Design of Middleware with EPC global by Using RFID Reader and Tag to Collect Traffic Information Implemented on Urban-bus

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Abstract **In this paper, we propose a website to exhibit the traffic information for every 5 minutes at certain places of street measured by three Radio Frequency Identification (RFID) readers for 216 tags installed on two different urban-bus companies and transmit those information via GPRS modem from testing point to control center. Each data can be used to indicate the exact point of traffic condition in a big city. Because the design hardware of reader is not suitable for the purpose of collecting traffic information, one can not adjust its resolution as you like. Thus, the analysis of turning point on the major errors of distance and timing errors is very important to let the system designer to take correct strategies to compensate for all of possible errors. One can conclude the following rule: 1) when speed is fast, timing error becomes dominant; 2) when speed is low, distance error becomes dominant. The result is very valuable for the local government to make a decision on the adjustment of urban-bus for their future use. The result shows that the application of RFID tag and reader is an alternative way to extract the traffic information instead of traditional loop detector. It is suggested that the vehicle speed estimated by 2 tags 1 reader is more accurate than that of by 1 tag 1 reader compared from historical data.**

Index Terms **RFID, ITS, TRACFFIC INFORMATION, GPRS MODEM, READER, TAG.**

I. PROBLEM STATEMENT

Using RFID tag implemented on urban-bus is one of the research project held in the Institute of Ministry of Transportation and Communication of Taiwan for this fiscal year. Traditionally, the embedded loop detector buried into road to collect traffic information is a general method for local government to control their traffic flows [1]. The use of RFID tag implemented on urban-bus to collect traffic information is the first project trial in Taipei city. Thus, the result is very valuable for the local government to make a decision on the adjustment of urban-bus for their future use [2]-[4].

This two-year trial project is performed by ChungHwa Telecom Labs in the second year now on certain section of roads to collect the traffic information specified as Fig. 1. The target of traffic information is included by the following factors: a) traffic flow, b) bus ID classification, c) average speed (spot speed), d) road occupied rate, e) traffic time, and f) vehicle stop-condition detecting (VSCD). Every reader can perform these six tasks, simultaneously. However, reader 1 with reader 3 is specifically designed to calculate the traveling time for longer distance and reader 2 with reader 3 is focused to calculate the sectional time and VSCD. The last item of VSCD is to detect whether the average speed and time of urban-bus between reader 2 and reader 3 is in VSCD or not. If the speed is less than 10 km/hr, or leaving the detecting area of reader 2 within specific time without entering the region of reader 3 is regarded as vehicle-stop. The specific time needed of VSCD for driving an urban-bus during the detection region of reader 2 and reader 3. If the needed driving time is larger than this value regarded as vehicle-stop; otherwise, the vehicle is leaving.

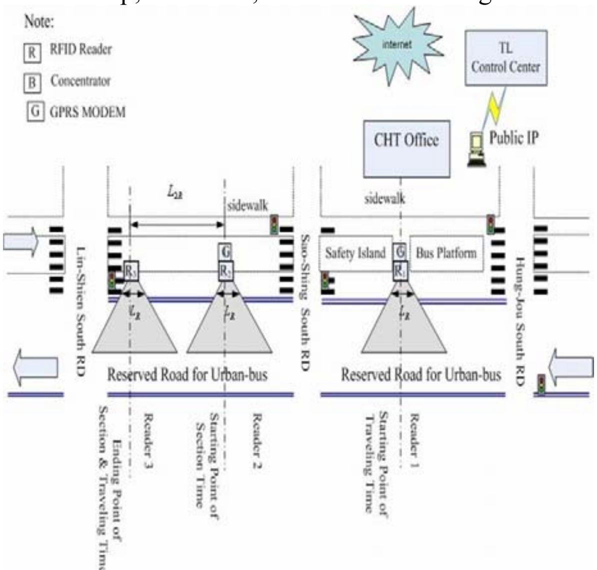


Fig. 1 Certain Road's section is implemented RFID reader and Tag to collect traffic information

There are 108 buses are installed on two different tags with odd number putting in the front and even number in the back for two main bus's companies. Three different readers installed in certain places shown in Fig. 1, called R_1, R_2, and R_3, respectively. Those readers are used to collect traffic information by recording the tag's information of incoming urban-buses. The design target shown in Fig. 1 is designed to obtain the traffic information such as traffic flow, road occupancy, average speed (spot speed), vehicle ID classification, and VSCD, etc by using RFID system and compare its result with traditional devices such as loop detector.

II. TRAFFIC INFORMATION SETTING

The traffic information is collected by RFID readers. The time of T_{L_R} is defined as the time passing the detecting zone. The time of T_{L_T} is defined as the time passing two tags. The time of T_{L_V} is defined as the time passing through the whole length of urban-bus shown in Fig. 2.

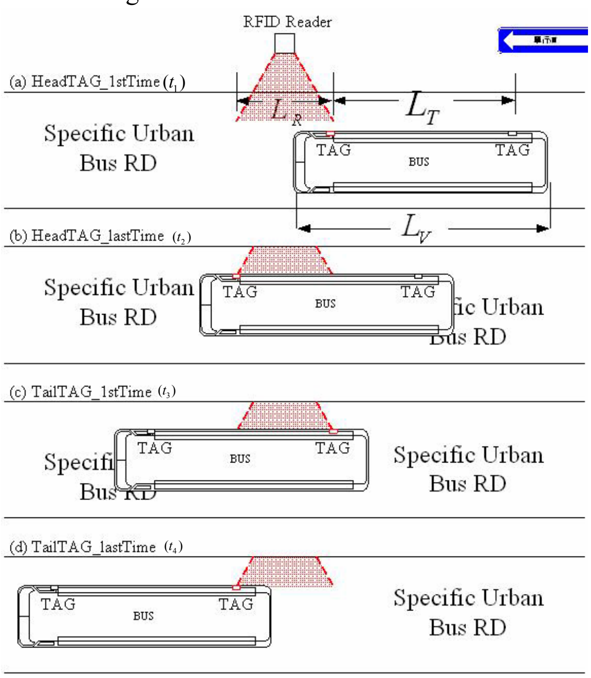


Fig. 2 Traffic Information is collected by tag's ID and three time intervals, $T_{L_R}(=t_2-t_1)$, $T_{L_T}(=t_3-t_1)$, and $T_{L_V}(=t_4-t_1)$.

2.1 Baseline Setting and Information acquired

The baseline setting for acquiring the reference speed of urban-bus is shown as Fig. 3. The following table is used to calculate the traffic information for each urban-bus. Manual method is used to record the vehicle ID via the image of tape to compare its result with the calculated formula embedded from the software of middleware.

2.2 The definitions of measured value for the layout of testing area

The layout of testing area is important for the definitions of traffic information shown in Fig. 3 by installing three cameras to capture the images of incoming bus entering and leaving the region of R1, R2, and R3, respectively.

