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The Simulation of MRT Transfer System Based on Bus Holding Strategies with platform constraints

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***Abstract*—This research aims at the bus holding strategies for the simulation of Mass Rapid Transit (MRT) transferring system in a terminal station with platform constraints for bus in the metropolitan area. We developed and evaluated the transfer system through computer simulation models for MRT with bus system that the goals of bus holding strategies in the model were: reduce bus waiting time, reduce passengers waiting time for the bus, and reduce passengers traveling time. In order to enhance the performance of the MRT-Bus transfer system, we develop several bus holding strategies scenarios that use different traveling time functions of buses at different time intervals, such as rush hours and off-peak hours, with bus platform capacity constraints in the transfer models to construct proposed transfer models in the MRT transfer system. Real-time traffic information acquired by the Intelligent Transportation Systems (ITS) through Global Positioning System (GPS) provided input data for the simulation models. Performance index function were derived and served as performance measure to compare different bus holding strategies.**

***Keywords*—transfer system, bus holding strategies, simulation, intelligent transportation systems**

I. INTRODUCTION

Mass Rapid Transit (MRT) system is the most important transportation invention in the modern metropolitan area. The MRT system usually relies on the subway system to provide fast and convenient service for travelers in the downtown area. One of the supporting parties in the MRT system is the bus system connecting from end terminals to expand their service area in the vicinity. In America or other continental countries, buses follow existing schedule from station to station in order to cover the whole operation area to provide on-time services. However, in most of the Asia countries, buses depart immediately after completing pick-up and drop-off passengers operation at the bus stops. That is, there is no waiting time or time table for the buses at the stops. The same operation applies to the MRT transfer terminals.

One of the key measurements for the MRT service quality is reliability. It needs continuous attentions and endless improvement to maintain proper service level for travelers, which leads to the issues of control strategies to improve the reliability of transit services [1]. These strategies are categorized as either planning control, or real-time control. Planning control strategies are long term and involve strategies for restructuring the routes and schedules. Real-time control strategies are short-term and involve strategies for adding extra buses or short-turning [2].

Efficient real-time station control strategies could maintain smooth operation for the whole bus system and reduce the impact from disturbances, such as accidents or vehicle break down. Station control strategies, including holding strategies, stop-skipping strategies, and short-turn strategies, are the most popular and frequently used by public transit operators to reduce the passengers waiting time, and prevent vehicles bunching along the route.

Holding strategies are used to delay bus movement deliberately when vehicles are ahead of the schedule. Stop-skipping strategies reduce travel time of the vehicle of interest. They could also reduce waiting times for passengers on board a vehicle at downstream stops. Short-turning strategy involves turning a vehicle around before it reaches the route terminals. This strategy is usually adopted when the headway variance or passenger waiting time in the opposite direction are to be reduced [3][4].

Among the strategies surveyed above, holding strategies are the focus of this paper due to their popularity among practitioners in public transit systems. Holding control strategies could be classified into two types. The first type uses threshold-base control models to hold a bus at control stops to correct the headway between consecutive buses. The second type use mathematical programming models with holding times as decision variables and passenger-waiting time as the cost function to be minimized.

Several studies had modeled threshold-base control strategies. Among the earliest studies was Osuna and Newell [5], who presented an analytic method that determined the optimal holding strategy for a hypothetical route consisting of one stop with either one or two vehicles with the uniformly passengers' arrival rate, which aimed to minimize average waiting times of passengers. Barnett [6] developed a two-point, discrete, approximate distribution of vehicle delay, with the intention of reducing the complexity of the problem discussed. Koffman [7] developed a simulation model to analyze a one way bus route. They tested several control strategies for buses in real-time. Abkowitz [8][9] developed an empirical headway deviation function aiming to minimize waiting times of passengers along a route, which were estimated by Monte Carlo simulation.

