vehicle *v*; otherwise, Step 7.

Step 9: Estimate transfer demand and the mean/standard deviation of the late vehicle arrival times.

Step 10: Formulate the total cost function for dispatching vehicle *v*, and optimize the holding time of vehicle *v* by minimizing the total cost.

Step 11: Go to Step 7, if the optimal holding time is less than the re-evaluation interval; otherwise, Step 12.

Step 12: Re-evaluate the dispatching decision of vehicle *v* and go to Step 4.

The development of the total cost function applied in Step 10 and the associated cost components considered in this study will be formulated and discussed next.

Model Formulation

The objective total cost function for dynamic vehicle dispatching is defined as the sum of vehicle holding cost, connection delay cost, and missed connection cost. Variables used for developing the total cost function are listed in Table 1. The total cost for dispatching vehicle v at a transfer station, dictated by TC_v, station can be represented by

$$TC_v = C_v^O + C_{b,v}^C + C_{b,v}^M \tag{1}$$

where C_v^O, $C_{b,v}^C$, and $C_{b,v}^M$ represent the vehicle holding cost, the connection delay and missed connection costs caused by holding vehicle v for waiting a late vehicle *b*, respectively.

Vehicle Holding Cost (C_v^O)

In order to evaluate the decision for holding a ready vehicle *v*, the vehicle holding cost can be obtained from the holding time multiplied by the average vehicle operating cost as formulated in Eq. 2.

$$C_v^O = t_v^h u_B \tag{2}$$

where t_v^h and u_B represent holding time and average vehicle operating cost of vehicle *v*, respectively.

Connection Delay Cost ($C_{b,v}^C$)

The connection delay cost is incurred by transfer passengers arriving at station between the departure times of vehicles $v-1$ and v. Note that vehicle $v-1$ is the vehicle arriving at the transfer station prior to vehicle v.

The connection delay cost $C_{b,v}^C$ incurred by passengers transferring from the late vehicle *b* to the ready vehicle *v* is affected by the arrival distribution of vehicle *b* at the transfer station. $C_{b,v}^C$ will be evaluated at dispatching decision point of time noted by t_v^{dd}. For instance, if vehicle *b* arrives before t_v^{dd}, the connection delay cost is equal to the vehicle holding time t_v^h multiplied by transfer demand $U_{b,v}$ from vehicle *b* to *v* and the value of users' wait time u_B. However, considering stochastic vehicle arrivals, if vehicle *b* arrives after t_v^{dd}, the connection delay cost should be formulated based on the probability that vehicle *b* arrives before dispatching vehicle v. Therefore, the connection delay cost of transfer passengers from vehicle b to vehicle v is the transfer demand $U_{b,v}$ multiplied by the probability of vehicle b arriving between the dispatching decision time t_v^{dd} and departure time t_v^{d} of vehicle v (area A shown in Figure 3), the corresponding wait time, and the value of users' wait time u_w. Thus, the connection delay cost can be formulated as

$$C_{b,v}^{C} = \begin{cases} t_v^h \sum_b U_{b,v} u_w & \text{if } t_{v-1}^{d} < t_b^a \le t_v^{dd} \quad \forall b \\ \sum_b \int_{t_v^{dd}}^{t_v^{dd}+t_v^h} f(t_b^a)[(t_v^{dd}+t_v^h)-t_b^a]\,dt_b^a U_{b,v} u_w & \text{if } t_v^{dd} < t_b^a \le t_v^{dd}+t_v^h \quad \forall b \end{cases} \tag{3}$$

where $f(t_b^a)$ and $U_{b,v}$ represent the probability distribution for the arrival of vehicle b, and the transfer demand from vehicle b to v, respectively. In Eq. 3, the dispatching decision time t_v^{dd} (or re-evaluation time) can be determined after knowing the arrival time t_v^a of vehicle v, the number of evaluation n for holding vehicle v, and the evaluation interval Δ (e.g., 30 seconds). Thus, t_v^{dd} can be formulated as

$$t_v^{dd} = t_v^a + (n-1)\Delta \tag{4}$$

For example, at the first dispatching decision time, n is equal to 1. Thus, the first dispatching decision time of vehicle v is t_v^a. The re-evaluation frequency can be altered by adjusting Δ, depending on the traffic conditions on the transit routes. If traffic is jammed by recurrent (e.g., peak hours volume) or non-recurrent (e.g., incidents) conditions, the duration Δ should be reduced to assist the dispatching decision making in a more dynamic way.