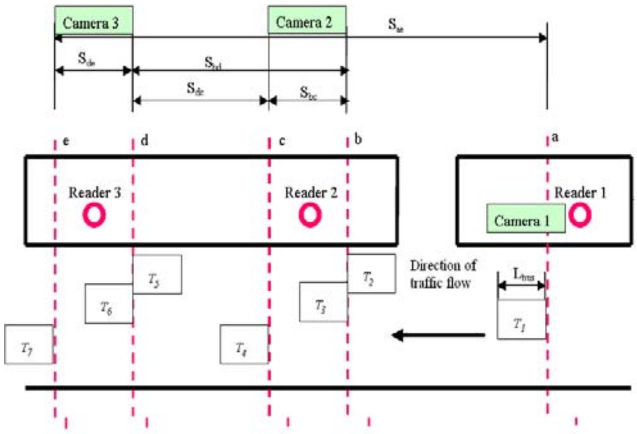


Fig.3 Baseline setting and information acquired

There are two methods to measure the estimated speed of passing vehicles. The following definitions are using 1 tag and 2 tags with a little bit different to obtain observed speed of vehicle. Those values can be compared with the real value obtained from RFID reader compared by manual method.

The relative speed calculated by one Reader two tag (1R2t) is defined as

$$V_{1R2t} = \frac{L}{T} = \frac{L_T}{t_3 - t_1} \qquad (1a)$$

where L_T shown in Figure2 is the length of urban-bus passing zone of R2 at the time of T_3 and T_1 and the measured velocity by urban-bus is calculated as

$$V'_{1R2t} = \frac{L_T + \Delta l}{t'_3 - t'_1} = \frac{L + \Delta l}{T + \Delta t}, \qquad (1b)$$

where Δl the measured distance error is defined as $\Delta l = l_t + l_l + l_e + \cdots$ and Δt is the measured timing error occurred by the sampling error on reader. The change of length l_t is defined for different tag and the change of communication length l_l is defined as for the driving paths (routes) of each urban-bus, and l_e is the change of communication zone at different temperature conditions.

The relative speed, V_{2R1t}, of two readers and one tag is defined as

$$V_{2R1t} = \frac{L}{T} = \frac{L_{2R1t}}{t_{1R2} - t_{1R1}}, \qquad (2a)$$

where L_{2R1t} is the whole installed length of two readers and the time $T = t_{1R2} - t_{1R1}$ is the time difference of between two readers. The measured velocity by microwave's beamforming, V'_{2R1t}, of urban-bus is measured by 2 readers and 1 tag (2R1t) defined by

$$V'_{2R1t} = \frac{L_{2R1t} + \Delta l_{2R1t}}{t'_{1R2} - t'_{1R1}} = \frac{L_{2R1t} + \Delta l_{2R1t}}{T_{2R1t} + \Delta t_{2R1t}}. \qquad (2b)$$

where the measured distance error is defined as $\Delta l = l_r + l_l + l_e + \cdots$, where l_r is the changing length of different readers with same tag. The change of communication length l_l is defined as for the driving path (route) of urban-bus, and l_e is the change of communication zone. The timing difference of Δt_{2R1t} is defined by the duration time needed on 2R1t. The percentage of road occupation rate on certain measured point on R2 shown in Fig. 3 is defined as

$$OCC = \frac{\sum_{i=1}^{n} T_i}{T} \times 100\% \qquad (3)$$

where the road occupation rate is defined as the total occupied time for the 1st tag's on bus summation from 1 to *n* while passing reader 2 divided by the unit time interval of (T), i.e. 5 minutes. The travel time is defined as the time $T_7 - T_1$ of duration of the bus passing R_1 and R_3, respectively. The VSCD detecting algorithm according to the content described in section 1 are defined and shown in Fig. 3 as follows

$$a) \quad T_7 - T_5 > 30 \text{ sec}, \qquad (4a)$$

$$b) \quad V_{dc} < 10\ km/hr, \qquad (4b)$$

$$c) \quad (T_5 - T_4) > (S_{dc}/10km/hr). \qquad (4c)$$

If those three conditions are satisfied, they are regarded for all the same classes as VSCDs.

III. MEASURING RESULTS FOR READER IN STATIC AND DYNAMIC CONDITIONS

The measuring readers and tags bought from Nedap Inc [5] needs to satisfy the regulation of industrial ISM band by the law of NCC in Taiwan. Some of the measured results for reader in static and dynamic conditions are shown in Fig. 4(a) and 4(b), respectively. The unsymmetrical waveform distribution is measured on the top of building with different materials and is reflected by a neighborhood higher building. The best communication zone for urban-bus passing through RFID's reader is within -2m to 2m from horizontal distance from Fig. 4 measured by using dynamic conditional trials with car driver for trying several different driving speeds. The tag is suggested to be installed on the urban-bus with the same height of reader.

The communication zone of line of sight (LOS) for reader [5] is shown in Fig. 5. The horizontal and vertical beams of reader with different angle are shown in Fig. 6. The blue and yellow curves in Fig. 7 are used to indicate the best possible communication region for left and right regions for -100 dbm, respectively. This figure compared with Fig. 6 is used to demonstrate the best measured communication area with -100 dbm with the same result as the specification shown in Fig 6.

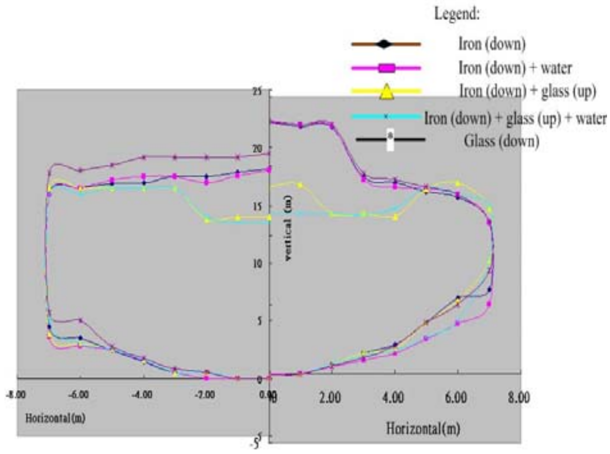


Fig. 4 (a) Static Testing Result Using RFID's tag and reader with different materials.

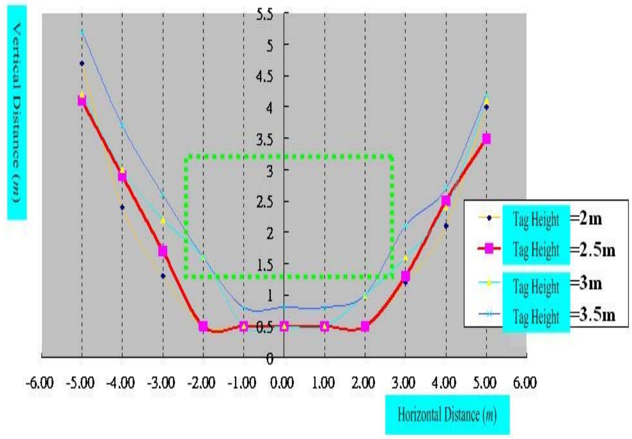


Fig. 4 (b) Dynamic Testing Result Using RFID's tag and reader with different heights and driving speeds.