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The emergence of Intelligent Transportation Systems (ITS), such as automatic vehicle location (AVL) and global positioning systems (GPS), Mobile Data Terminals, and Electronic Fare boxes [10]-[12], facilitated the design of computer-based real-time decision support systems for public transit. GPSs are particularly useful for vehicle tracking and mobile data terminals may be used for passenger counting. Eberlein et al. [4] presented the first research on real-time routine control problems. O'Dell and Wilson [13] presented formulations for disruption control problems in rail transit systems with more than one rail branch. Dessouky et al. [14][15] compared control strategies that based on technologies for communication, tracking and passenger counting, with those that based solely on local information. A bus arrival time prediction model was developed, which was more accurate for lines with long headways. These results by simulations showed these methods were advantageous when the schedule slack was close to zero, when the headway was large, and when there were many connecting buses. Zhao [16] presented a distributed control approach based on multi-agent negotiation, wherein stops and buses act as agents that communicate in real-time to achieve dynamic coordination of bus dispatching at various stops.

This paper presents bus holding strategies for the simulation of Mass Rapid Transit (MRT) transferring system in a terminal station with bus platform capacity constraints. We used GPS data collected by the Taipei e-bus system to construct statistics analysis, and utilized the system simulation software to build the real world MRT transfer model. We added functions with different holding strategies to the models, and used different traveling time functions for the vehicles at different time intervals in the transfer models to construct proposed transfer models with holding strategies. Finally, we evaluate the performance of the holding strategies for transfer models by comparing waiting time for passengers with simulation results.

The remainder of the paper is organized as follows. Section 2 outlines the formulation of the MRT-bus transfer system. Section 3 provides the framework of the bus holding strategies with the experimental results from simulation models. Section 4 offers conclusions.

II. THE MRT-BUS TRANSFER SYSTEM

The focus of the research is one of the most important transfer terminals of the MRT system in Taipei, Taiwan, called Kunyang Station. Five bus routes (Blue 12, Blue 20, Blue 21, Blue 25, and Blue 36) were selected to provide transferring service for traveler to travel from Taipei City to Taipei County. All five bus routes were covered inside the Taipei e-bus system, which provided GPS signals from every bus operating along the route. Location data, such as longitude, latitude, time of day, etc., were sent to traffic management center (TMC) continuously and were stored in Microsoft SQL Server database. We acquired the database from the Department of Transportation, Taipei City Government.

The input data for the simulation models was analyzed and organized for a two-month time period from the e-bus database. The database contained several data tables, such as BSTOP, BSTOP_XY, BUS, BUSLOG, BUS_ROUTE, ROUTE from the Taipei e-bus system. The table BSTOP contains information about bus stations, such as bus station ID and name of the stations. The table BSTOP_XY contains information about bus routes, such as operating company, service area, longitude and latitude for the stations. The table BUS stores bus ID, license plate, and route information. The table BUSLOG responses for storing arrival time and depart time for every stop. BUS_ROUTE table contains operating order for the buses along every route. Finally, ROUTE table stores route ID and private-own bus company's ID.

Using Query Analyzer from Microsoft SQL Server, we first acquired all information for the bus routes along the path, including name of bus station, bus ID, operating order along the route, arrival time and depart time, etc., for the five bus routes connecting with Kunyang Station. Then we fed the data into Excel spreadsheets for further analysis. The data were first analyzed by ARENA simulation software to build statistical functions, finding traveling time from bus stop to bus stop with arrival time and depart time. These functions were further verified by Input Random Number block in the Generic Module from EXTEND simulation software to locate parameters for all random variables of probability distributions. After these steps, we had probability functions for the traveling time from stop to stop, waiting time on the stops, and departing time functions. These are primary input for the EXTEND to build our MRT-bus transfer models.

