AN ASSESSMENT ON BUS TRIP TIMES FOR METROPOLITAN CORRIDORS

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abstract: This paper discussed the door-to-door trip time characteristics of bus transit users in Taipei metropolitan area. Research results indicated that the trip time and its components (i.e., access, wait, and in-vehicle times) are good indicators for evaluating bus transit services, since these trip time attributes can directly link to network design and operation management of the bus transit systems. It is also shown that the all-day average door-to-door trip time for bus riders in Taipei Metropolitan is 52.18 minutes, while the average in-vehicle time is 36.48 minutes, wait time is 8.67 minutes, and walk time is 7.03 minutes. Additionally, this study also evaluate trip time savings from implementing exclusive bus lanes and network in Taipei city.

1. INTRODUCTION

In Taiwan highly urbanized area, promotion of public transportation service is the first priority to improve metropolitan transportation level of service. As the statistics shows, the ridership of Taipei metropolitan area bus service has been decreasing at the average rate of -4% since 1978. Poor service of mode accessibility, amenity and privacy lead to the loss of market share drastically. However, the bus service in Taipei metropolitan area still take account for 33% of daily travel demand regardless of low service quality.

The research took the past years household home interview results as the database to investigate the trip characteristics in terms of temporal-spatial distribution relationship. The survey results has shown that time issue is the most concerned item of transit riders and the savings in walking time, waiting time and in-vehicle time for bus riding could stimulate the ridership significantly. Therefore, this paper investigated these effects in terms of bus level of service versus rider perception, and further discuss the consequent impacts from the changes of operation strategies and system innovation.

2. LIETERATURE REVIEW

In the past, there are a lot of literature pointed to discuss about the definition of level of service (LOS) for public transportation Taiwan and worldwide. Botzow (1974) selected average speed, delay, passenger space, bus acceleration, temperature, noise level and ventilation to define the LOS of public transportation. However, Bakker (1976) recognized that bus occupancy would be an appropriate LOS index for public transportation service, and Alter (1976) added mode accessibility, travel time ratio, schedule reliability and path connectivity to well define the LOS function. Whereas, Tong (1980) identified travel time, service frequency, service reliability, connectivity, passenger amenity and safety as the six key factors to define Taiwan long distance bus service performance function, and Lan (1983) used safety, efficiency, fare, convenience and amenity as the five major categories to cover 17 evaluation items including accident rate, bus crime, service business time, etc.. Han (1986) conducted a research to evaluate the bus level of service based on the extents of congestion, wait time, travel speed and occupancy, and lately Chang (1987) concluded an evaluation system by synthesizing congestion and wait index for Taipei metropolitan area joint bus service.

However, the evaluation of LOS can be categorized into the following six categories and related literature reference was tabulated in Table 1:

1. Convenience: including all aspects of travel time (walking time, transfer time, waiting time, in-vehicle time), transfer penalty, system service time and customer related service.
2. Cost: direct out-of-pocket fare
3. Reliability: schedule on-time rate
4. Safety: accident rate and bus crime
5. Amenity: friendly facility, temperature and noise control, vehicle operating condition
6. Occupancy: on-board ridership

Table 1 LOS Indicators and Literature References

Category	Literature References
1. Convenience	Botzow (1974), Alter (1976), Sown (1978), Tong and Pon (1980), Vuchic (1981), Hwang (1981), Lai (1981), Kuo (1982), Lan (1983), Chou (1983), Shiu (1983), Chen (1984), Han et al. (1986), Chang (1991).
2. Cost	Lan (1983), Chang (1987), Chang (1991).
3. Reliability	Alter (1976), Tong (1980), Vuchic (1981), Chen (1982), Kuo (1982), Han et al. (1989), Chang (1991).
4. Safety	Tong (1980), Vuchic (1981), Chen (1982), Kuo(1982), Lan (1983), Chang (1987), Han et al. (1989), Chang (1991).
5. Amenity	Botzow (1974), Tong (1980), Hwang (1981), Chen (1982), Lan (1983), Chou (1983), Han et al (1989), Chang (1991).
6. Occupancy	Bakker (1976), Alter (1976), Chou (1983), Chen (1984), Han (1984), Chang ,C. (1987), Chang (1991), Chang (1994).