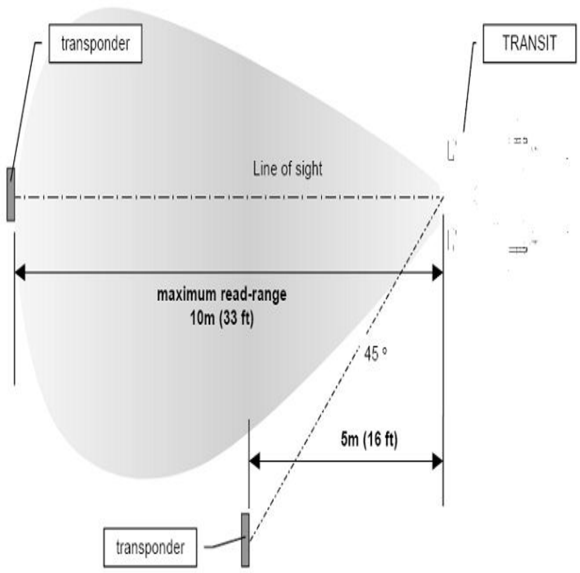


Fig.5 The communication zone of reader

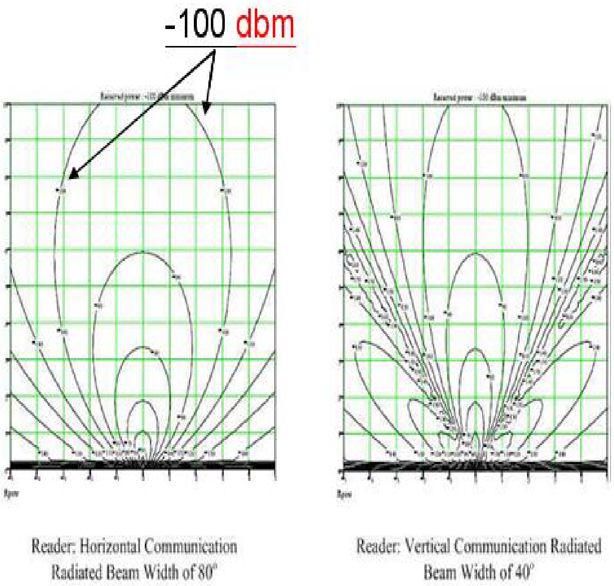


Fig. 6 The horizontal beam of reader with different angle

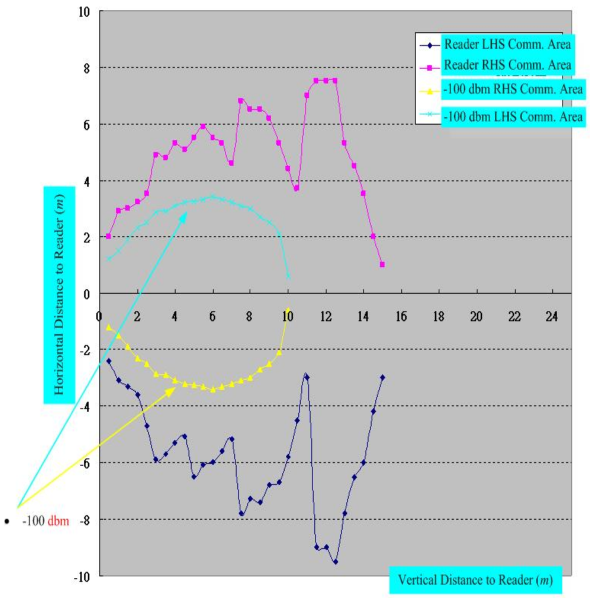


Fig. 7 The communication zone for RFID reader and tag.

The communication zone testings for same style reader with different tags are measured in Fig.8 by 2 two readers and 5 tags. The conclusion is that if tag is not the same, then the response time is different. But, the communication zone is guaranteed to communicate correctly when the urban-bus drivers drive his/her bus stopping near the installed readers. However, it will be introduced one of the major errors to count the spot speed and other traffic parameters using Radio Frequency (RF) beams.

The vehicle-stop and normal conditions are detected by our program executed from the website of Fig. 10 to 13 when urban-bus passes through the reader 1 to reader3, simultaneously. The detected result is correct when one compare with the real traffic conditions from the recorded video tape.

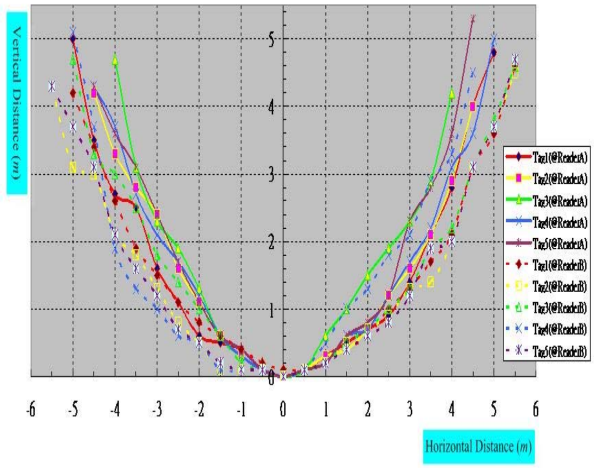


Fig. 8 Stability test for different Reader/Tags (2R×5T).

IV. Design of Middleware using Reader and Tag for Traffic Information on Urban-Bus using EPC Global with ALE Engine

The design flow of middleware for real-time monitoring and data searching is designed with sequential sequence shown in Fig. 9a for the whole system. At first, the reader initialization setting should be done for all of the readers. Then, the initialization of the system parameters for middleware should be finished accordingly. The tag identification (ID) number sequence is arranged for odd in front and even in the back while installing on the outside of urban-bus with the same height of reader. The GPRS modem is installed with the roadside unit inside the box of concentrator. The information of tag sequence, reader ID, and time stamp are filtered from the program of work station, which received it from the base-station of GPRS via public IP. Then, the designed software on the middleware according to the definitions of our formula can be shown to the website shown in Fig 9b.

