Taichung City BRT Design Record

Hung-Jen Huang [a], Chao-Yang Liao [b], Corey Tseng [c], Liang-Tay Lin [d]

[a] *Research Fellow, Civil, Hydraulic Engineering and Railway Transportation Research Center, Sinotech Engineering Consultants, Inc., Taipei 10570, Taiwan; E-mail: hjhuang@sinotech.org.tw*
[b,c] *Professional Engineer, Railway Engineering Department II, Sinotech Engineering Consultants, Ltd., Taipei 10570, Taiwan*
[b] *E-mail: cyliao@mail.sinotech.com.tw*
[c] *E-mail: corey@mail.sinotech.com.tw*
[d] *Director-General, Taichung City Government, Transportation Bureau, Taichung City 40341, Taiwan; E-mail: ltlin@fcu.edu.tw*

Abstract: This paper aims at sharing the detail design experiences on the first BRT in Taichung, Taiwan. The core design concept is SPEED, the acronym standing for Sustainability, Passion, Exciting, Evolution, and Dream. The simulation demonstrates that passengers have a new mode choice that is as fast as private vehicles but costs much less. Furthermore, the LOS varies slightly before and after the construction. The evidences show that BRT will compete with other modes by its distinguishing features rather than increase due to the restraint of private vehicles by the government.

Keywords: BRT, LOS, Sustainability

1. INTRODUCTION

Bus Rapid Transit (BRT) has been one of the most cost-effective mechanisms for cities to rapidly develop a public transport system that can achieve a full network as well as deliver a rapid and high-quality service (Institute for Transportation and Development Policy, 2007). Nowadays, BRT is one of the most popular public transportation in the world (Tiglao et al., 2007; Jaensirisak and Klungboonkrong, 2009; Munawar et al., 2009; Tan et al., 2009; Wachi et al., 2009).

The Taichung City is located in central Taiwan. The government plans to construct BRT to reduce the congestion in the urban area. The Taiwan Avenue is the most crowded road in Taichung City. The congestion problem has not been solved although traffic signal re-timing plans have been implemented at least four times. The Blue Line of the BRT along the avenue is the first priority alternative to alleviate the congestion.

To make the first BRT line successful, we proposed the concept of “SPEED” to design the line. SPEED is the acronym of Sustainability, Passion, Excitement, Evolution, and Dream. The design principles of Stations, Runway, Bus Priority Signal (BPS), Intelligent Transportation Systems, and other supporting measures should fit the concept.

This paper introduces the interests of the design works including 1) the trade-off between the station allocation rules in terms of uniform and location adaptive; 2) the aesthetics of station design for refreshing the city sightseeing; 3) the coordination between BPS and mixed traffic control; 4) the supporting measurements for realizing the line; 5) the cost and mobility evaluations for the Taiwan Avenue before and after BRT.

Section 2 introduces the profile of Taichung City. Section 3 illustrates BRT design concept of the basic elements and supporting measures. Section 4 presents the expected benefits of the BRT. Section 5 demonstrates the simulation results for the mobility before and after the introduction of BRT. Section 6 summarizes our conclusion remarks.

2. PROFILE OF TAICHUNG CITY

Taichung City is one of the five direct-controlled municipalities in Taiwan. It comprises 29 administrative districts with a population just over 2.6 millions and covers an area of 2,215 km2, as shown in Fig. 1, Taichung City is a cultural and economic center in central Taiwan and is dotted with excellent cultural attractions, venues, institutions and events. Taiwan Avenue is the backbone of urban network with the most congested traffic. Motorcycles and passenger cars are the main modes of transportation and contribute 85% of all journeys. The mode share of the city is shown as Fig. 2.

Figure 1. The location of Taichung City

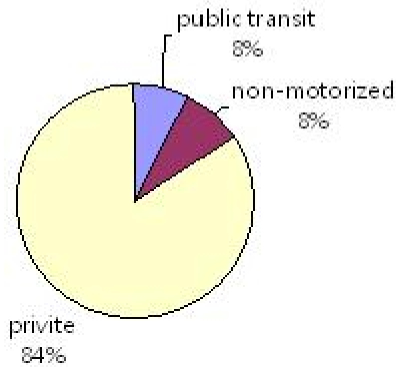


Figure. 2 Mode share in Taichung City

3. BRT DESIGN CONCEPT

SPEED (Sustainability, Passion, Excitement, Evolution, and Dream) is the core design concept of the BRT blue line in Taichung City. The concept aims at rebuilding Taiwan Avenue as a corridor for stringing up the city images along the way. “Sustainability” implies BRT project reforms the public transportation system to become Affordable, Inter-generationally Equitable, and Environmentally Aware. “Passion” guides the system to restore the economic vitality of the Aged City region. “Excitement” implies the design will fit the city sightseeing of Greenway and Developing Zone which are dotted with amazing cultural attractions, venues, institutions and events. “Evolution” represents the contribution fit the endless creativity and productivity of the Industrial Zone. “Dream” symbolizes the expectation that reflects the imaginative power of the University City for the future. Fig. 3 shows these four regions (Aged City, Green Avenue, Industrial Zone, and University City).

3.1 Network

The planned network of Taichung BRT, as shown in Fig. 4, is 216 km in length. The main line of Blue Line is 35 km long. Herein, the first phase construction will finish part of the line (from Taichung Train Station to Providence University) with a length of 17.2 km by the beginning of 2014. Twenty-three stations are allocated along the line, as shown in Fig. 5. The average station interval is 820 m. Tab. 1 shows the draft plan for the line.