Based on the literature reference, the number of bus performance index increases as the extent of recognition for system getting detail. Most of performance measurement index focused in the aspects of customer perception and satisfaction level, while overall system functionality as well as business management strategy have not been well considered. This paper will investigate the overall system performance from the aspects of corridor travel time to reflect the aggregate efficiency of individual bus line services.

3. ANALYSIS METHODOLOGY

The hypothesis of this research is that variation of trip time from different corridor pairs as a level of service is resulted from different service supply. The trip time between an origin-destination pair include three parts: access time (Twk), wait time (Twt) and in-vehicle time (Tiv), and it is depicted as follows:

$$T = Twk + Twt + Tiv \qquad (1)$$

The access time includes the access time from an origin/destination point to bus terminal (or stop) and transfer time between stop to stop. As usual, the access mode to bus terminal includes walking, park & ride, kiss & ride, motorcycle and bike in Taiwan. Other than the portion of time spending with these access mode, the access time is affected by network connectivity and density as well as bus stop spacing. Therefore, access time reflects the following effects:

1. network pattern,
2. network connectivity,
3. intersection bus stop position, and
4. bus stop spacing.

The waiting time factor accounts for the time spending for the next bus arrival. Factors contribute to waiting time include the service frequency, bus transfer system design and intelligent vehicle position system availability. As far as the in-vehicle time, traveling distance, passenger volume and stop frequency account for the majority of time spending in vehicle. Other than those, the intersection control strategies, right of way and exclusive bus lane could significantly reduce the in-vehicle time and its variation.

More specifically, the average access time represents the difficulty of passengers to access the bus facility, and the less indicates the better service. The term is given below:

$$T_{wk} = \frac{\sum_{i=1}^{n}\left(owk_i + \sum_j xwk_{ij} + dwk_i\right)}{n} \qquad (2)$$

owk_i: the access time to terminal facility from an origin
xwk_{ij}: the walking time for transferring
$dwki$: the access time from terminal facility to a destination
i: the i-th bus trip
j: the j-th transfer
n: the total bus trips

The term of average waiting time is affected by bus system service schedule and related business management, and the smaller value of this term indicates less time spending in waiting for the next bus arrival. The average waiting time is formulated then as below:

$$T_{wt} = \frac{\sum_{i=1}^{n}\left(wt_i + \sum_j xwt_{ij}\right)}{n} \quad (3)$$

wt: the waiting time at terminal
xwt: the waiting time at transferring stop
i: the *i*-th bus trip
j: the *j*-th bus transfer (*j*=0 for no transfer)
n: the total bus trip number

As discussed earlier, the in-vehicle time is affected by trip length and external environments such as network pattern and intersection traffic control.

$$T_{iv} = \frac{\sum_{i=1}^{n}(iv_i + \sum_j iv_{ij})}{n} \quad (4)$$

iv: in-vehicle time
i: the *i*-th bus trip
ij: the *j*-th bus transfer on *i*(*j*=0 for no transfer)
n: the total bus trip number

4. TAIPEI METROPOLITAN CORRIDORS AND GENERAL INFOMRAITON

4.1 Taipei Transportation Corridors

The data used in this study was adopted from 1991 Taipei Metropolitan Household Travel Survey. The Taipei bus service corridor coverage is depicted in Figure 1. This survey covered a total number of 23,119 households, and 25,172 out of 81,247 trips are bus oriented. The Taipei metropolitan area includes Taipei city (16 municipal districts) and 24 neighborhood cities and towns. The bottlenecks between Taipei old town and new development areas as well as the transportation corridors are defined in Table 2. These corridors are formed naturally by municipal boundaries or physical barriers such as rivers or bridges.

About 30% of populations center at the old town area for 25,000 person/ sq. kilometer, and 65% of service and related business are located in this old town area. Therefore, the old town has attracted most of urban trips, and it leads to tremendous traffic load to pass through the bottlenecks (bridges or unique connecting arterials). The description of corridor area and population density is given in Table 3.