Here are the definition of parameters for the multiple routes transfer system: $(TT_{IK})_i$: traveling time for the bus on route i from stop K-1 to stop K on the I's time; $(HT_{IK})_i$: holding time for the bus on route i at stop K on the I's time; $(WT_{IK})_i$: waiting time for the passenger I waiting for the bus on route i at stop K; $(SHT_K)_i$: strategic holding time for the bus on route i at stop K; $(RT)_i$: reduce time for passenger due to holding strategy for the bus on route i; $(OT_{IK})_i$: original time for passenger without holding strategy for the bus on route i at stop K; $(ETT_I)_i$: extra travel time for the bus on route i on the I's time; $(MT_I)_i$: total travel time for the bus on route i on the I's time.

Inside the simulation system, we define Rush Hour as 6:30 AM to 8:30 AM and 5:00PM to 7:00PM for both morning and evening traffic pattern, respectively, and Off-peak Hour otherwise. Two sets of probability functions were prepared from ARENA analyzer.

Other parameters include number of stops on the route (N), number of data for the route i (n_i), the stop for passenger on board (k), the number of bus route (x), the number of bus stops travel by passenger (s), MRT terminal's bus platform capacity (M), maximum waiting time for the passenger waiting for the bus on route i (W_i), maximum total travelling time for the bus on route i (T_i), the number of shift for the bus on route i (u_i), the number of stops for the bus on route i (Q_i).

From the GPS database, we can calculate mathematical expectation for various travelling/waiting times. The average travelling time for the bus on route i from stop K-1 to stop K is

$$E(TT_K)_i = \sum_{I=1}^{n_i} (TT_{IK})_i / n_i \,. \tag{1}$$

The average holding time for the bus on route i at stop K can be calculated as

$$E(HT_K)_i = \sum_{I=1}^{n_i} (HT_{IK})_i / n_i \cdot \qquad (2)$$

The total travel time for the bus on route i on the I's time can be calculated as

$$[\sum_{K=1}^{N} (TT_{IK})_i + \sum_{K=1}^{N} (HT_{IK})_i] \cdot$$

Hence, the average total travel time for the bus on route i can be calculated as

$$\sum_{I=1}^{n_i} [\sum_{K=1}^{N} (TT_{IK})_i + \sum_{K=1}^{N} (HT_{IK})_i] / n_i \cdot$$

Also, the waiting time for the passenger with holding strategies on the route i is

$$[(WT_{IK})_i + \sum_{K=k}^{k+s} (SHT_k)_i] \cdot$$

Therefore, the average waiting time for the passenger with holding strategies on the route i is

$$\sum_{I=1}^{n_i} [(WT_{IK})_i + \sum_{K=k}^{k+s} (SHT_k)_i] / n_i \cdot$$

On the other hand, the average reduce time for the passenger with bus holding strategies on the route i can be calculated as

$$(RT)_i = \sum_{I=1}^{n_i} \left\{ (OT_{IK})_i - \left[\sum_{I=1}^{n_i} [(WT_{IK})_i + \sum_{K=k}^{k+s} (SHT_k)_i] / n_i \right] \right\} / n_i \cdot$$

The average extra travelling time for the bus with holding strategies on the route i is

$$(ETT)_i = \sum_{I=1}^{u_i} \left\{ \left[\sum_{I=1}^{n_i} [\sum_{K=1}^{N} (TT_{IK})_i + \sum_{K=1}^{N} (HT_{IK})_i] \right] / n_i - (MT_I)_i \right\} / u_i \cdot$$

Therefore, the mix-integer programming model with multiple goals for the MRT-bus transfer system in order to reduce overall bus travelling time and overall passenger waiting time can be summaried as (3). Three major constraints are set in the model to represent three conditions. The first constraint is the platform capacity constraint which manages platform operation as a queue; the second constraint is the maximum waiting time for the passenger waiting for the bus on route i as the boundry condition; and the third constraint is the maximum total travelling time for the bus on route i.