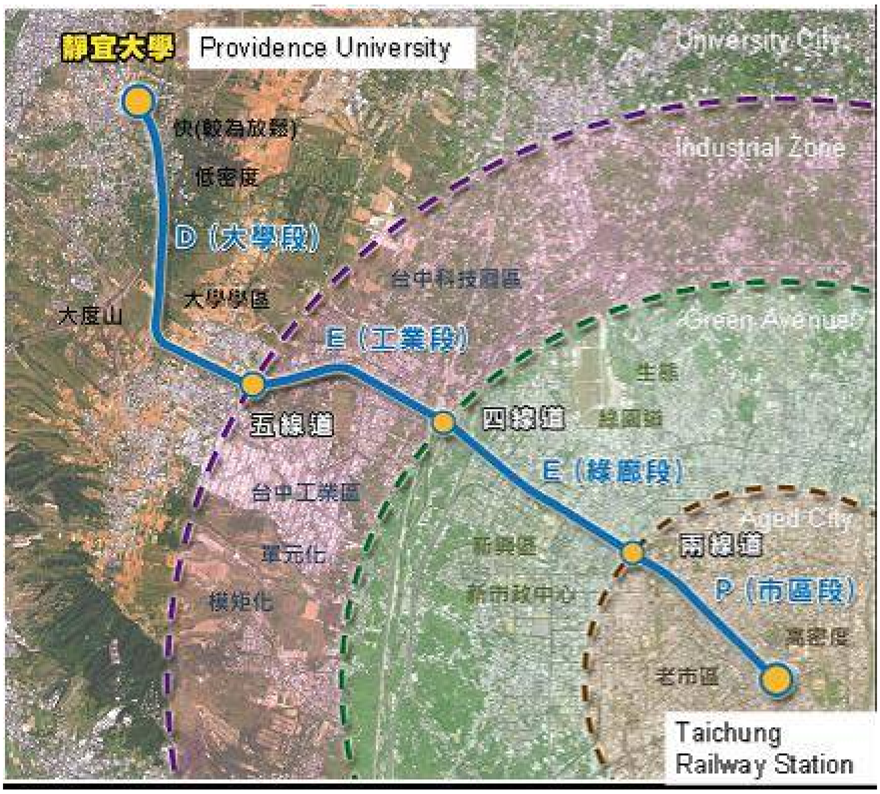


Figure 3. Land use distribution along BRT Blue Line

Table 1. Features of the Blue Line of Taichung BRT

Scope	Section	Length (km)	Design Vehicle	Fleet (vehicle)	
				12m	18m
Main Line	Taiping—Taichung Train Station	9	12m	22	-
	Taichung Train Station—PU*	17	18m	-	32
	PU—Taichung Harbor	9	18m	-	7
Extension I	Taichung HSR station—Shalu	20	18m	-	12
	Shalu—Tachia	14	18m	-	9
Extension II	Chungchi Rd.—Chungchi Rd.	11	18m	-	7

* Providence University

3.2 Station

The appearance of general type station is an abstract model of the Chinese White Dolphin. Dolphins are animals of high intelligence with speedy swimming ability. Their friendly appearance, smiling face, and seemingly playful attitude have made them very popular in human culture. Fig. 6 shows two stations, the general type and the switchback stations. Dolphin is adopted as the appearance of the general type station (Figure 6 (b) and (c)), and wave is the roof of switchback station (Figure 6 (d) and (e)). Here, wave represents ocean, the environment dolphins live in. The aesthetics design of the stations not only begins the evolution of bus but also city sightseeing along the Taiwan Avenue.

However, Chinese White Dolphin is a rare animal which needs a friendlier living environment, such as moderated fishing and ocean protection. These aim at preaching environmental awareness in everyday life of passengers and to characterize BRT as a sustainable and environmental public transportation system.

The station is expected to be smart, friendly and popular. The characteristics of dolphin inspire architect to design a station with dolphin appearance to reflect SPEED. Automated Fare Collection (AFC) system, Automatic Ticket Issuing Machine (ATIM), Passenger Information Display Systems (PIDS), and Remote Customer Service Systems (RCSS) enable the stations to become automated and smart. Accessible design such as the level of platform fitting to vehicle floor, expanded gates, Closed Circuit Televisions (CCTV), and platform gates make station friendly, safe, and secure.

Figure 4. BRT planning network in Taichung City (draft)

3.3 Traffic Engineering

3.3.1 Cross Section

Fig. 7 shows that four sections from the east to the west along the Taiwan Avenue have the widths of 18 m, 50 m, 60m, and 50m, respectively. More than sixty percent of the areas covered by the Taiwan Avenue belong to private sectors. Consequently, land acquisition costs billions of US dollars. Therefore, the stations are designed to locate in the curbside of the express lanes to avoid huge budget. The same reason guides the stations setback from the stop lines rather than the far-side or near-side principles. Section 2 and 3 are the most congested area from urban traffic. The number of lanes will be preserved by resizing the width of lanes and slightly cutting the dividers and medians. The preservation harmonizes the supply of road area for mixed traffic and BRT vehicles, and diminishes the impacts on the level of service along the avenue. Fig. 8 and Fig. 9 illustrate the cross sections of Sections 2 and 3.