Figure 1. Taipei Metropolitan Area and Corridor Coverage

Table 2 Description of Taipei Transportation Corridors

Corridor	Coverages	Bottleneck
Old Town	Chun-Chan, Wan-Hwa, Da-Ann, Hsin-Yi, Da-Tung, Chun-Shan and Shun-Shan Districts	N/A
Shan-Jong	Shan-Jong, Lu-Jou, Hsin-Chuang, Wu-Gu, Tai-Shan, Lin-Ko and Pa-Li Counties	Taipei Bridge, Chun-Hsiao Bridge, Chun-Hsin Bridge
Ban-Chao	Ban-Chao city, Tu-Chen City and Shu-Lin Town	Hwa-Chiang Bridge and Kwan-Fu Bridge
Chun-Ho and Yun-Ho	Chun-Ho and Yun-Ho Cities	Hwa-Chun, Chun-Cheng, Fu-Ho and Yun-Fun Bridge
Hsin-Dan	Hsin-Dan City	Rossvelt Road
Mu-Cha	Wun-Shan district and Shan-Ken County	Hsin-Hi and Chuang-Chin tunnels
Nan-Kung	Nan-Kung District and Shi-Chi Town	Chun-Hsiao E. Road, Nan-Kung and Pa-Der Roads
Na-Hu	Na-Hu District	Ming-Chuan, Na-Hu and Da-Chi Bridges
Shi-Lin and Pa-Tow	Shi-Lin and Pa-Tow Districts and Dan-Shui Town	Chun-Shan N., Chun-Chin N., Yen-Pin N., and Hwan-Ho N. Road, Cheng-Ker Road

Table 3. Socioeconomic Characteristics of Transportation Corridors for Year 1991

Corridor	Area (Km^2)	Population (x1000 persons)	Density (1,000 per./Km^2)	Agriculture & Manufacture (x 1000 persons)	Service Business (x 1000 persons)
Old Town	63.03	1,600	25.4	241	1,244
Shan-Jong	189.72	940	5.0	270	151
Ban-Chao	82.44	795	9.6	186	113
Chun-Yun Ho	25.90	620	23.9	60	83
Hsin-Dan	122.87	310	2.5	61	50
Mu-Cha	48.22	157	3.3	14	25
Nan-Kung	95.18	258	2.7	67	45
Na-Hu	27.16	166	6.1	14	20
Shi-Lin & Pa-Tow	193.32	655	3.4	121	155
Total	847.84	5,501	6.5	1034	1886

4.2 Taipei Metropolitan Bus Network

There are two bus systems servicing the entire Taipei metropolitan area, namely, the Taipei Bus Union and Regional Bus System. The Bus Union includes 10 independent transit agents that serving the Taipei area as shown in Figure 2. Nine of the ten transit agents are owned privately, and only one is operated by Taipei City Government. The Bus Union service area covers the old town and neighboring cities, and 80% of bus routes radiates out from Taipei Rail Road Station. The service lines distribution for the Bus Union and Regional Bus System is depicted in Table 4.

Table 4. Number of Service Lines and Corridors

Corridor	No. of Service Lines	
	Bus Union	**Regional Bus**
Shan-Jong	17	19
Ban-Chao	7	5
Chun-Yun Ho	22	8
Hsin-Dan	13	7
Mu-Cha	8	4
Nan-Kung	17	2
Na-Hu	7	2
Shi-Lin and Pai-Tow	36	4
Old Town	40	0
Out-skirt	4	0
Total	141	51

Figure 2. Taipei Bus System Coverage

Based on the data of November, 1994, there are independent 174 bus lines operated by the Taipei Bus Union who owned 3,268 buses. These buses operated between 5 am to 23 pm and are air-conditioned. On average, there are 55,307 bus rounds being dispatched in Taipei, that responsible for pick up 5,674,342 passenger-trips everyday. The detail spilts of bus passenger loads and average occupancy are provided in Table 5.

Table 5. Daily Bus Passenger Load by Corridors

Corridor	Bus Rounds	Passenger	Occupancy (Persons/Bus)
Shan-Jong	6,807	241,581	35.5
Ban-Chao	4,606	179,837	39.0
Chun-Yuan Ho	10,273	330,071	32.1
Shin-Dan	5,629	205,082	36.4
Mu-Cha	1,308	33,922	25.9
Nan-Kung	5,318	200,629	37.7
Na-Hu	3,027	119,795	39.6
Shi-Lin and Pai-Tow	12,711	465,647	36.6
Old Town	5,357	213,029	39.8
External	600	14,561	24.2

4.3 Trip Characteristics

The 1991 trip data from the Institute of Transportation (IOT) revealed that 10,580,000 trips were produced in Taipei metropolitan area versus only 6,030,000 trips everyday in 1981. In 10 years, the trip production doubles itself and daily person's trip grows from 1.43 trips/day to 1.74 trips/day. In the same time, the bus share in market for ridership decreased from 62% to 26% and private vehicles boomed from 19% to 50%. The deficiency in bus management and quality control lead to the big loss of public transit passenger volume and complaints from bus users. The share distribution of various transport modes is provided in Figure 3.