$$\begin{aligned} \text{Max} \quad & Z = [\sum_{n_i=1}^{x} (RT)_i - \sum_{n_i=1}^{x} (OMT)_i] \\ \text{s.t.} \quad & \sum_{i=1}^{x} Q_i \leq M, \\ & [(WT_{IK})_i + \sum_{K=k}^{k+s} (SHT_k)_i] \leq W_i, \\ & [\sum_{K=1}^{N} (TT_{IK})_i + \sum_{K=1}^{N} (HT_{IK})_i] \leq T_i. \end{aligned} \qquad (3)$$

where x is the number of bus rutes, $M \geq 1$, $Q_i \geq 0$, $W_i \geq 0$, $T_i \geq 0$, and $M, Q \in Z$. Also,

The simulation was created by EXTEND software for simulation modules for transfers, and non-transfers, holding strategy, as shown in Fig. 1, Fig. 2, and Fig. 3, respectively. Various scenarios were created with different parameters. The MRT terminal, Kunyang Station, along with five bus routes was embedded together. Buses travelled individually from their depots in orders and turned back to home depot after arrived at Kunyang Station and completed its pick-up/drop-off passengers operation at the bus platform in the transfer terminal. Probability functions with proper parameters settings were set to every component in the simulation model for travelling time, waiting time, arrival time, and departure time. There is no holding for the original scenario and serves as benchmark model for comparison (Strategy 1).

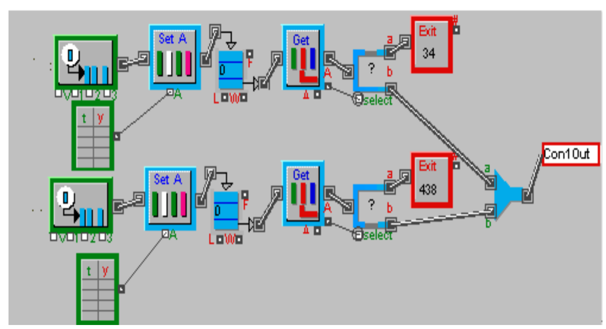

Figure 1. Simulation module for number of transfer from MRT to bus.

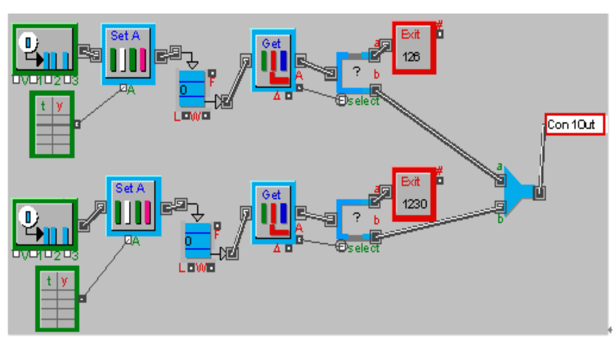

Figure 2. Simulation module for number of non-transfer at bus station.

