AN OBSERVATION-BASED EVALUATION OF FUEL ECONOMY AND SPEED MEASURES FOR CITY BUS DRIVERS

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Submitted to the 3rd International Conference on Road Safety and Simulation,
September 14-16, 2011, Indianapolis, USA

ABSTRACT

The aim of this study was to understand the unsafe driving behaviors of city bus drivers. Thirty city bus drivers of thirty different buses along eight different routes were observed. The city buses were equipped with data logging devices to record data on a second-by-second basis. The total recorded travel time for each driver ranged from 0.62 to 2.82 hours. Drivers went through five acceleration behaviors (medium acceleration, heavy acceleration, medium deceleration, heavy deceleration, coasting), eight nonacceleration behaviors (defined by eight levels of travel speed), and two turning behaviors (left and right turns). The mean speed and fuel economy during these behaviors were examined as potential surrogates for unsafe driving behaviors. The pooled data were analyzed using a paired-samples T-test and the Pearson correlation. The results indicated that when buses were travelling faster or decelerating, they consumed fuel in an economical way. During nonacceleration behaviors, fuel economy increased with travel speed. During acceleration behaviors, the influence of acceleration on fuel economy appeared to be larger than the influence of mean speed. During turning behaviors, low speed and acceleration contributed to poor fuel economy. Additionally, the positive linear relationship between fuel economy and speed during nonacceleration behaviors, which is typical for a smaller vehicle, hold for the bus fleet. Furthermore, heavy acceleration may result in better fuel economy at high travel speeds, but not at low travel speeds. The way people drive strongly influences the fuel consumption of the vehicle, as was seen in the unsafe behaviors that were observed from the recorded video images in the current study.

Keywords: driving, safety, fuel consumption.

INTRODUCTION

CO2 emissions are directly associated with carbon-based fuels. Globally, transportation departments are responsible for 21% of CO2 emissions, although this statistic varies regionally (Gorham, 2002). On the other hand, traffic accidents are one of the major causes of death and injury in several regions (Mathers and Loncar, 2005).

Being potential surrogates for unsafe driving behaviors, fuel economy and speed measures are both influenced by various factors, including drivers, vehicles, roads, and environments. For example, aggressive driving, as defined by sudden acceleration and deceleration, results in fuel wastage of approximately 5%–30% under different road conditions (reviews in Saboohi and Farzaneh, 2009).

Generally, three methods have been used to investigate the influence of interactions among drivers, vehicles, roads, and environments on driving behaviors. The first method involves instrumenting a vehicle to continuously record driver behavior under real-world driving conditions (Dingus et al., 2006). The second method is to perform field tests of a driving task along a predefined route (Östlund et al., 2004). The third method is to use a driving simulator to measure driver behavior under various controlled and virtual scenarios (Angell et al., 2006). Each method has its own advantages and disadvantages. However, the behaviors observed under natural driving conditions are closest to driver behaviors in daily life. This method has contributed to traffic safety; for example, a recent 100-car study provided valuable information about distracted driving behaviors (Dingus et al., 2006).

The purpose of the present study is to understand the unsafe driving behaviors of city bus drivers. To achieve this aim, driving behavior observation was performed on city bus drivers following their regular schedules. Five acceleration behaviors (medium acceleration, heavy acceleration, medium deceleration, heavy deceleration, coasting), eight nonacceleration behaviors (defined by eight levels of travel speed; named travel speed 1 to travel speed 8), and two turning behaviors (left turn and right turn) were examined. The acceleration behaviors involved acceleration or deceleration. The nonacceleration behaviors did not involve acceleration or deceleration. The mean speed and fuel economy during these behaviors were examined as potential surrogates for unsafe driving behaviors. Additionally, correlations between the two indexes of each driving behavior were examined. Evaluations of mean speed and fuel economy were used to explore the outcomes of a variety of driving behaviors. The correlation analyses were used to explore associations between one behavior (or index) and another behavior (or index).

METHODS

Overview

The data were gathered as part of a project to train bus drivers to improve their fuel efficiency. Eight routes and thirty buses were used in the study. The length of the routes ranged from 10.00 to 39.86 km (mean 21.04 km and standard deviation 9.71 km) from terminal to terminal. The speed limit of the city roads on which the buses travelled was 50 km/h. In total, 45.31 h of data, covering 631.19 km of travel, were collected from the buses. The total recorded travel time for each driver ranged from 2221 to 10155 s (mean 5437.43 s and standard deviation 2462.61 s), i.e., 0.62 to 2.82 h.

Apparatus

The city buses were equipped with four portable digital video cameras, one global positioning system, one 3-axis accelerometer, and an OBDII (On-Board Diagnostic System) data logging device to record data on a second-by-second basis. Four video cameras were used to record driving behavior, the view from the driver's perspective view, a right-side view of the bus, and a left-side view of the bus. The position of the bus was recorded by the global positioning system. Lateral and longitudinal accelerations were measured by a 3-axis accelerometer. The data from the OBDII included speed, fuel consumption, revolutions per minute, and the position of the accelerator pedal.

Participants

All participants were male drivers from two bus companies. Data were recorded for all drivers of the equipped buses, and data from thirty randomly selected drivers were included in the present study. The ages of the participants in the study ranged from 27 to 60 years (mean 44.48 years and standard deviation 8.94 years). Their bus driving experience ranged from 0.17 years to 33.00 years (mean 12.43 years and standard deviation 8.06 years).