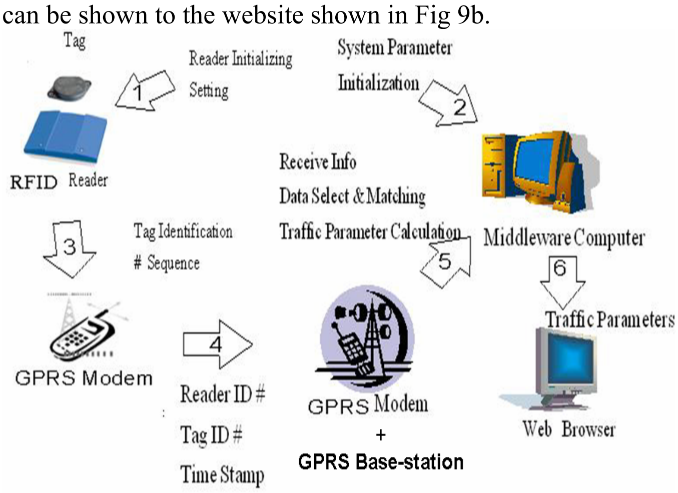


Fig. 9a The Design Flow of RFID Middleware.

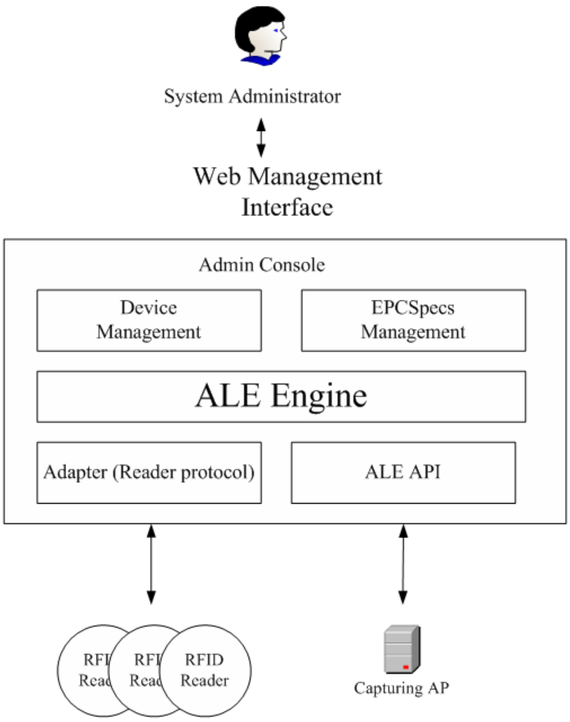


Fig. 9b The EPC global of web management interface with ALE engine.

The traffic parameters can be obtained via two main folds. Mainly, one is the so called using the structure of two tags or one tag (2t/1t). The other is using the structure of two readers or one reader (2R/1R). Those results may lead to different results of each sampling speeds. The traffic parameter outputs for one tag and double tags on single reader and double readers can be shown in the following table 1(a) and (b), respectively. The historical results measured by three RFID readers are shown in Figure 11 with (a) historical event evaluation result for every 5 minutes. The website to show the real-time traffic information is designed to have three major functions. Mainly, the 1st one is real-time monitoring; the 2nd item is the traffic information of readers; the 3rd one is the section traffic information to obtain the road occupancy, traffic flow, average sectional speed, VSCD and abnormal status. The sectional traffic information between R2 and R3 is to show the abnormal and normal of VSCD in Fig. 12 and 13, respectively. The collected traffic information on different readers (R1 to R3) is shown on Fig. 16 for traveling time and sectional information is shown in Fig. 15, respectively.

Content Of Demo	Entering time	route	Veh. ID	Detecting time	Instant spot speed			Stat. instant spot speed	Traffic flow	Occupancy			Stop condition detecting
					Head of tag	Tail of tag	**Double** tags			Head of tag	Tail of tag	**Double** tags	
Output Column	(20)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)

Stat. time	Traffic flow	average sectional speed (km/hr)	occupancy (%)	Stop Condition detecting	Abnormal status
(ex.) 08:00~08:05	(13)	(14)	(15)	(16)	(17)

Table 1 (a) The traffic parameter output for one tag and double tags on single reader (b) (a) The traffic parameter output for one tag and double tags on double readers.

Fig. 10 The designate website shows real-time traffic information.

GIS即時監控 即時資訊

●RFID讀取器1測試點(信義路、杭州南路口)交通資訊

進入時間	公車路線	車號	瞬間車速(km/hr)	統計瞬間車速(km/hr)	流量(車輛/5分鐘)	佔有率(%)	停止偵測
2006-08-22 13:47:45	22	230-AD	20.430927835051...	20.43092783505155	1	0.19	正常
2006-08-22 13:47:50	20	351-AB	27.711940298507...	27.71194029850746	1	0.13	正常
2006-08-22 13:48:29	22	242-AD	4.3136911281489...	4.313691128148959	1	0.88	停止(2)
2006-08-22 13:48:59	信義幹線	689-AC	22.192814371257...	22.192814371257487	1	0.16	正常
2006-08-22 13:51:06	20	388-AB	12.983916083916...	12.983916083916084	1	0.28	停止(2)
2006-08-22 13:51:10	204	890-AG	19.058823529411...	19.058823529411764	1	0.2	停止(2)

●RFID讀取器2測試點(信義路)交通資訊

進入時間	公車路線	車號	瞬間車速(km/hr)	統計瞬間車速(km/hr)	流量(車輛/5分鐘)	佔有率(%)	停止偵測
2006-08-22 13:48:08	22	230-AD	46.630588235294...	46.63058823529412	1	0.08	正常
2006-08-22 13:48:11	20	351-AB	35.032075471698...	35.03207547169811	1	0.1	正常
2006-08-22 13:49:02	22	242-AD	33.661538461538...	33.66153846153846	1	0.11	正常
2006-08-22 13:49:20	信義幹線	689-AC	38.208247422680...	38.208247422680415	1	0.09	正常
2006-08-22 13:51:28	20	388-AB	41.723595505617...	41.72359550561797	1	0.09	正常
2006-08-22 13:51:34	204	890-AG	40.926315789473...	40.92631578947368	1	0.09	正常

●RFID讀取器3測試點(信義路、林森南路口)交通資訊

進入時間	公車路線	車號	瞬間車速(km/hr)	統計瞬間車速(k...	流量(車輛/5分...	佔有率(%)	停止偵測	滯留時間
2006-08-22 13:48:15	22	230-AD	44.04	44.04	1	0.09	正常	0分0秒
2006-08-22 13:48:18	20	351-AB	42.1977272727...	42.19772727272727	1	0.09	正常	0分0秒
2006-08-22 13:49:09	22	242-AD	36.1321100917...	36.1321100917431...	1	0.11	正常	0分0秒
2006-08-22 13:49:27	信義幹線	689-AC	37.062	37.062	1	0.1	正常	0分0秒
2006-08-22 13:51:35	20	388-AB	41.26	41.26	1	0.09	正常	0分0秒
2006-08-22 13:51:39	204	890-AG	38.88	38.88	1	0.1	正常	0分0秒

Fig. 11 The measured speed of urban-bus for its historical event evaluates the result for every 5 minutes.