In trip characteristics, the morning and evening peak hours departure trips account for 23% and 24% of total daily trip productions, respectively. The distribution of departure and arrival trip production is provided in Figure 4. About 22.5% of daily trip productions are between 21 and 30 minutes (see Figure 4 for details), and overall trip length is about 38.2 minutes (in-vehicle 32.6 min., wait time 3.0 min., walk time 2.6 min.). By mode, the average urban traveling time for car and bus are 37.7 min. and 52.2 min., respectively, and that exclusively explaining the relative efficiency of private vehicles and public transit.

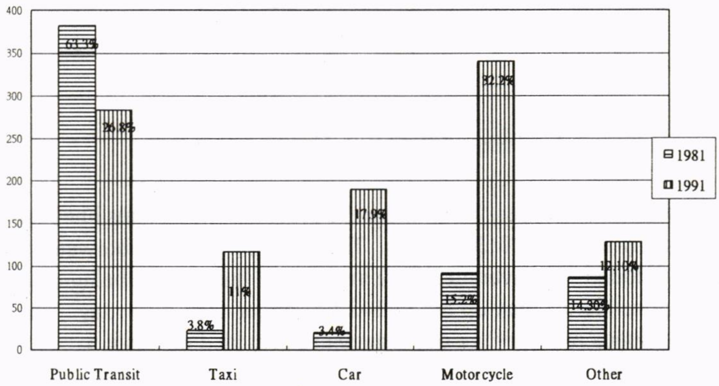

Figure 3. Mode Share Distribution for Year 1981 and 1991

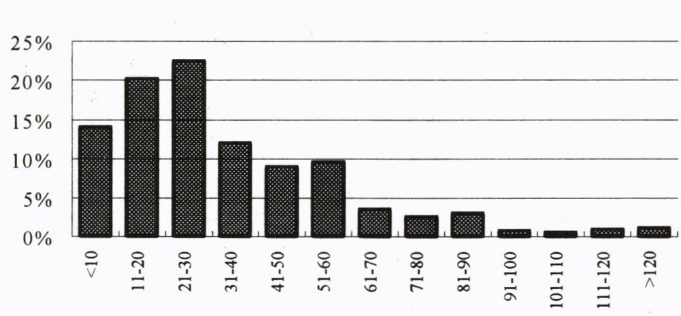

Figure 4. Distribution of Trip Length

5. BUS TRIP TIME PERFORMANCE EVALUATION

5.1 General Description of Bus Trip Time

Performance of bus trip time among the corridors mentioned above are discussed in this section, and the computation of trip time efficiency is based on the scale of travel time between old town and each corridor. The total travel time, walk time, wait time and in-vehicle time are compared in the aspects of AM and PM peak hours, as in Table 6.

Table 6 Statistics of Trip Time by Corridor

Components	Corridor	Old Town	Shan-Jong	Ban-Chao	Chun-Yuan Ho	Hsin-Dan
Total Trip Time	AM Peak	38.95	58.21	64.64	57.33	68.53
	PM Peak	48.83	70.59	78.13	67.78	76.51
	Off-Peak	37.02	53.30	59.77	52.01	57.53
	Daily Mean	41.71	61.22	67.94	59.99	67.73
Walk Time	AM Peak	6.46	7.93	9.00	7.84	8.16
	PM Peak	6.86	7.52	9.36	8.78	8.18
	Off-Peak	6.08	7.64	8.25	6.72	7.24
	Daily Mean	6.48	7.70	8.92	7.94	7.88
Wait Time	AM Peak	7.05	8.36	10.13	8.68	10.04
	PM Peak	8.86	10.22	12.70	10.66	10.70
	Off-Peak	7.18	7.45	9.23	7.93	9.85
	Daily Mean	7.70	8.77	10.77	9.24	10.20
In-Vehicle Time	AM Peak	25.41	41.85	45.50	40.81	50.17
	PM Peak	33.09	52.84	56.04	48.34	57.56
	Off-Peak	23.77	38.14	42.29	37.35	40.42
	Daily Mean	27.52	44.70	48.23	42.81	49.57
Continued						
Components	Corridor	Mu-Cha	Nan-Kung	Na-Hu	Shi-Lin / Pai-Tow	
Total Trip Time	AM Peak	65.62	52.72	61.64	60.54	
	PM Peak	72.93	61.87	68.86	69.79	
	Off-Peak	55.45	46.13	52.64	57.21	
	Daily Mean	65.98	53.90	62.40	62.99	
Walk Time	AM Peak	8.00	8.16	7.28	8.62	
	PM Peak	7.86	8.55	7.13	7.71	
	Off-Peak	6.91	6.33	7.06	7.92	
	Daily Mean	7.70	7.76	7.18	7.73	
Wait Time	AM Peak	11.14	7.70	10.13	8.59	
	PM Peak	12.28	9.57	11.82	9.97	
	Off-Peak	10.71	7.39	9.25	9.57	
	Daily Mean	11.46	8.24	10.57	9.32	
In-Vehicle Time	AM Peak	46.61	36.83	44.23	44.25	
	PM Peak	52.65	43.71	49.92	52.08	
	Off-Peak	37.84	32.41	36.80	39.72	
	Daily Mean	46.75	37.86	44.77	45.89	