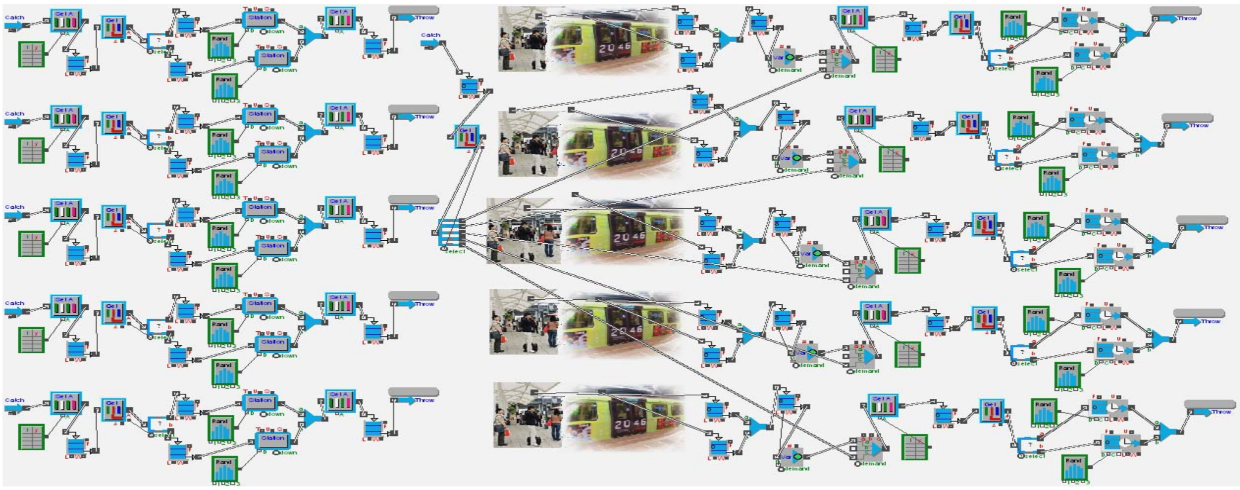

Figure 3. Simulation module for holding strategy – benchmark model.

III. THE BUS HOLDING STRATEGIES AND EXPERIMENT ANALYSIS

In this section, we summarized the experimental results from our simulation models for the design of various holding strategies. Due to the limit of paper length, only selected results were presented in the paper. TABLE I shows a total 19 strategies, which are divided into 5 category.

TABLE I. INDEX OF HOLDING STRATEGIES

Group 1: Fixed holding strategy
1. No holding strategy for the bus.
2. Hold the bus for 30 seconds.
3. Hold the bus for 60 seconds.
4. Hold the bus for 90 seconds.
Group 2: Holding strategy regarding MRT arrival time, rush hour
5. Hold the bus for 45 sec if MRT train arrived within 15 sec and rush hour.
6. Hold the bus for 60 sec if MRT train arrived within 30 sec and rush hour.
7. Hold the bus for 75 sec if MRT train arrived within 45 sec and rush hour.
8. Hold the bus for 90 sec if MRT train arrived within 60 sec and rush hour.
Group 3: Holding strategy regarding MRT arrival time, off-peak hour
9. Hold the bus for 45 sec if MRT train arrived within 15 sec, off-peak.
10. Hold the bus for 60 sec if MRT train arrived within 30 sec, off-peak.
11. Hold the bus for 75 sec if MRT train arrived within 45 sec, off-peak.
12. Hold the bus for 90 sec if MRT train arrived within 60 sec, off-peak.
Group 4: Holding strategy if less than 3 buses waiting in the bus platform, rush hour
13. Hold the bus for 30 sec if less than 3 buses waiting in the bus platform.
14. Hold the bus for 60 sec if less than 3 buses waiting in the bus platform.
15. Hold the bus for 90 sec if less than 3 buses waiting in the bus platform.
Group 5: Holding strategy regarding MRT arrival time, bus platform capacity, and off-peak hour
16. Hold the bus for 45 sec if less than 3 buses waiting in the bus platform and MRT train arrived within 15 sec in off-peak hour.
17. Hold the bus for 60 sec if less than 3 buses waiting in the bus platform and MRT train arrived within 15 sec in off-peak hour.
18. Hold the bus for 75 sec if less than 3 buses waiting in the bus platform and MRT train arrived within 15 sec in off-peak hour.
19. Hold the bus for 90 sec if less than 3 buses waiting in the bus platform and MRT train arrived within 15 sec in off-peak hour.

Each strategy simulation model for MRT-bus transfer system was executed 10 times to simulate 10 days of bus operation. We collected data from 19 strategies of 5 groups and calculated five performance indexes: average travelling, average waiting time for passenger, maximum waiting time for passenger, additional bus travelling time, and average reduction in passenger's waiting time for all five bus routes as shown in TABLE II. Also, for the purpose of further analysis, Fig. 4 to Fig. 8 show waiting time reduction for passenger by bus route and Fig. 9 to Fig. 13 show additional travelling time by bus route due to the cause of holding strategies.