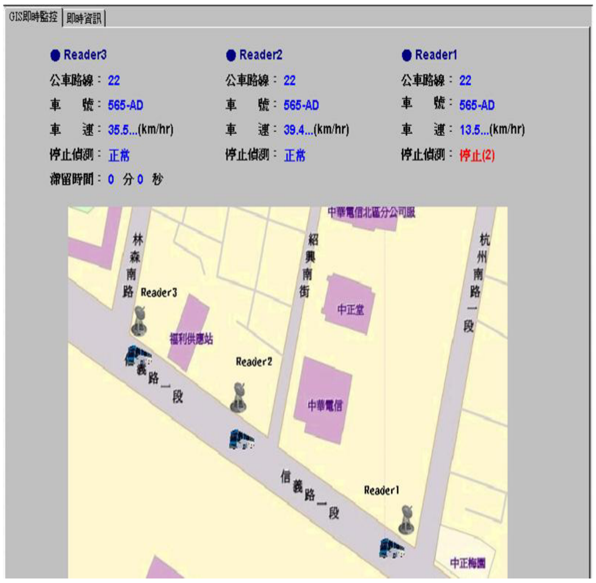
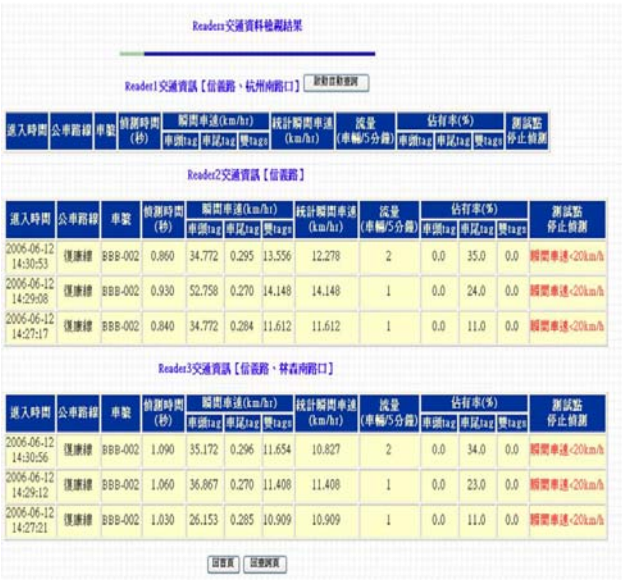


Fig. 12 The urban-bus is detected in the abnormal condition of VSCD.

Fig. 13 The urban-bus is detected in the normal condition of VSCD.



Readers交通資料檢測結果

Reader1交通資訊【信義路、杭州南路口】

進入時間	公車路線	車號	偵測時間(秒)	瞬間車速(km/hr) 車頭tag	車尾tag	雙tags	統計瞬間車速(km/hr)	流量(車輛/5分鐘)	佔有率(%) 車頭tag	車尾tag	雙tags	測試點停止偵測

Reader2交通資訊【信義路】

進入時間	公車路線	車號	偵測時間(秒)	瞬間車速(km/hr) 車頭tag	車尾tag	雙tags	統計瞬間車速(km/hr)	流量(車輛/5分鐘)	佔有率(%) 車頭tag	車尾tag	雙tags	測試點停止偵測
2006-06-12 14:30:53	[illegible]	BBB-002	0.860	34.772	0.295	13.556	12.278	2	0.0	35.0	0.0	瞬間車速<20km/h
2006-06-12 14:29:08	[illegible]	BBB-002	0.930	52.758	0.270	14.148	14.148	1	0.0	24.0	0.0	瞬間車速<20km/h
2006-06-12 14:27:17	[illegible]	BBB-002	0.840	34.772	0.284	11.612	11.612	1	0.0	11.0	0.0	瞬間車速<20km/h

Reader3交通資訊【信義路、林森南路口】

進入時間	公車路線	車號	偵測時間(秒)	瞬間車速(km/hr) 車頭tag	車尾tag	雙tags	統計瞬間車速(km/hr)	流量(車輛/5分鐘)	佔有率(%) 車頭tag	車尾tag	雙tags	測試點停止偵測
2006-06-12 14:30:56	[illegible]	BBB-002	1.090	35.172	0.296	11.654	10.827	2	0.0	34.0	0.0	瞬間車速<20km/h
2006-06-12 14:29:12	[illegible]	BBB-002	1.060	36.867	0.270	11.408	11.408	1	0.0	23.0	0.0	瞬間車速<20km/h
2006-06-12 14:27:21	[illegible]	BBB-002	1.030	26.153	0.285	10.909	10.909	1	0.0	11.0	0.0	瞬間車速<20km/h

Fig. 14 Traveling time is calculated by R1-R3

區段交通資訊【Reader2-3】

統計時間	流量	平均區段車速(km/hr)	佔有率(%)	區段停止偵測	異常狀態
2006-06-12 14:30:00 2006-06-12 14:40:00	2	45.2	0.19	2	1
2006-06-12 14:40:00 2006-06-12 14:50:00	2	61.93	0.06	0	0
2006-06-12 14:50:00 2006-06-12 15:00:00	6	42.58	0.28	0	0

Fig. 15 Sectional traffic information is obtained by R_2 - R_3.

V. DATA VALIDATION AND ERROR ANALYSIS FOR FINAL RESULTS

The testing vehicles for urban-bus on Hsin-Yi Road in Taipei city has been classified into two major operating companies, Metropolitan bus and So-Do bus with 108 urban-buses in total and running in pick hour and off-pick hour for three major different temperature conditions, i.e. blue sky, cloudy, and raining. The base-line setting of acquiring the reference speed is designed by using manual record shown in Fig. 16. The 1st and 2nd pilot-run test on different temperatures were executed on 9/14 and 10/4, with blue and cloudy skies in 2006. The speed calculated by head/tail of tags is recorded in Fig. 17, which is larger than expected in head tag. However, the traffic flow can reach the 100 % accuracy rate.

The major errors of speed estimation after adjustment come from the following three reasons: 1) the width of communication zone (distance error) which is changed due to different weather conditions shown in Fig. 18a; 2) the change of driver's path and the stability of RFID system; and 3) the resolution of hardware in sampling time (timing error).

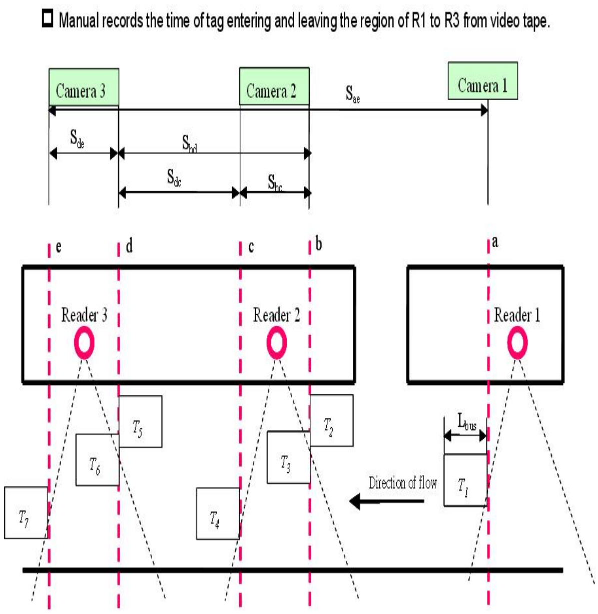


Fig. 16 Data validation method.