Missed Connection Cost ($C_{b,v}^{M}$)

The missed connection cost is incurred by the passengers arriving between t_v^{dd} and t_{v+1}^{a}. $C_{b,v}^{M}$ can be formulated based on the probability of missed connection. As shown in Figure 3, a missed connection occurs when the late vehicle *b* arrives between t^d_v and t^a_{v+1} (area B). Thus, the missed connection cost $C^M_{b,v}$ is the transfer demand $U_{b,v}$ multiplied by the probability of missed connection, the corresponding wait time, and the value of users' wait time:

$$C^M_{b,v} = \sum_b [\int_{t^{dd}_v + t^h_v}^{t^a_{v+1}} f(t^a_b)[t^a_{v+1} - t^a_b] dt^a_b U_{b,v} u_w \qquad \forall b \tag{5}$$

The costs of connection delay and missed connection incurred by passengers transferring from the late vehicle *b* are affected by the arrival distribution of vehicle *b*. Therefore, the probability of late vehicle arrival $f(t^a_b)$ at the transfer station should be carefully determined before estimating connection delay and missed connection costs formulated in Eqs. 3 and 5. For example, the arrival distribution of the late vehicle could be a lognormal distribution (*16*) rather than a normal distribution. Figure 4(a) shows that if vehicle v is dispatched $(t^d_v = t^{dd}_v + t^h_v)$ before the earliest arrival time t^e_b of late vehicle b, the connection delay cost can be ignored. At this moment the transfer passengers from late vehicle b will take vehicle $v+1$ instead of vehicle *v*. However, if vehicle v is dispatched after the earliest arrival times of vehicle b as shown in Figure 4(b), both connection delay and missed connection costs exist and are formulated in Eqs. 6 and 7, respectively.

$$C^C_{b,v} = \sum_b t^C_{b,v} U_{b,v} u_w \qquad \forall b \tag{6}$$

$$C^M_{b.v} = \sum_b t^M_{b,v} U_{b,v} u_w \qquad \forall b \tag{7}$$

where $t^C_{b,v}$ and $t^M_{b,v}$ represent connection delay and missed connection delay times that can be obtained from Eqs. 8 and 9, respectively.

$$t_{b,v}^{C} = \begin{cases} \int_{t_b^e}^{t_v^{dd}+t_v^h} f(t_b^a)[t_v^{dd} + t_v^h - (t_b^e + t_b^a)]dt_b^a & if\ t_v^{dd} + t_v^h > t_b^e \quad \forall b \\ 0 & otherwise \quad \forall b \end{cases} \tag{8}$$

$$t_{b,v}^{M} = \begin{cases} \int_{t_v^a+t_v^h}^{t_{v+1}^a} f(t_b^a)[t_{v+1}^a - (t_b^e + t_b^a)]dt_b^a & if\ t_v^{dd} + t_v^h > t_b^e \quad \forall b \\ \int_{t_l^e}^{t_{v+1}^a} f(t_b^a)[t_{v+1}^a - (t_b^e + t_b^a)]dt_b^a & otherwise \quad \forall b \end{cases} \tag{9}$$

4. MODEL EVALUATION

The main purpose of this section is to demonstrate the application of the dynamic vehicle dispatching model. The results are obtained from a computer program coded in FORTRAN. The studied transfer station, as shown in Figure 1, is a transfer terminal serving four transit routes. Vehicle arrivals from routes 1, 2 and 3 are assumed to follow lognormal distributions, while vehicle arrivals on route 4 is deterministic and always follow the schedule. The baseline values of design variables, such as the value of user's wait time and vehicle operating cost, are given in Table 1, while the vehicle operational information (e.g. headways) and transfer demand from one vehicle to another are shown in Table 2. In real world, the value of user's time can be determined based on the average annual income of the residents in the service region. For estimating vehicle operating cost, the expenses of maintenance, administration, and insurance for operating a vehicle should be considered in addition to the labor and energy consumption costs.

In order to optimize dynamic vehicle dispatching time, assume that vehicle a on route # 1 arrives at the transfer station on time, while vehicles b and c on routes # 2 and # 3 are late (see Figure 1). Since vehicle arrival time on route 4 is deterministic, thus arrival time of vehicle *d* on route 4 is known. If the reference time to start the analysis is $00:00$ (zero minutes and zero seconds), the schedule time for the next arrival on route #1 is assumed $20:00$ (i.e., 20 minutes). Given that vehicle arrival times from all routes are synchronized but at the dispatching decision time of ready vehicle a, vehicles b and c are late and 0.51 and 1.02 miles away from the transfer station, respectively. Thus, the holding time for vehicle a needs to be optimized. The travel time distributions of vehicle b and c from their locations to the transfer station are shown in Table 3.