The above travel time components reflect the average level of service for bus traveling, and it implicitly indicates the qualify of uniform service. As the probability distribution centers around the mean, it implies the reliability of bus performance and service quality. The fatter tail of this probability distribution indicate a wider variation of performance, which greatly reduces the reliability of bus service quality and overall level of service. In Figure

5, the best bus service corridor - old town area, only 15% of total trip length exceed 1 hour, and 2% of them over one and half an hour. However, Nan-Kung, the best second service corridor is still with an average of 30% of total trip length exceeding the limit of one hour, and Hsin-Dan corridor (the worst) has 45% of trip length over one hour. The split AM and PM peak hour corridor travel time plots are provided in Figure 6. and Figure 7, respectively.

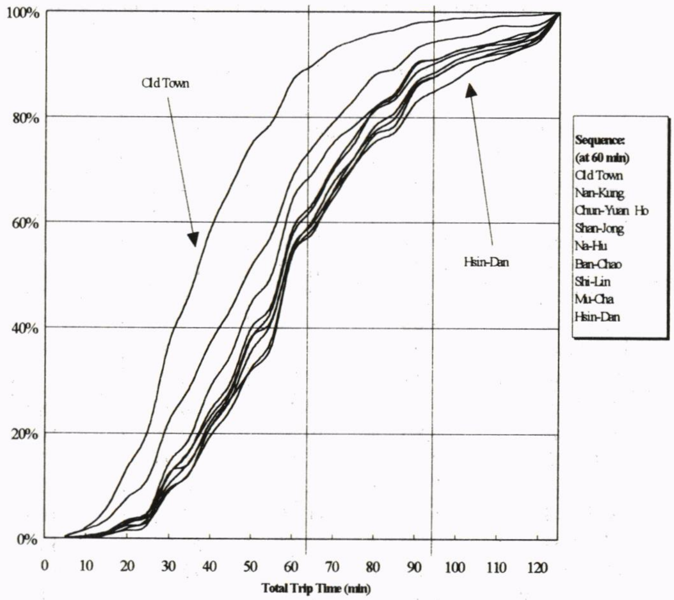

Figure 5 The Daily Average Accumulated Distribution of Corridor Travel Time

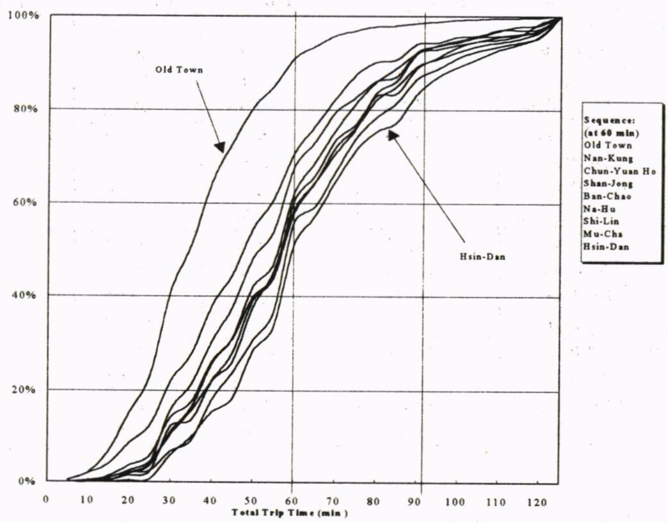

Figure 6 The AM Peak Accumulated Distribution of Corridor Travel Time

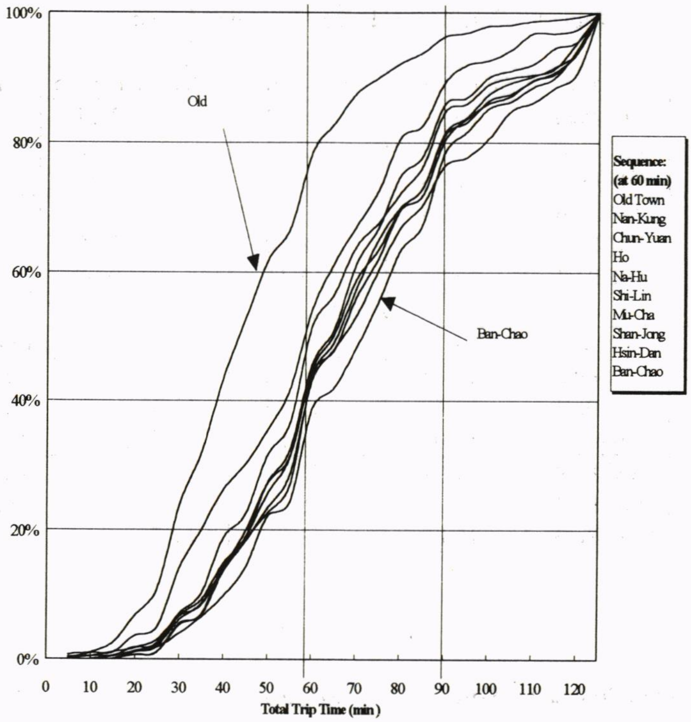

Figure 7 The PM Peak Accumulated Distribution of Corridor Travel Time

As far as the traveling distance, the original household survey didn't include this attribute. Traveling distance is estimated by the least cost shortest path between an origin-destination pair, and this cost consists of out-of-pocket cost and travel time cost. The average travel distance and traveling speed for each corridor are provided in Table 7 and Table 8.