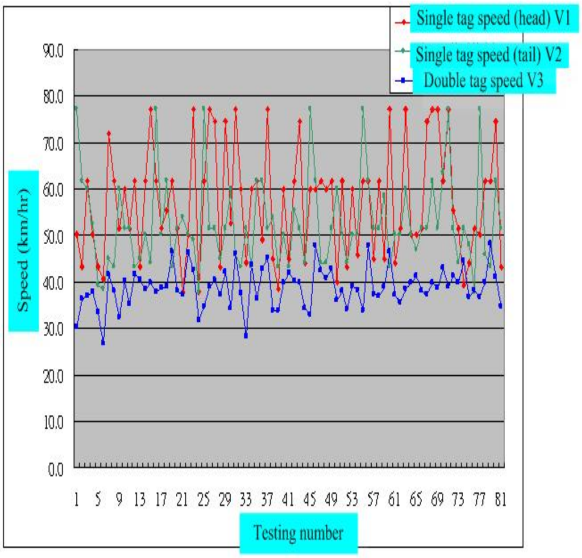


Fig. 17 Two different testing results are shown with 100% accuracy for traffic flow.

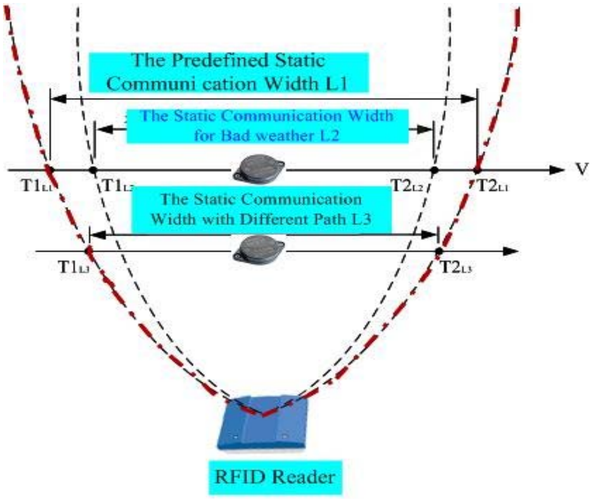


Fig. 18a Use 1R1T to measure speed.

The use of 1 reader with 2 tags to measure speed may produce the following error results: 1) the different tag response times may counter timing error, 2) different driving paths to nullify distance errors, 3) different tag vs. same reader may introduce the variation on the width of communication zone shown in Fig. 18b.

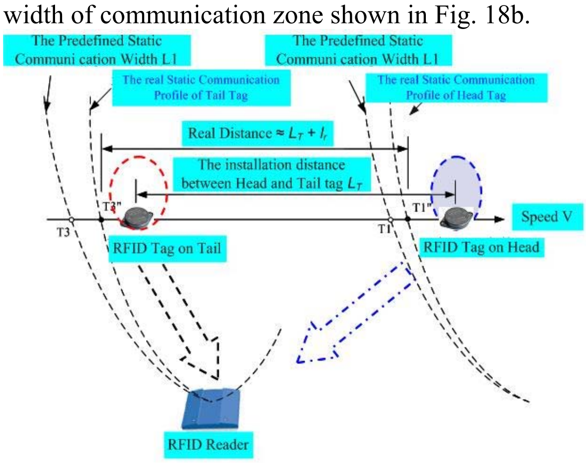


Fig. 18b Use 1R2T to measure speed.

It will become the resources of three major errors when time is consuming. The last item for error analysis is the case of different reader vs 1 tag to measure speed: 1) tag's response time is diminished, 2) the effect of driver's different paths may be cancelled, 3) different reader vs same tag will introduce the change of communication zone. The scenario can be drawn in Fig. 18c.

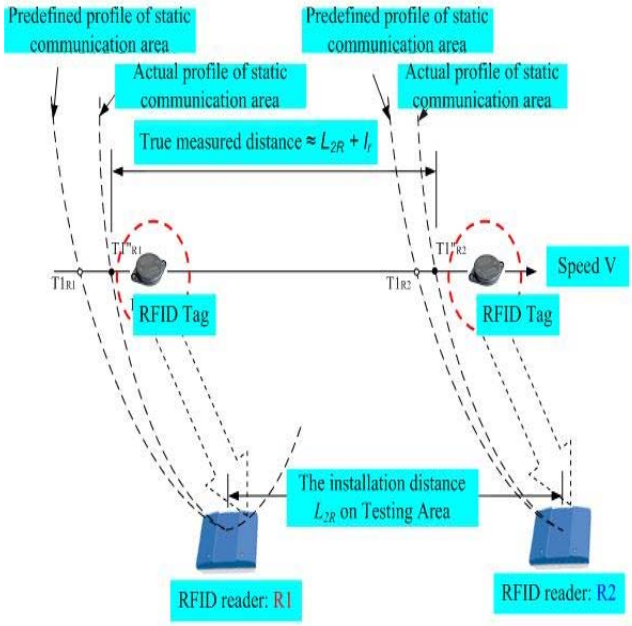


Fig. 18c Use 2R1T to measure speed.

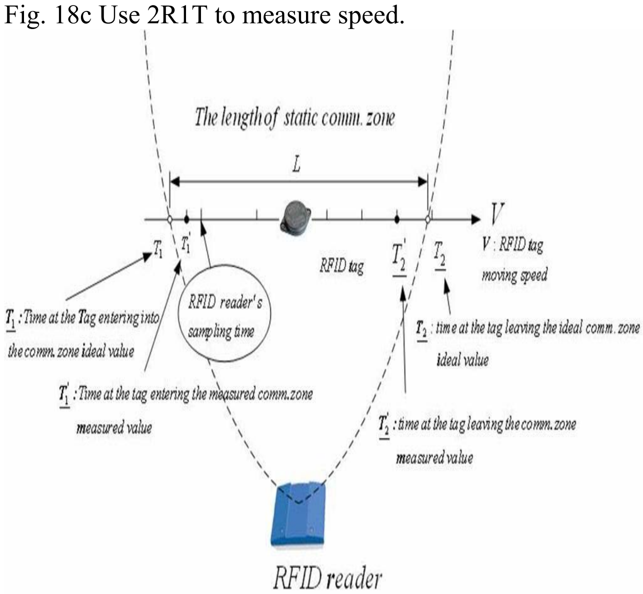


Fig. 18d The resolution of hardware in sampling time (timing error).