TABLE II. HOLDING STRATEGIES ANALYSIS

Strategies	passengers' waiting time(sec)	Maximum passengers' waiting time(sec)	Additional bus traveling time(sec)	Reduction in passengers' waiting time(sec)
1	817.62	4427.42	0.00	0.00
2	707.60	4037.91	63.63	110.02
3	735.99	3764.85	96.03	81.63
4	710.48	3678.10	126.28	107.15
5	732.17	4231.09	31.20	85.45
6	722.61	4098.98	20.15	95.02
7	717.18	3892.89	15.45	100.44
8	705.01	3775.79	28.27	112.62
9	717.26	3783.46	37.42	100.36
10	715.52	3790.52	9.70	102.10
11	727.29	4103.85	28.85	90.33
12	713.50	3939.57	39.02	104.12
13	723.08	4123.75	28.78	94.54
14	741.41	4052.99	65.19	76.21
15	738.80	3890.79	86.18	78.82
16	727.34	4094.06	24.62	90.28
17	734.33	4049.66	9.17	83.30
18	742.31	4111.69	10.17	75.32
19	716.67	3804.52	15.43	100.95

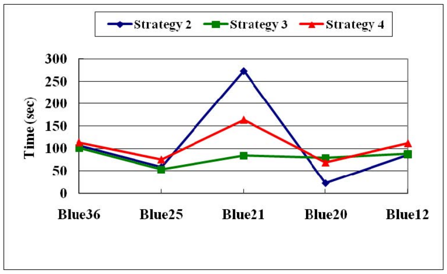

Figure 4. Group 1: Waiting time reduction for passenger by bus route.

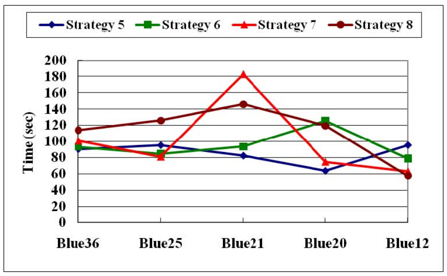

Figure 5. Group 2: Waiting time reduction for passenger by bus route.

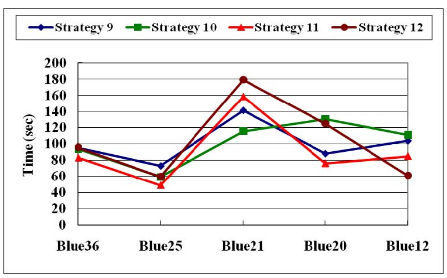

Figure 6. Group 3: Waiting time reduction for passenger by bus route.

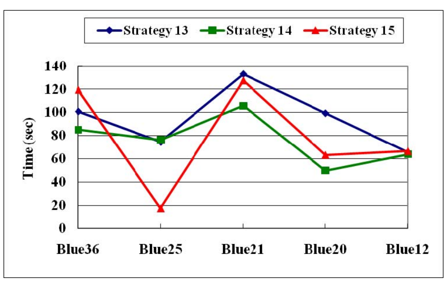

Figure 7. Group 4: Waiting time reduction for passenger by bus route.

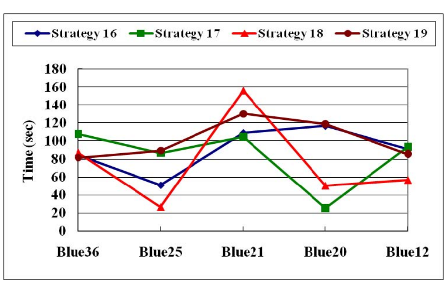

Figure 8. Group 5: Waiting time reduction for passenger by bus route.

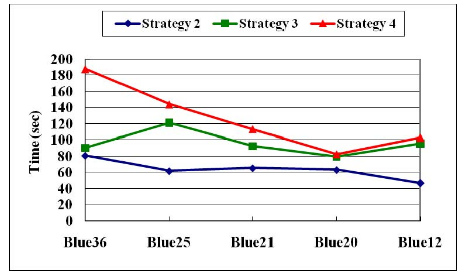

Figure 9. Group 1: Additional travelling time by bus route

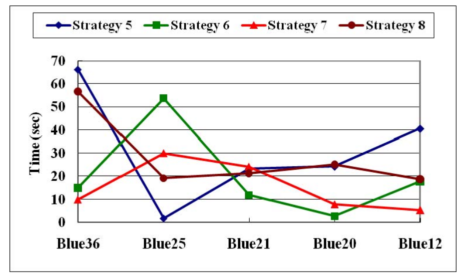

Figure 10. Group 2: Additional travelling time by bus route.