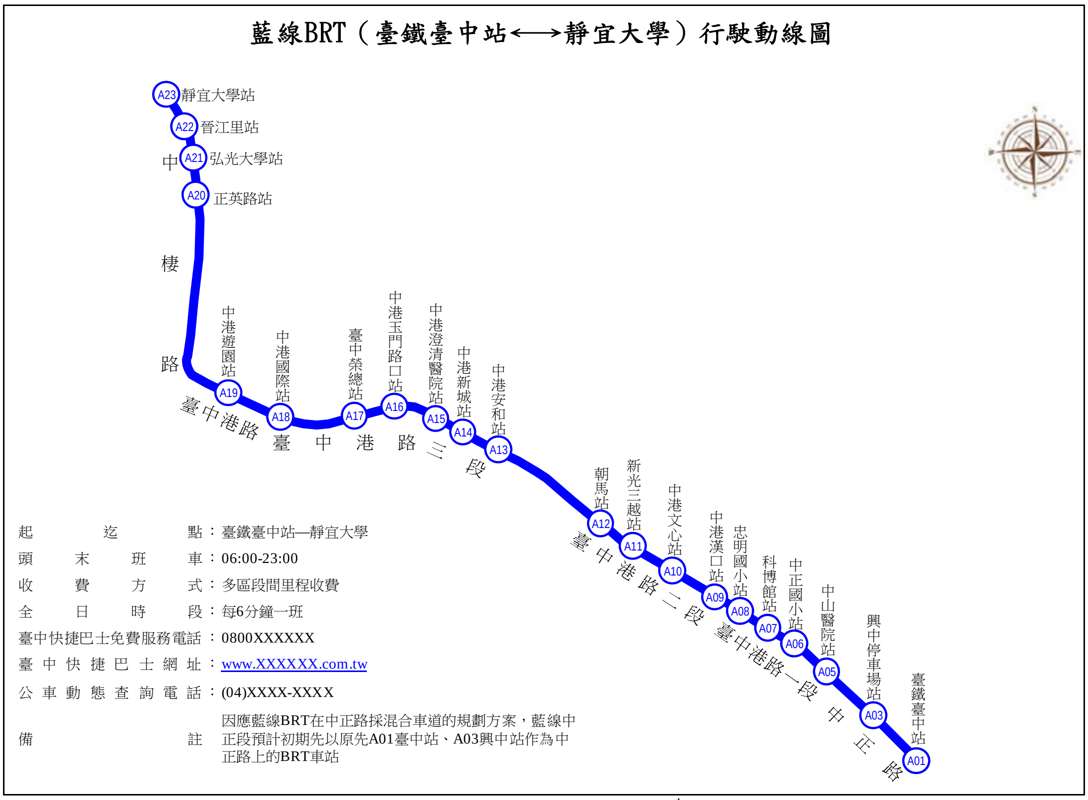


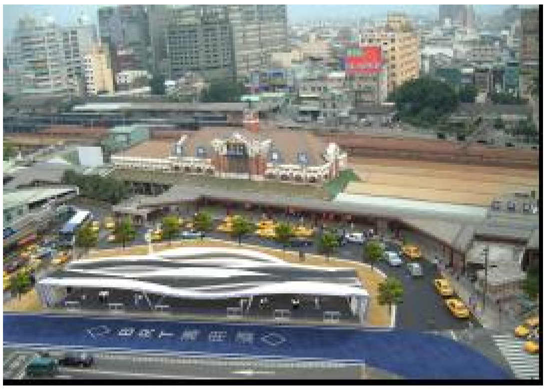
Figure 5. BRT Blue Line (1st phase)

(a) Chinese White Dolphin (Sousa Chinensis)

(b) General type during nighttime

(c) General type during daytime

(d) Switchback station in front of Taichung Train Station (back view)



(e) Switchback station in front of Taichung Train Station (front view)