Finally, the resolution of hardware in sampling time (timing error) can be formulated as the following reasons shown in Fig. 18d. The time at the tag entering into and leaving away the communication zone may or may not match the resolution of hardware's sampling time, which it may induce the timing error on the calculation of speed. The speed error rate can be calculated as

$$\Delta V\big|_{\Delta t=0} = \frac{\Delta l}{\Delta t} = \frac{V_1}{1+V_1\Delta t/L} - V_1 = \frac{-V_1^2\Delta t/L}{1+V_1\Delta t/L} = \frac{-V_1}{\frac{L}{V_1\Delta t}+1}.$$

$$SpeedErrorRate\big|_{\Delta l=0} = \frac{1}{1+L/(V\Delta t)} = \frac{V\Delta t}{V\Delta t+L} \quad (5)$$

The policy to compensate this kind of error is (1) to add real-time-clock on the hardware of reader, (2) to give the parameter of time with $t_c = 0.15$ sec.

The revised result analysis for single tag vs single reader is obtained by adjusting the real-time clock on the hardware and giving the worst-case parameter compensation for sampling time. Because the design hardware of reader is not suitable for the purpose of collecting traffic information, one can not adjust its resolution as you like. Thus, the analysis of turning point on the major errors of distance and timing errors is very important to let the system designer to take correct strategies to compensate for all of possible errors. The turning point of major errors has been obtained in Fig. 18e. One can conclude the following rule: 1) when speed is fast, timing error becomes dominant; 2) when speed is low, distance error becomes dominant. For example, when $L = 6\ m$, the distance error $\Delta l = dL = 0.1 \sim 3\ m$ and timing error $\Delta t = dT = 0.01 \sim 0.2\,\text{sec}$, the speed error rate can be found with the following compensating rules:

(1) the speed error rate induced by measured distance (ΔL) is an increasing constant;

(2) The speed error rate induced by measured time (Δt) is also an another increasing constant;

(3) From the intersection point of ΔL and Δt, one can judge which one is the major dominant factor. For example, when the speed of urban-bus is equal to 40 km/hr, the compensation distance is about equal to 1~1.5 m for Δt = 0.15 sec.

(4) If the distance error rate is larger than this range, the compensation of speed error will become worse. The timing error will become a dominant factor.

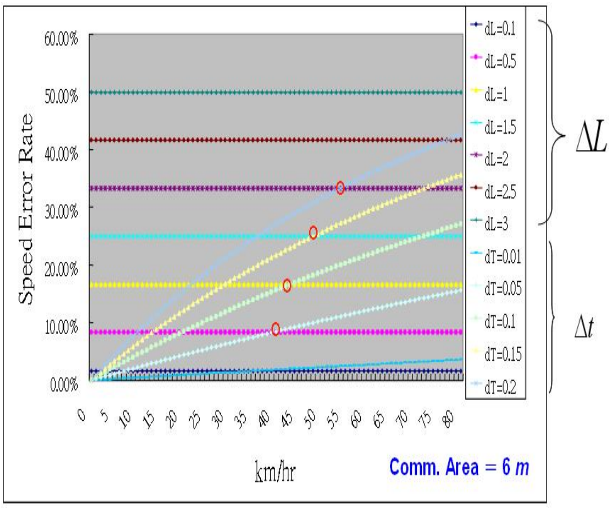


Fig. 18e The turning point of major errors on distance and timing errors vs the speed error rate.

The revised speed curve for single reader vs single tag (1R1T) was taken on a record for five different weathers and on day and night shown in Fig. 19a.

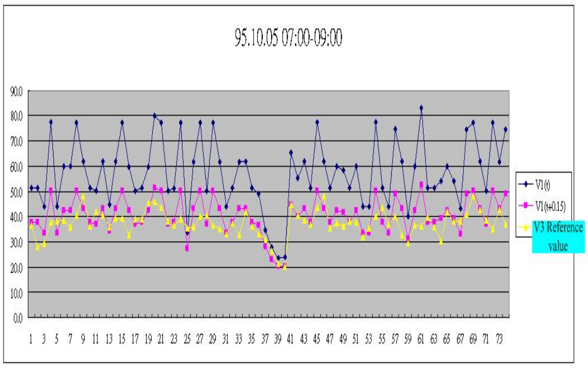


Fig. 19(a) Use 1T1R to measure 5 different conditions

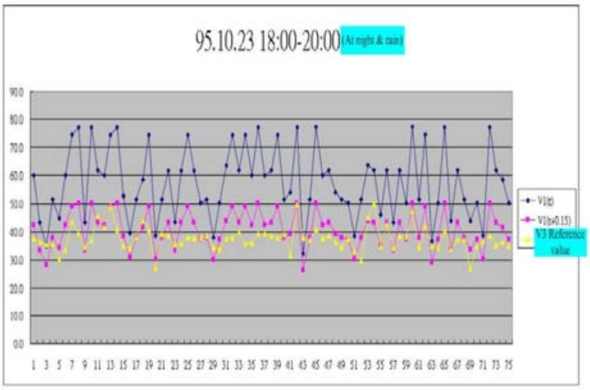


Fig. 19(b) Use 2T1R to measure 5 different conditions

The revisited result can be found by our effort with five major different conditions shown in Fig. 19(b). Thus, our adjustment can be regarded as a better compensation for this kind of product.

The revised result analysis for Single Tag vs. Single Reader

Testing time	95.10.04		95.10.05		95.10.06		95.10.12		95.10.23	
weather	Blue sky		Blue sky		Blue sky		Blue sky		Rain	
Item	Before adjust	After adjust	Before adjust	After adjust	Before adjust	After adjust	Before adjust	After adjust	Before adjust	After adjust
Avg. speed (km/hr)	57.1	40.6	57.4	40.6	53.5	38.6	58.2	41.1	57.5	40.7
Avg. error	47.79%	12.30%	52.61%	13.10 %	45.68%	11.68%	48.57%	11.26%	52.73%	12.95 %
σ^2	0.2638	0.0882	0.2906	0.1125	0.2695	0.105	0.2427	0.0773	0.2594	0.0978
2 Tag 1Reader Avg. speed (km/hr)	38.8		37.6		36.7		39.1		37.7	
Test point	Hsin-Yi Road, Taipei City									

Fig.19b. The revisited result is obtained by adjusting hardware resolution.