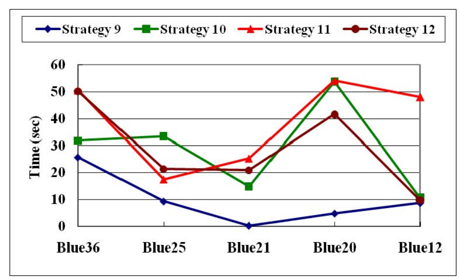

Figure 11. Group 3: Additional travelling time by bus route.

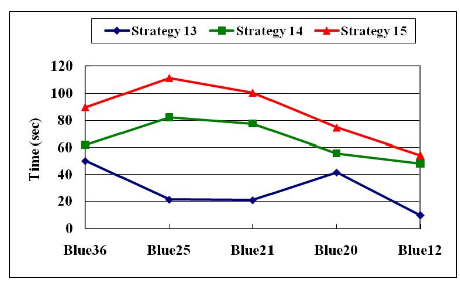

Figure 12. Group 4: Additional travelling time by bus route.

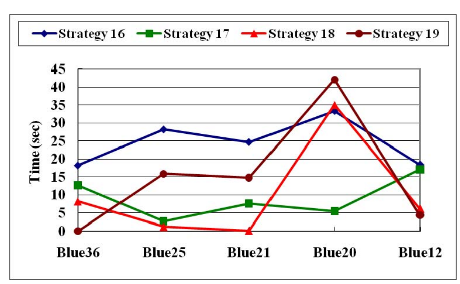

Figure 13. Group 5: Additional travelling time by bus route.

According to the results from previous tables and figures, Strategy 2 in Group 1 had better transferring improvement of all fixed holding strategies. All the strategies in Group 1 had equal waiting time reduction achievement, but they also extended bus travel time at the same time. Hence, there is no significant effect for the total travel time (waiting time for bus plus travel time on bus) reduction for travelers in this group.

Strategy 8 (Group 2) had better transfer improvement of all holding strategies regarding MRT arrival time during rush hour. All strategies in this group had major waiting time reduction improvement, especially when applied to the route with longer headway.

Similar to Group 2, Strategy 10 in Group 3 had better transferring improvement of all the holding strategies regarding MRT arrival time during off-peak hour. All strategies in this group had major waiting time reduction improvement, especially when applied to the route with longer headway. Also, strategies from Group 2 or 3 did not increase additional bus travel time significantly when compared with Group 1.

Strategies in Group 4 had the same performance with strategies in Group 1. If there were less than 3 buses waiting in the bus platform during rush hour, waiting time for the bus will increase and contributes to the increase of total travel time for bus.

Finally, strategies in Group 5 had better transfer improvement of all holding strategies. They not only reduced waiting time for travelers but also reduced additional travelling time for bus at the same time. Therefore, strategies in this group had better system performance than any other groups.

IV. CONCLUSIONS

In this paper, we present a dynamic simulation model for the MRT-bus transfer system in a terminal station with platform constraints for bus in the metropolitan area. We used GPS data collected by the Taipei e-bus system to construct MRT terminal operation along with five bus routes to build simulation models. We also added functions with different holding strategies to the models based on the time of day to construct proposed transfer models with holding strategies.

According to the experiment results, passenger's waiting time can be reduced while increasing small amount of bus waiting time to achieve overall system performance by the support of intelligent transportation system technology. Although we performed static analysis in this paper by using computer simulation models for the MRT-bus transfer system, it can be further researched by building artificial intelligent system, such as neural network models or fuzzy system models to construct more flexible bus holding strategies.

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