Figure 6. Land use distribution along BRT Blue Line

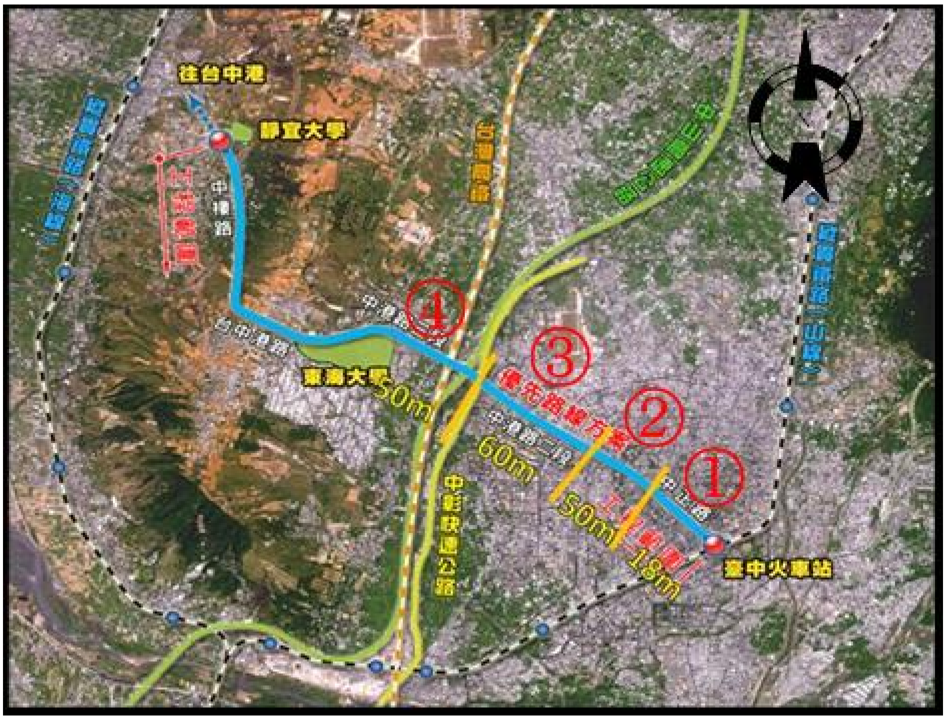


Figure 7. Roadway length distribution

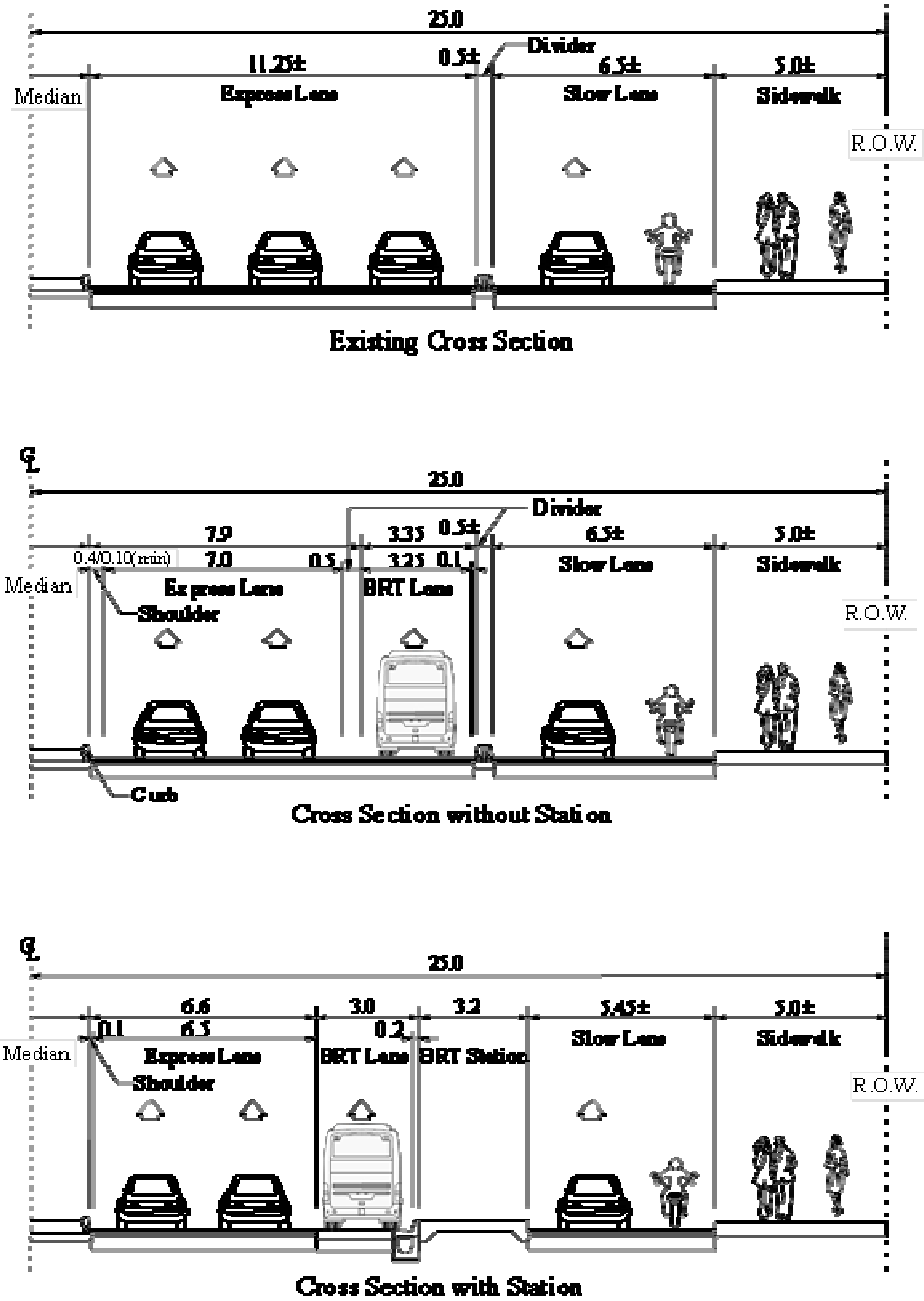


Figure 8. Cross section of section 2

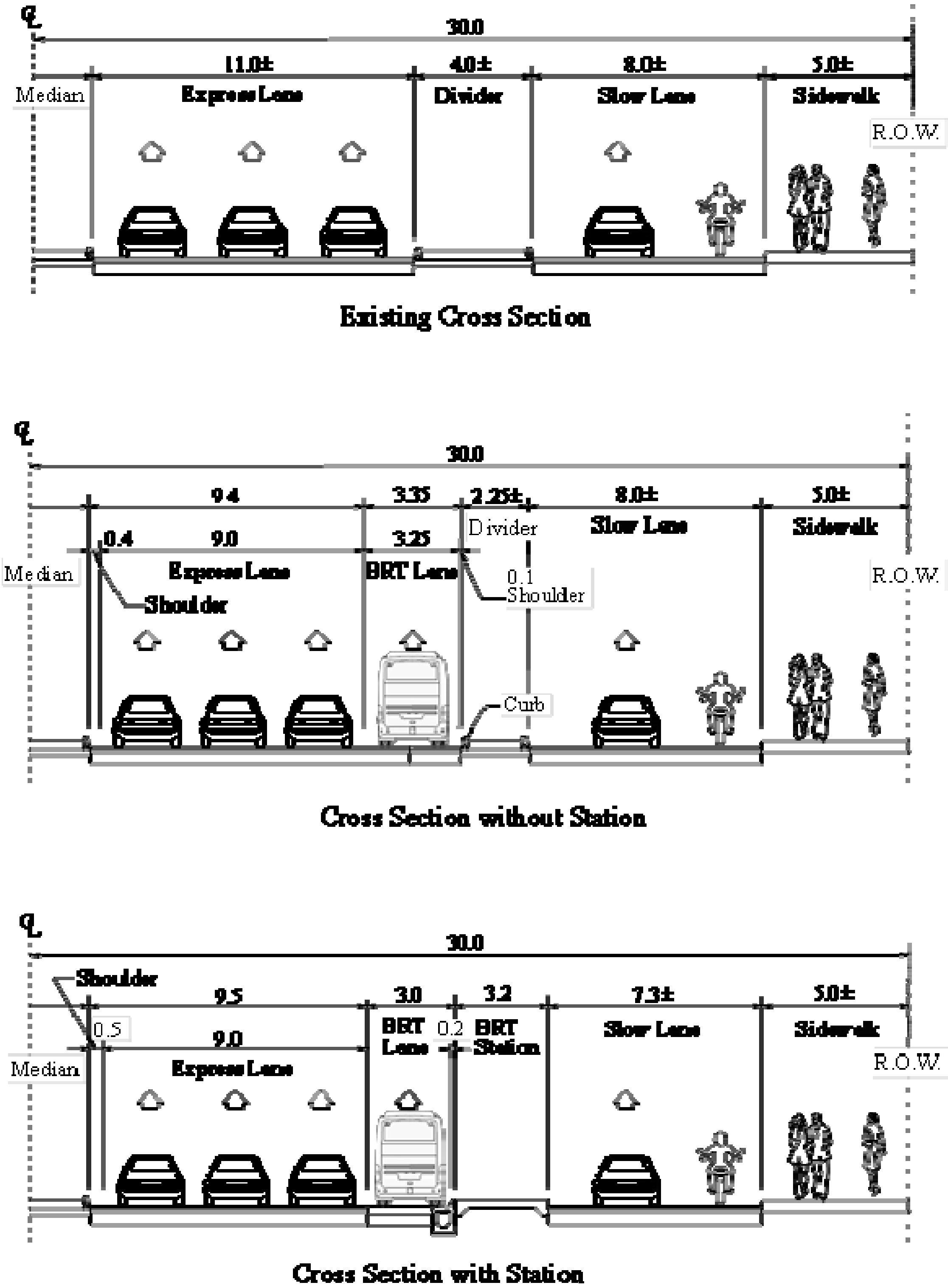


Figure 9. Cross section of section 3

3.3.2 Bus Priority System

Bus Priority Signal (BPS) could ensure the punctuality of BRT vehicles. The system operation principle is categorized as a passive BPS (Han, 2009; Han, and Kim, 2009). The traffic signals render delayed BRT vehicles the priority phase to reschedule; otherwise, they will execute the timing plans according to the Time of Day (TOD). The procedure rendered by the BPS tries to maximize the proceeding capability of BRT vehicles and minimize the delay and stop of other vehicles. However, BPS still delays the mixed traffic at intersections. The influences could be diminished by scheduling the signal timing plans in coordination with the trajectory of BRT vehicles to avoid executing BPS.