According to the information (e.g., travel times and transfer demand) may be available from AVLS and APTS, the holding time of vehicle a at the first dispatching decision time (i.e. 00:00) can be optimized by minimizing the total cost function formulated in Section 4. The maximum holding time can be determined by considering that both vehicle b and c are successfully connected with vehicle a. Based on an incremental line search procedure (set size = 2 seconds), the total costs for different holding times are calculated and shown in Figure 5. The global minimum total cost and the corresponding holding time can be identified.

At the first dispatching decision time, the optimal holding time of vehicle a is found to be 5.08 minutes, which minimizes the total cost of \$21.19. However, under no holding situation, the total cost is \$ 29.88. Significant benefit from the holding emerges. Therefore, the departure time of vehicle a is $05:05$. The relationship between the total cost and holding time is shown in Figure 5. We found that the total cost with respect to holding time is a non-convex function with three local minimum points A, B and C. The total cost curve shows that point B (5.08 min) is at the global minimum point. The relationships between the holding time and various cost components including the connection delay cost incurred by passengers transferring from vehicle d, the connection delay and missed connection costs incurred by passengers transferring from vehicles b and c, and the holding cost of vehicle a are shown in Figure 6. We found that the minimum cost achieved at 5.08 min holding time is benefited from the saving of the missed connection cost incurred the passengers transferring from vehicle *b* to *a*.

Since vehicle arrival times may vary over time due to passenger demand, vehicle breakdown and roadway congestion, the dispatching decision should be re-evaluated during the holding period. Assuming that the dispatching decision will be re-evaluated at a 30-second interval, the second dispatching decision (re-evaluation) time will be at $00:30$. At that time, it requires to update every late vehicle location, and re-estimating the late vehicle arrival times to the transfer station.

In order to examine the sensitivity of the optimal holding time, three situations are considered at the second dispatching decision time as shown in Table 4. The first situation shows that vehicle b moves toward the transfer station during the re-evaluation interval, while vehicle c does not move due to unpredictable reasons. The second situation shows that vehicle c moves toward the transfer station during the re-evaluation interval, but vehicle b does not move. The third situation shows that neither vehicle b nor c moves toward the transfer station during the re-evaluation interval.

At the second dispatching decision time, the holding time of vehicle a is re-optimized based on the three situations defined above, while the determination of optimal holding and departure times of vehicle a are discussed below.

Situation 1:

In this situation, the optimal holding time of vehicle *a* is found to be 3.44 minutes (Figure 7), which minimizes the total cost of $17.87. Therefore, the new departure time of vehicle a evaluated at 00:30 is updated from $05:05$ to $03:56$. The new departure time of vehicle a is earlier than that was determined at the first dispatching decision time, because vehicle b is expected to arrive earlier than that was expected at first dispatching decision time.

Situation 2:

The optimal holding times under situation 2 is found to be 7.98 minutes (see Figure 7), which minimizes the total cost of \$19.43. The new departure time of vehicle a reevaluated at $00:30$ is updated from $05:05$ to $08:29$. The new departure time of vehicle a is later than that was determined at the first dispatching decision time due to the transfer demand in the late vehicles and their updated arrival times.

Situation 3:

The optimal holding time under situation 3 is found to be 5.08 minutes (See Figure 7), which minimizes the total cost of \$20.64. Therefore, the new departure time of vehicle a evaluated at $00:30$ is updated from $05:05$ to $05:35$. The departure time of vehicle a is 30 seconds later than that was determined at first dispatching decision time, because vehicles *b* and *c* did not move during the past evaluation interval. The iterative evaluation of holding time will be continued until vehicle *a* is dispatched.

5. CONCLUSIONS

A model for dynamic dispatching of vehicles operating in an intermodal transfer station has been developed in this study. A numerical example consisting of four transit routes feeding a transfer station is presented, while holding times are optimized considering realistic vehicle arrival distributions, delays of vehicle arrivals, and transfer demand. Results obtained from the evaluation of the dynamic vehicle dispatching model conclude the following:

1. The optimal holding time is a trade-off among several cost components including connection, missed connection and vehicle holding costs.
2. Optimized real-time dispatching decisions when some vehicles are delays and others are ready to leave provide substantial opportunities for cost savings.
3. Dynamic vehicle dispatching can significantly improve the transfer efficiency and reduce the total cost.
4. At each vehicle dispatching decision time, the holding time can be optimized based on the arrival times of connecting vehicles and transfer demand. In general, holding a late vehicle is preferred if the vehicle carries enough transfer passengers.
5. Excessive fluctuation in predicted arrival times and transfer demand may reduce the benefit from holding a vehicle, specially when the delay of vehicle arrival is large and the standard deviation of vehicle arrival times is high.