Table 7. Statistics of Corridor Trip Production Traveling Distance

Corridor	Distance (Standard Deviation) Unit: km
Old Town	3.9 (2.4)
Shan-Jong	9.7 (4.7)
Ban-Chao	8.4 (3.6)
Chun-Yuan Ho	7.7 (2.8)
Hsin-Dan	8.9 (2.8)
Mu-Cha	9.3 (2.8)
Nan-Kung	7.9 (3.7)
Na-Hu	9.6 (3.0)
Shi-Lin/ Pei-Tow	10.6 (5.1)

Table 8. Corridor-wide Bus Traveling Speed

	Period	Old Town	Shan-Jong	Chun-Yuan Ho	Hsin-Dan
Average Vehicle Speed KPH	AM Peak	10.51	15.53	13.21	12.63
	PM Peak	8.38	12.05	11.68	11.41
	Off-Peak	11.40	16.42	14.53	16.30
Average Bus Trip Speed	AM Peak	6.35	10.57	8.82	8.56
	PM Peak	5.33	8.68	7.79	8.14
	Off-Peak	6.73	11.15	9.99	10.90
continued					
	Period	Mu-Cha	Nan-Kung	Na-Hu	Shi-Lin/ Pei-Tow
Average Vehicle Speed KPH	AM Peak	14.15	15.46	15.43	15.43
	PM Peak	12.47	13.25	13.32	13.18
	Off-Peak	16.07	16.55	17.52	17.48
Average Bus Trip Speed	AM Peak	9.91	10.48	10.60	10.51
	PM Peak	8.53	8.73	9.40	9.25
	Off-Peak	10.87	11.00	11.70	11.60

5.2 Evaluation of Alternative Operating Strategies

In order to evaluate the impacts of alternative bus operating strategies, the network path selection behavior is simulated based on the principle of least cost path. The travel cost consists of two portions: travel time value and out-of-pocket money cost. The travel cost matrix for all public transportation modes is given as in Table 9, and penalty for mode transferring is defined as in Table 10. These values have officially introduced by the Mass Rapid Transit Bureau of Taipei City, which have been calibrated previously in their regional forecasting model.