Fig. 10 illustrates that BPS is comprised of Roadside Unit (RSU), On-board Unit (OBU), and BRT operation and control center. The RSU consists of traffic controller and short range communication (SRC) system. The OBU notifies BPS of the arrivals of BRT vehicles. The SRC detects the arrivals of BRT vehicles for the controller to decide whether to render priority phase. Then, BRT operation and control center records the logs of priority events and monitors fleet operation. The urban traffic control center authorizes BPS operation. The two centers collaborate with each other for the passive BPS.

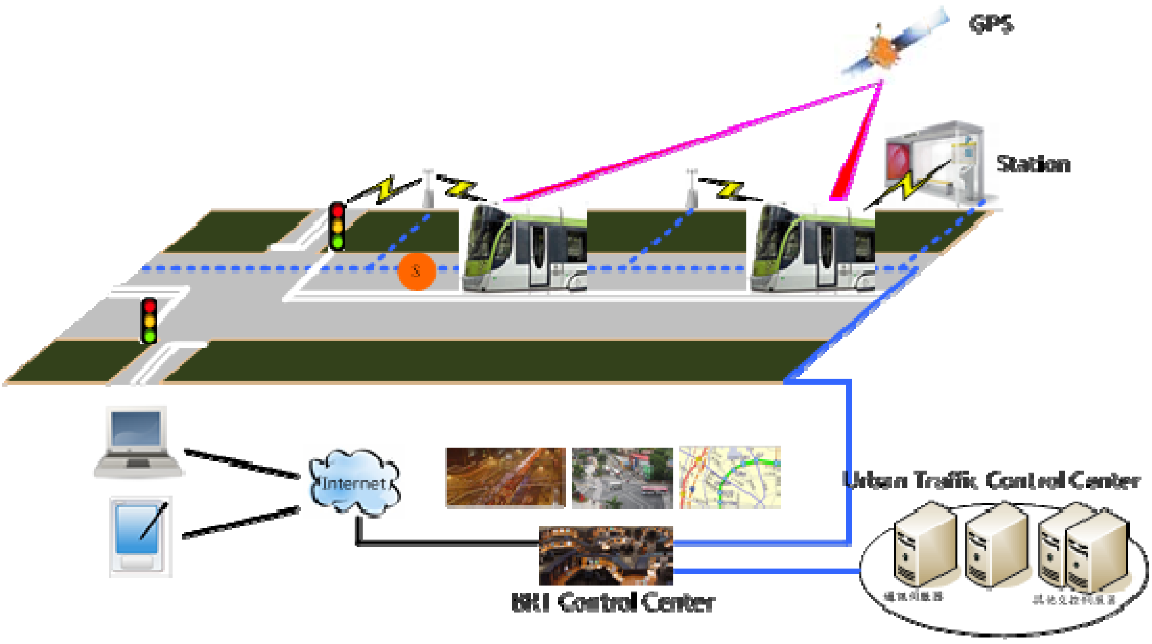


Figure 10. Bus Priority Signal architecture

3.3.3 Circulation

Fig. 11 shows sixteen intersections along the Taiwan Avenue prohibit left-turn traffic. This simplifies signal phases for conflict deduction between BRT vehicles and mixed traffic so as to ensure the efficiency of BPS.

3.3.4 Design Vehicle

The design vehicle of the project refers to A-BUS suggested by The American Association of State Highway and Transportation Officials (AASHTO, 2011). Fig. 12 shows that the dimension and minimum turning trajectory of the design vehicle. The appearance of the vehicle will not be decided until the public procurement evaluation is completed. However, the appearance is expected to fit the style of station design and to attract more ridership from private vehicles.

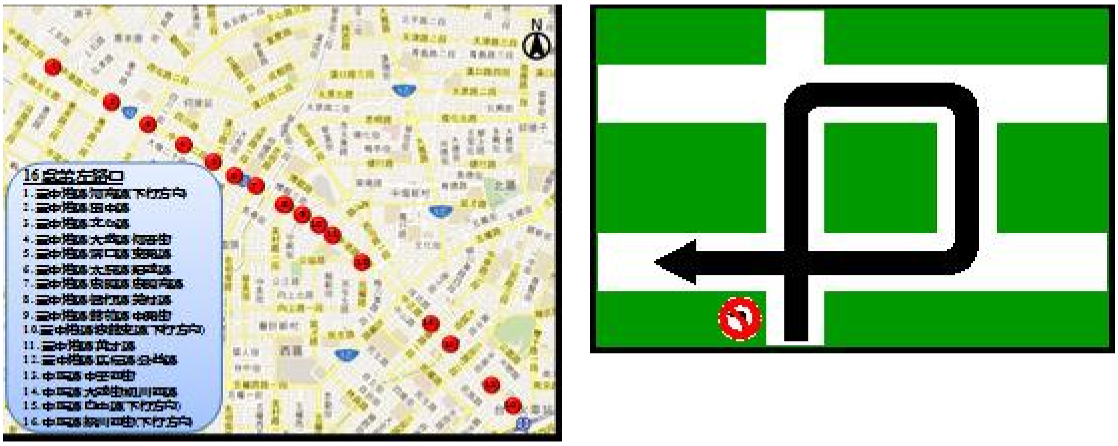
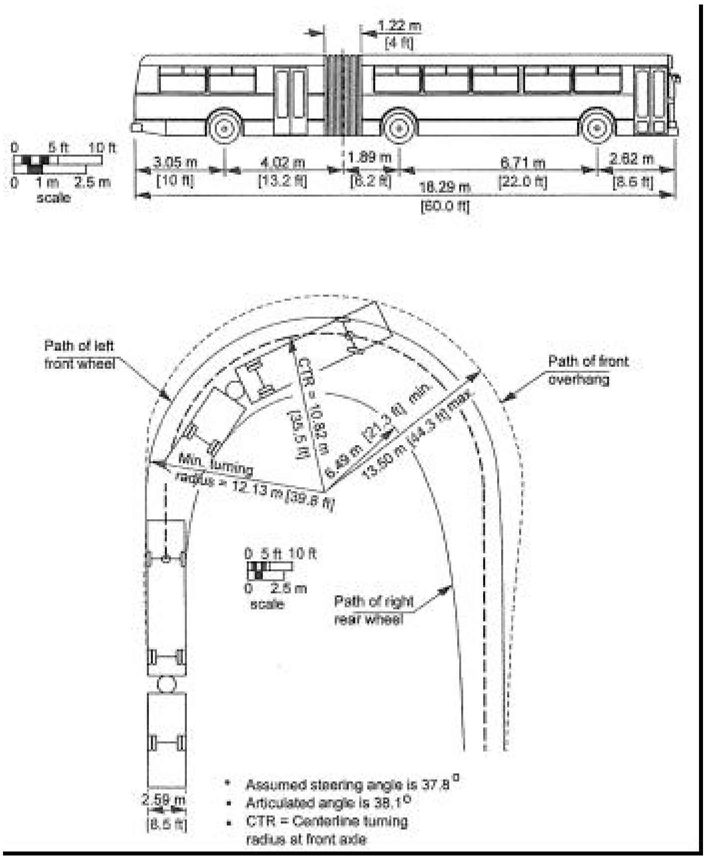