VI. The Verification and Validation for Final Result

In this section, there are five major traffic information needed to be checked: traffic flow and vehicle ID check, average speed, traveling time, occupied rate, and VSCD. We will discuss them in sequence. First, the accuracies of traffic flow and vehicle ID check can reach 100 % shown in Fig. 20.

		pick hour			Off-pick hour		
		Avg. flow (veh.)	# of sample not coincident (%)	Error rate (%)	Avg. flow (veh.)	# of sample not coincident (%)	Error rate (%)
Blue sky	R1	3.91	0%	0%	3.11	0%	0%
	R2	3.91	0%	0%	3.11	0%	0%
	R3	3.91	0%	0%	3.11	0%	0%
	Comparison value	3.91	—	—	3.11	—	—
Cloudy	R1	3.70	0%	0%	3.43	0%	0%
	R2	3.70	0%	0%	3.43	0%	0%
	R3	3.70	0%	0%	3.43	0%	0%
	Comparison value	3.70	—	—	3.43	—	—
Rainy	R1	3.68	0%	0%	2.39	0%	0%
	R2	3.68	0%	0%	2.39	0%	0%
	R3	3.68	0%	0%	2.39	0%	0%
	Comparison value	3.68	—	—	2.39	—	—

Fig. 20 Verification & validation of traffic flow & vehicle ID .check

The average (spot) speeds for H(ail), T(ail), 2T1R, and 1T1R are compared in Fig. 21. We can find that 1) 2T1R is better than 1T, 2) 1T's result is a little bit higher than expected, 3) Head speed is larger than tail speed, 4) The detections of different weather's condition are shown here without too much difference.

The traveling time check can be found with following result: 1) Testing value is larger than reference value, 2) The detected behaviors of temperature variation: rain > cloudy > blue sky, shown in Fig. 22. The error discrimination for rush hour and leisure hour: rain > cloudy > blue sky.

The road occupied rate check is found to have following results: Error is located within 20 %~30%. The reason is that horizontal communication zone change leads to the snapped sampling point, which is not coincident with that of system shown in Fig. 23. The VSCD check can be found to perform very good for pick hour and off-pick hour no matter at R3 or at R2-R3 shown in Fig. 24.

		pick hour			Off-pick hour		
		Avg. speed (km/hr)	Avg. error (%)	Error variance	Avg. speed (km/hr)	Avg. error (%)	Error variance
Blue sky	Head Tag	44.98	18.67%	0.17	48.24	26.02%	0.18
	Tail Tag	41.89	13.65%	0.12	44.31	18.49%	0.15
	2 Tags	39.06	6.95%	0.06	39.28	6.27%	0.05
	comparison	39.14	—	—	38.5	—	—
cloudy	Head 1 tag	43.57	19.25%	0.20	43.84	17.07%	0.17
	Tail 1 tag	40.26	12.04%	0.11	41.84	13.97%	0.12
	2 Tags	38.44	7.17%	0.05	38.92	7.04%	0.06
	comparison	38.45	—	—	38.6	—	—
rainy	Head 1 tag	44.56	20.55%	0.19	44.34	16.10%	0.18
	Tail 1 tag	40.46	13.60%	0.10	40.08	10.43%	0.08
	2 Tags	38.89	8.25%	0.06	39.45	6.18%	0.04
	comparison	38.18	—	—	40.23	—	—

Fig. 21 VSCD check for different weather conditions.

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We would like to thank for the cooperation of Metropolitan Bus and So-Do Buses for them to provide us 108 buses in total for test. Secondly, we should thank the Taipei City Hall to provide us a good environment for test especially in the supply of electricity. Thirdly, we would like to appreciate those who have helped us without mentioning earlier. Without your help, we can not complete this job.

		pick Hour			Off-pick Time		
		Avg. travel time (sec)	Avg. error rate(%)	σ^2	Avg. travel time (sec)	Avg. error rate(%)	σ^2
blue	Test value	35.66	4.08%	0.05	31.15	3.89%	0.06
	Reference value	34.58	—	—	30.16	—	—
cloudy	Test value	36.84	4.99%	0.09	31.33	3.64%	0.05
	Reference value	36.42	—	—	30.69	—	—
rainy	Test value	40.25	8.68%	0.15	31.13	5.30%	0.08
	Reference value	38.58	—	—	29.74	—	—

Fig. 22 Traveling-time for pick hour and off-pick hour.

		pick Hour			Off-pick Time		
		Avg. occupied rate(%)	Avg. error rate(%)	σ^2	Avg. occupied rate(%)	Avg. error rate(%)	σ^2
B.S	Test value	0.88%	21.27%	0.04	0.47%	27.68%	0.05
	Reference value	1.02%	—	—	0.65%	—	—
CL	Test value	0.97%	21.26%	0.04	0.48%	24.30%	0.07
	Reference value	1.12%	—	—	0.64%	—	—
RY	Test value	0.73%	21.27%	0.05	0.47%	20.29%	0.03
	Reference value	0.89%	—	—	0.59%	—	—

Fig. 23 Road occupied-rate check for pick hour and off-pick hour.

		Blue sky		cloudy		rain	
		Test value	Real value	Test value	Real value	Test value	Real value
Pick Hr	R3 VSCD	3	3	3	3	2	2
	R3 SCD error rate(%)	0%	—	0%	—	0%	—
	R2 – R3 VSCD	0	0	0	0	0	0
	R2 – R3 VSCD error rate (%)	0%	—	0%	—	0%	—
off-pick Hr	R3 VSCD	0	0	0	0	0	0
	R3 SCD error rate (%)	0%	—	0%	—	0%	—
	R2 – R3 VSCD	0	0	0	0	0	0
	R2 – R3 VSCD error rate (%)	0%	—	0%	—	0%	—

Fig. 24 VSCD check for pick hour or off-pick hour.

VII. CONCLUSION

From the historical data of website, one can calculate the required traffic parameters including instant traffic flow, average speed of bus, traffic flow, road occupied rate, and the VSCD detection. If one uses 1T1R may produce a higher speed error, then, 2T1R or 2R1T may produce a more accurate result. The real-time clock is needed for RFID system to have more accurate result. Each data can be used to indicate the exact point of traffic condition in a big city. Because the design hardware of reader is not suitable for the purpose of collecting traffic information, one can not adjust its resolution as you like. Thus, the analysis of turning point on the major errors of distance and timing errors is very important to let the system designer to take correct strategies to compensate for all of possible errors. The result shows that the application of RFID tag and reader is an alternative way to extract the traffic information instead of traditional loop detector. It is suggested that the vehicle speed estimated by 2 T 1R is more accurate than that of by using 1T1R compared from historical data. The compensating rules of the turning point with different measured distance and measured timing can be regulated as following:

(1) the speed error rate induced by measured distance (ΔL) is an increasing constant;

(2) The speed error rate induced by measured time (Δt) is also an another increasing constant;

(3) From the intersection point of ΔL and Δt, one can judge which one is the major dominant factor. For example, when the speed of urban-bus is equal to 40 km/hr, the compensation distance is about equal to 1~1.5 m for $\Delta t = 0.15$ sec.

(4) If the distance error rate is larger than this range, the compensation of speed error will become worse. The timing error will become a dominant factor.

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