Table 9. Public Transportation Travel Cost and Time Value

Time Value (Dollars/Min)	**AM Peak** 0.79		**PM Peak** 0.69	**All Day** 0.79
Fare = (a +b*Distance)	Bus		Rail Road	
	Joint Union	Regional Union	Not Air Conditioned	Conditioned
a (Dollars)	9.75	12.0	8.0	12.0
b (Dollars/KM)	0.61	0.28	0.4	0.7

The based network for this specific network is adopted from Taipei Mass Rapid Transit Bureau. Before applying the transportation model for real world case, the inter-corridor travel time impedance should be calibrated and validated with household interview survey data. As a result, the initial output of original transportation model lower estimates of the travel time and a over-estimate of the corridor's bus trip level of service performance.

Table 10. Penalty for Public Transportation Mode Transferring

Mode	Bus	RailRoad
Bus	6.0	5.0
RailRoad	6.0	4.0

5.3 Performance Evaluation of Proposed Taipei Bus Exclusive Network

In order to improve the bus priority to increase ridership, the Taipei City Government has started to establish several bus exclusive lanes on major arterials. The establishment of exclusive bus lane will reduce the interruption between buses and private vehicles, and it will greatly increase bus traveling speed on surface streets. As the fact, after the implementation of Hsin-Yi Road exclusive bus lane, the bus traveling speed increased 152% in AM peak hours and gained another 52% after the bus lane extension of the second phase (Chang et al., 1996). An assessment also indicates that the ridership has increased up to 28.5% for a bus route on the Hsin-Yi Road (Chang and Chen, 1995). The proposed exclusive bus lanes project in this research includes four east-west bound lanes and five north-south bound lanes as indicated in Table 11, which we assume the current bus operating speed will gain 30%, 60% and 90% after the implementation of proposed exclusive bus network. The performance evaluation of the three proposed strategies is given in Table 12, where the average travel time saving is about 3% - 9%. Effects of the bus exclusive lanes on ridership and travel time have also been assessed based on a field survey by Chang et al. in 1996.

Table 11. Proposed Exclusive Bus Lane Network and Current Travel Speeds

	Name	Original Speed
1	Ming-Chuan E. & W. Road	9.50
2	Nan-King E. & W. Road	9.02
3	Ren-I Road	17.11
4	Hsin-Yi Road	16.18
5	Chun-Shan N. & S. Road	8.67
6	Hsin-Shen S. Road	11.68
7	Fu-Hsin N. & S. Road	10.60
8	Dun-Hwa N. & S. Road	10.18
9	Fun-Yuan Street	7.85

Table 12. Performance Evaluation for Proposed Operating Strategies

Corridor	Overall Travel Time Saving		
	Strategy 1	Strategy 2	Strategy 3
Old Town	-5.4%	-10.0%	-13.0%
Shan-Jong	-1.8%	-4.2%	-5.3%
Ban-Chao	-1.4%	-2.6%	-3.4%
Chun-Yuan Ho	-4.9%	-8.3%	-11.1%
Hsin-Dan	-5.8%	-9.8%	-13.4%
Mu-Cha	-3.4%	-7.0%	-9.1%
Nan-Kung	-2.3%	-4.5%	-5.8%
Na-Hu	-1.9%	-4.8%	-6.1%
Shi-Lin / Pei-Tow	-3.5%	-7.3%	-9.6%

Strategy 1: Increasing Exclusive Bus Lane Speed 30%
Strategy 2: Increasing Exclusive Bus Lane Speed 60%
Strategy 3: Increasing Exclusive Bus Lane Speed 90%

6. CONCLUSIONS

The perception of trip time for bus riders was used to evaluate the service performance of Taipei bus system. The trip time factors consisting of walk time, wait time and in-vehicle time were used efficiently to represent the level of service. Also, this research reflects the bus performance resulted from the urban spatial distribution and transportation infrastructure, then highlights the need to provide favorable bus environments to sustain the bus operation and ridership. The effects of providing exclusive bus lanes and network to promote bus level of service is validated.

This research provide a framework for assessing transit system in metropolitan with which a better bus service system can be provided by using the suggestions of the proposed evaluation hierarchy. The proposed analysis methodology efficiently brings the transportation planning model and household interview survey data together to verify with user's perception. Therefore, the transportation planning prediction model output can be further validated. Suggestion from the proposed approach can be used to enhance the bus system performance. A consumer-based bus operating environment can also be established.

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