Figure 11. Implementing the ban on left-turns along Taiwan Avenue



Source: AASHTO (2011)

Figure 12. Minimum turning trajectory for articulated bus (A-BUS) design vehicle

3.4 Intelligent Transportation System

ITS for BRT is comprised of BRT control center, OBU, RSU, Client applications, bus information center, and PIDS in BRT stations. The system architecture is shown in Fig. 13. OBU helps BRT control center to monitor the trajectories of BRT vehicles, manage BRT fleet, and notify the RSU of the BRT vehicle arrivals. The trajectories are also revealed to the client side for passengers to plan their trips at origins and to identify the arrivals of BRT vehicles at BRT stations. BRT control center works in coordination with bus information center to continuously improve public transit environment and with the (urban) traffic control center to coordinate BRT operation and traffic control performance.

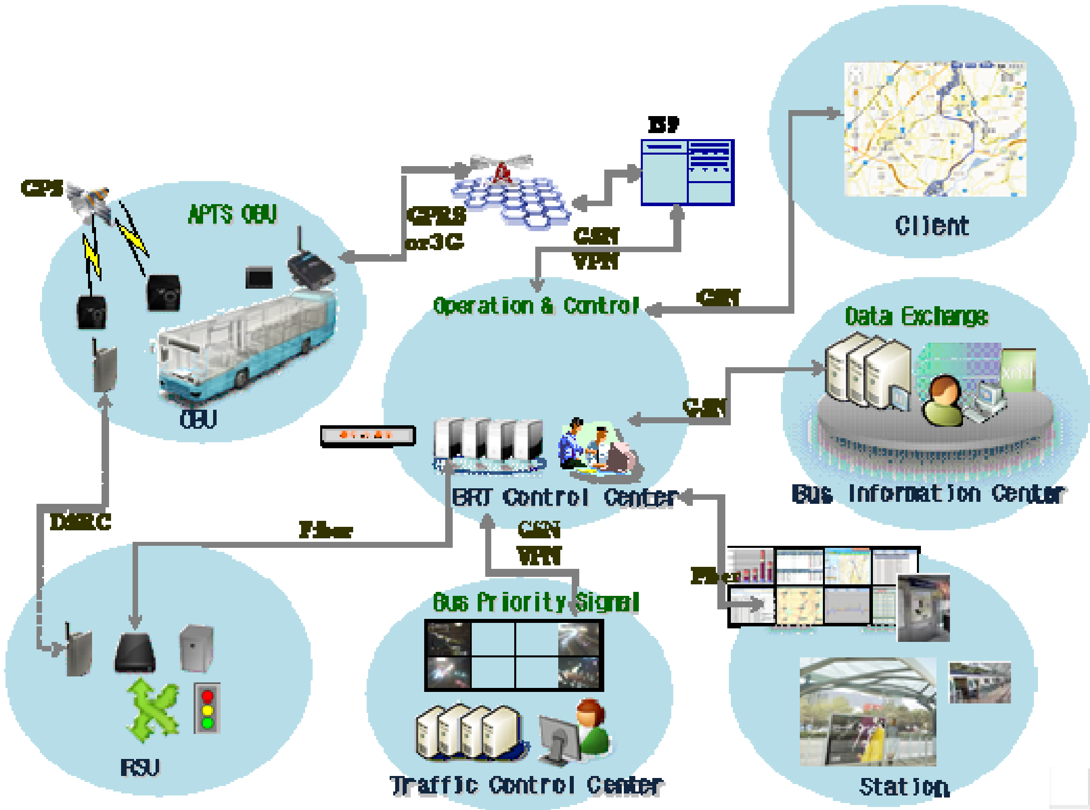


Figure 13. ITS architecture of Taichung BRT

3.5 Design Features

Tab. 2 summarizes design features of the Blue Line of Taichung BRT. The table covers most quantitative features the Institute for Transportation and Development Policy (ITDP) proposed.

Table 2. Features of the Blue Line of Taichung BRT

BRT Feature	Taichung BRT (Blue Line) in 2014
Year system commenced	The beginning of 2014
Number of corridors	2
Total length of trunk corridors (km)	35
Number of trunk routes	3
Location of busway lanes	Curbside of express lanes
Location of doorways	Curb side (right)
Type of surface material on runways	Asphalt
Type of surface material on runways at stations	Concrete
Number of stations	21
Average spacing between stations (m)	820
Number of stations with passing lanes	0
Number of terminals	1
Number of depots	1

BRT Feature	Taichung BRT (Blue Line) in 2014
Number of total system passenger-trips per day	53,700
forecasted peak ridership (passengers per hour per direction)	7,890
Average commercial speed (km/h)	23
Average peak headway (minutes)	3
Average non-peak headway (minutes)	6
Average dwell time at stations (seconds)	40
Number of trunk vehicles	25
Trunk vehicle type	Bi-articulated
Trunk vehicle capacity	180
Trunk vehicle length (m)	18
Type of guidance system, if applicable	Kaiser curb
Type of fare collection / verification technology	Smart card and token
Number of intersections with priority signal control	57
Number of grade-separated intersections	0
Fare (US$)	0.73 (smart card), 1.4 (otherwise)
Total planning cost (US$)	1 million
Average trunk vehicle cost (US$)	400,000
Total infrastructure cost (US$per km)	67 million

3.6 Integration

The Transportation Bureau of Taichung City coordinates the integration works supervised by the Deputy Mayor. The tasks include Physical and Operational Integration of Public Transportation, Modal Integration, Integration with Market Needs, Integration with Social Objectives, Environmental Issues in Transportation Policy Making, Institutional and Administrative Integration, Integration of Policy Sectors, and Integration of Policy Measures (Hull, 2005). Furthermore, two shuttle loop services (draft), shown in Fig. 14 and Fig. 15, are supportive measures to extend BRT accessibility in the Aged City to promote social economic activities.