It is recommended that the dispatching decisions should be made when some vehicles at the transfer station are ready to leave while others are late. For each ready vehicle we must consider the merits of costs of leaving immediately or waiting for some or all of the late vehicles. The decision can be based the value of a cost function that consider current traffic congestion, the cost of delaying the ready vehicles and their passengers, the cost of missed connections to passengers on the late vehicles, and the cost of further perturbations in schedules and future connections if vehicle are held back. Future research should include the application of the model into real world environment that will assist transit operator to analyze operational performance in their systems with timed transferred terminals. Special attention should also go to how dynamic vehicle arrival and departure information could be disseminated to the travelers in real time, how to predict accurate vehicle arrival times for the late vehicles, and how to give the preferential treatment to reduce the delay of the late vehicles.

REFERENCES

1. Chowdhury, M. S. *Intermodal Transit System Coordination with Dynamic Vehicle Dispatching.* Ph.D. Dissertation, Current Research @ NJIT (Digital Dissertations, http://www.library.njit.edu/dbases/allDBU.cfm), New Jersey Institute of Technology, Publication Number AAT 9971398, ISBN 0-599-76489, UMI Company, 2000.
2. Federal Transit Administration. *Advanced Public Transportation Systems: The State of Art Update' 98.* FTA-MA-26-7007-98-1 DOT-VNTSC-FTA-97-9, U.S. Department of Transportation, 1998.
3. Abkowitz, M., and J. Tozzi. Transit Route Characteristics and Headway-Based Reliability Control. *Transportation Research Record 1078,* TRB, National Research Council, Washington, D.C., 1986, pp. 11-16.
4. Abkowitz, M., Josef, R., and M. Driscoll. Operational Feasibility of Time Transfer in Transit System. *Journal of Transportation Engineering,* ASCE, 113(2), 1987 pp.168-177.
5. Dessouky, M., Hall, R., Nowroozi, A., and K. Mourikas. Bus dispatching at timed transfer transit stations using bus tracking technology. *Transportation Research C*, 7C, 1999, pp. 187-208.
6. Lee, K. T., and P. M. Schonfeld. Real-Time Dispatching Control for Coordianted Operation in Transit Terminals. *Transportation Research Record 1433,* TRB, National Research Council, Washington, D.C., 1994, pp. 3-9.

7. Miller, M. A., and C. Tsao. *Passenger Intermodal Operations and Services: A Synthesis of the Challenges and Opportunities for Successful Implementation.* Preprint CD-ROM, The 79th Annual Meeting, TRB, Washington D.C., 2000.
8. Strathman, J. G., Dueker, K. J., and T. Kimpel. *Automated Bus Dispatching, Operations Control, and Service Reliability: Baseline Analysis.* Preprint CD-ROM, The 78th Annual Meeting, TRB, Washington D.C., 1999.
9. Levine, J., Hong, Q., Hug, G., and D. Rodriguez. *Impacts of an Advanced Public Transporation System Demonstration Project.* Preprint CD-ROM, The 79th Annual Meeting, TRB, Washington D.C., 2000.
10. Taylor, M. P. Travel Time Variability- The Case of Two Public Modes. *Transportation Science,* Vol. 16 No. 4, 1982, pp-507-521.
11. Turnquist, M. A. A Model for Investigating the Effects of Service Frequency and Reliability on Bus Passenger Waiting Time. *Transportation Research Record 663,* TRB, National Research Council, Washington, D.C., 1978, pp. 70-73.
12. Chien, S., and Y. Ding. *Application of Artificial Neural Networks in Prediction of Transit Arrival Times.* The 9th Annual Conference of ITS America, Washington D.C. 1999.
13. Abdelfattah, A. M., and A. M. Khan. Models for Predicting Bus Delays*.* *Transportation Research Record 1623,* TRB, National Research Council, Washington, D.C., 1998, pp. 8-15.
14. Zeng, J., and W. Lin. *An Experimental Study on Real Time Bus Arrival Time Prediction with GPS Data.* Preprint CD-ROM, The 78th Annual Meeting, TRB, Washington D.C., 1999.
15. Wall, Z., and D. J. Dailey. *An Algorithm for Predicting the Arrival Time of Mass Transit Vehicles Using Automatic Vehicle Location Data.* Preprint CR-ROM, The 77th Annual Meeting, TRB, Washington D.C., 1998.

16. Hines, W. W., and, D. C. Montgomery. *Probability and Statistics in Engineering and Management Science.* John Willy and Sons, Inc., New York, 1990.

LIST OF TABLES

LIST OF FIGURES