4. EXPECTED BENEFITS

Reasonable travel time and affordable ticket fare are simple and specific benefits to guide engineers in planning, designing, and constructing Taichung BRT. Tab. 3 shows that BRT saves 20-30 min in-vehicle time when compared with traditional buses. BRT and taxi have the same travel time. However, passengers would pay 20 times the fare of BRT for taxi.

5. SIMULATION

Simulation is a very powerful technique to evaluate the performance of a BRT and to improve the design (Rangarajan, 2010). Tab. 4 summarizes the simulation results carried out by VISSIM (PTV, 2009) on the mobility of 11 key blocks before and after the introduction of BRT. The mobility (average speed) varies slightly (within 21%). Level of Service of most blocks stays unchanged. The evidence demonstrates that BRT has better mobility than traditional buses and slightly impacts mixed traffic flow.

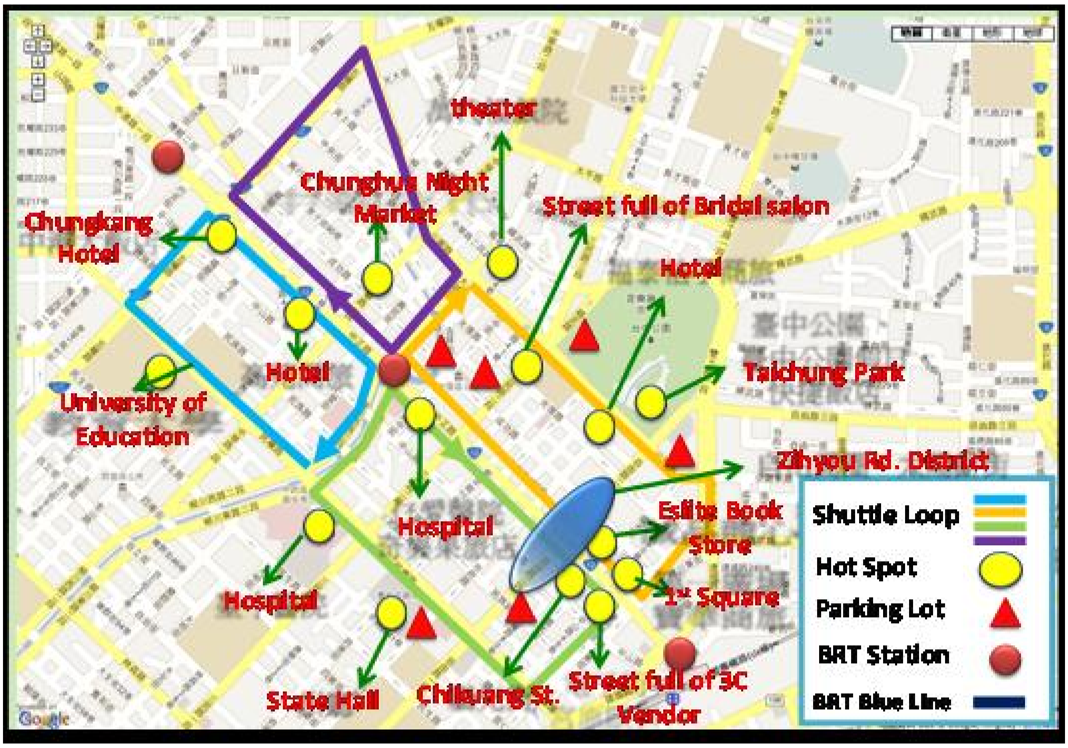


Figure 14. Routes of shuttle loop bus for the aged city (butterfly lines)

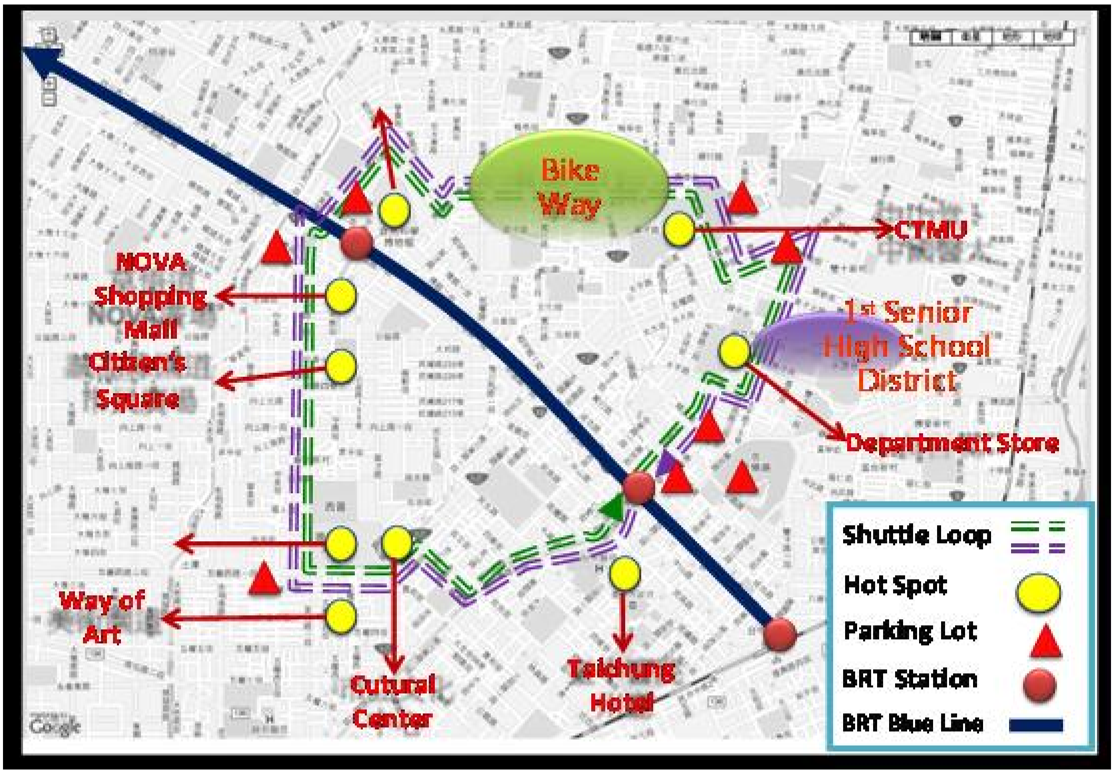


Figure 15. Routes of shuttle loop bus for the aged city (circle line)

Table 3. Public transit performance

Performance	BRT	Taxi	Bus
In-vehicle Time (min.)	45 (peak) 40 (off-peak)	40-46 (peak) 30-38 (off peak)	75 (peak) 60 (off peak)
Fare (NT$)	22 (pay by Smart Card) 42 (otherwise)	480 (peak) 380 (off peak)	22 (pay by Smart Card) 42 (otherwise)
Off-vehicle Time (min.)	1.5~3	3~10	5~15

Table 4. Simulation summary before and after BRT construction

Block		Average Speed (km/h)						Level of Service			
		Before		After		Difference		Before		After	
		W-E*	E-W*	W-E	E-W	W-E	E-W	W-E	E-W	W-E	E-W
Taiwan Ave.	PU-Zhengying Rd.	36.1	34.2	35.4	33.3	-1.94%	-2.63%	C	C	C	D
	Zhengying Rd.-Zhongxing Rd.	34.2	34.7	33.0	32.8	-3.51%	-5.48%	D	C	D	D
	Zhongxing Rd.-International St.	32.8	35.5	31.2	33.6	-4.88%	-5.35%	D	C	D	D
	International St.-1st Industry Rd.	25.8	36.3	24.6	29.6	-4.65%	-18.46%	E	C	E	D
	1st Industry Rd.-Anhe Rd.	20.1	25.4	19.0	20.1	-5.47%	-20.87%	F	E	F	F
	Anhe Rd.-Chaofu Rd.	26.2	38.5	27.6	38.0	5.34%	-1.30%	E	C	E	C
	Chaofu Rd.-Wenxin Rd.	14.3	27.1	17.3	26.4	20.98%	-2.58%	F	E	F	E
	Wenxin Rd.-Zhongming South Rd.	18.7	28.1	19.3	29.6	3.21%	5.34%	F	E	F	D
	Zhongming South Rd.-Minquan Rd.	23.8	25.3	14.0	23.8	-41.18%	-5.93%	E	E	F	E
	Minquan Rd.-Wuquan Rd.	17.5	8.6	16.9	10.1	-3.43%	17.44%	F	F	F	F
	Wuquan Rd.-Jianguo Rd.	20.7	23.6	23.1	25.8	11.59%	9.32%	F	E	D	D

*E-W: eastbound; W-E: westbound.

7. CONCLUSION

After long periods of debate and discussions, Taichung City finally decides to build BRT to solve the congestion problem along the Taiwan Avenue. The construction follows the abstract design concept of “SPEED”. The distinguishing features include 1) stations that are designed for practicability, aesthetics and environmental awareness; 2) ITS to increase fleet operation efficiency; 3) BPS that are not randomly activated; 4) roadway reform that slightly impacts mixed traffic; and 5) vehicles of special designs. Supporting measures consist of shuttle loop bus planning, left-turn prohibition along the Taiwan Avenue, resource integration among the administrative authorities. The designs of vehicles and stations are expected to attract more passengers from private vehicles. The traffic simulation results demonstrate that the proposed BRT has the same travel time as private cars with much cheaper cost. Moreover, the BRT does not exacerbate the LOS along the Taiwan Avenue. On the contrary, it provides passengers with a new choice. With its distinguishing design features, the proposed BRT will reform the public transportation system and facilitate the development of Taichung Metropolitan.

REFERENCES

AASHTO (2011) *A Policy on Geometric Design of Highways and Streets*. 6th Edition, John Horsley, Washington, D.C.

Han, L. D. (2009) Active and Passive Bus Priority Strategies in Mixed Traffic Arterials Controlled by SCOOT Adaptive Signal System—Assessment of Performance in Fortaleza, Bracial. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2128, 58-65.

Han, Y. and Kim, Y. (2009) The Methodology of Bus Passive Priority on BRT. *Proceedings of the Eastern Asia Society for Transportation Studies*, 7.

Hull, A. (2005) Integrated transport planning in the UK: From concept to reality. *Journal of Transport Geography*, 13, 318-328.

Institute for Transportation and Development Policy (2007) *Bus Rapid Transit Planning Guide*. NY USA.

Jaensirisak, S. and Klungboonkrong, P. (2009) Why Bus Rapid Transit (BRT) is Interested by Transport Planners and Travellers in Thailand. *Proceedings of the Eastern Asia Society for Transportation Studies*, 7.

Munawar, A., Priyanto, S., and Malkhamah, S. (2009) Urban Public Transport Reform in Indonesia, Yogyakarta Model. *Proceedings of the Eastern Asia Society for Transportation Studies*, 7.

PTV, (2009) *VISSIM User Manual—V.5.2*, Karlsruhe, Germany.

Rangarajan, A. (2010) BRTS- Bus Rapid Transit System in Pune: Modeling, Simulation and Feasibility Analysis. *Proceedings of the 2010 International Conference on Industrial Engineering and Operations Management*, 781-785.

Tan, T. D., Y Cao, N., Sano, k., and Tu, T. V. (2009) A Study of Applying Bus Rapid Transit in Hanoi. *Proceedings of the Eastern Asia Society for Transportation Studies*, 7.

Tiglao, Noriel Christopher C., Patdu, Ildefonso T., Jr. (2007) Issues and Directions on Integrated Public Transport in Metropolitan Manila. *Proceedings of the Eastern Asia Society for Transportation Studies*, 5.

Wachi, T., Yagi, S., Hagiwara, T., Kawaguchi, H., and Kennedy, T. L. (2009) Development of Regional Railway System in the Central Java Region. *Proceedings of the Eastern Asia Society for Transportation Studies*, 7