Data and definitions

From the logged driving data, we classified fifteen driving behaviors and calculated two indexes. Table 1 presents an overview of the selected behaviors, including their names, abbreviations, definitions, and analysis durations. The abbreviations of the behaviors are used in the tables to represent the names of the behaviors. The following five acceleration behaviors were evaluated: medium acceleration, heavy acceleration, medium deceleration, heavy deceleration, and coasting (i.e., engine braking). In addition, speed was selected as another important measurement because it is a popular variable in traffic safety studies (e.g., Adams-Guppy and Guppy, 1995; Haglund and Å berg, 2000). Measures of speed were taken under conditions in which vehicles did not stop. We defined eight nonacceleration behaviors based on vehicle speed (travel speed 1 to travel speed 8). Additionally, left and right turns were also examined in the study.

Table 1: The examined driving behaviors

Name	*Abb.*[a]	*Definition*	**Dur.[c] (s)**
Acceleration behaviors:			
Medium acceleration	acc_m	0.06≦G[b]＜0.12 measured by the accelerometer	9695
Heavy acceleration	acc_h	G≧0.12 measured by the accelerometer	632
Medium deceleration	dec_m	-0.15＜G≦-0.06 measured by the accelerometer	6541
Heavy deceleration	dec_h	G≦-0.15 measured by the accelerometer	771
Coasting	coast	Percent throttle≦5% and duration≧3 s	11764
Nonacceleration behaviors:			
Travel speed 1	trv_s1	Speed＜10 km/h but＞0 km/h	3914
Travel speed 2	trv_s2	Speed interval 11–15 km/h	2958
Travel speed 3	trv_s3	Speed interval 16–20 km/h	4218
Travel speed 4	trv_s4	Speed interval 21–25 km/h	5173
Travel speed 5	trv_s5	Speed interval 26–30 km/h	6347
Travel speed 6	trv_s6	Speed interval 31–35 km/h	7764
Travel speed 7	trv_s7	Speed interval 36–40 km/h	7451
Travel speed 8	trv_s8	Speed＞40 km/h	6521
Turning behaviors:			
Left turn	turn_l	The starting and ending point of a turning behavior at an intersection was based on vehicle position as determined from on-bus recorded images. Starting point: when the front of the instrumented vehicle arrived at the stop line, before turning. Ending point: when half of the instrumented vehicle arrived at the pedestrian crossing, after turning.	4271
Right turn	turn_r	Same as above	2912

Note. [a] Abb. denotes abbreviation. [b] 1 G = 9.8 m/s^2. [c] Dur. denotes analysis duration.

The mean speed was calculated as the mean speed during movement only. Because the on-board device recorded travel speed every second, the mean speed was calculated as the mean of speed (km/h) samples of each driving behavior. Fuel economy (km/l) was calculated as the summation of travel speed divided by the summation of fuel consumption per unit time in each driving section. The higher the fuel economy, the more economic a vehicle is (i.e., the further it can travel with a certain volume of fuel).

Statistical methods

The pooled data from all thirty participants were used in the statistical analyses. A paired-samples T-test was used to investigate the differences in mean speed and fuel economy between each driving behavior pair. The Pearson correlation was used to analyze the association of fuel economy between each driving behavior pair, and the association between mean speed and fuel economy by each driving behavior. A Pearson correlation factor $\geqq$ 0.70 was regarded as a high correlation. Highly correlated behaviors or indexes were further investigated for linear relationships. Statistical analyses were performed using Statistical Product and Service Solutions (SPSS) software Version 13.

RESULTS

Mean speed and fuel economy for each behavior pair

Table 2 shows the mean and the standard deviation of speed and fuel economy for each driving behavior. In the present study, the speed ranged from 3.50 km/h to 50.40 km/h and the acceleration ranged from -0.42 G to 0.48 G. As shown in Table 3, there were significant differences in mean speed between each nonacceleration behavior pair ($p<0.05$). For the nonacceleration behaviors, with the exception of travel speed 4, the mean speed of each behavior group was significantly different from that of each acceleration behavior ($p<0.05$). In addition, the mean speed of every acceleration and nonacceleration behavior, except for travel speed 2, was significantly different from that of the left/right turn groups ($p<0.05$). The mean speed differences between medium acceleration and coasting as well as between medium deceleration and coasting were also significant ($p<0.05$).

In summary, the speed definitions of nonacceleration behavior can distinguish the speed differences. The mean speeds of the five acceleration behaviors were equivalent to that of the nonacceleration behavior of travel speed 4. The mean speed of the left/right turn groups were equivalent to that of travel speed 2. The mean speed of medium acceleration/deceleration was higher than that of coasting.

Table 2: Mean and standard deviation of speed and fuel economy for each behavior

	Mean speed (km/h)		*Fuel economy (km/l)*	
	Mean	Std.[a]	Mean	Std.
acc_m	24.04	3.68	1.42	0.52
acc_h	24.96	9.23	1.40	0.95
dec_m	23.99	4.30	2.86	0.50
dec_h	23.31	7.66	2.92	0.87
coast	21.71	4.59	3.25	1.36
trv_s1	6.17	0.55	0.72	0.22
trv_s2	13.19	0.19	1.26	0.37
trv_s3	18.10	0.25	1.44	0.35
trv_s4	23.05	0.17	1.72	0.36
trv_s5	28.09	0.18	2.01	0.38
trv_s6	32.97	0.10	2.30	0.45
trv_s7	37.84	0.25	2.52	0.50
trv_s8	44.41	2.09	3.06	0.62
turn_l	12.31	3.61	1.22	0.42
turn_r	13.42	3.75	1.32	0.47

Note. [a] Std. denotes standard deviation.

Table 3: T-test of mean speed for each behavior pair

	acc_m	*acc_h*	*dec_m*	*dec_h*	*coast*	*trv_s1*	*trv_s2*	*trv_s3*	*trv_s4*	*trv_s5*	*trv_s6*	*trv_s7*	*trv_s8*	*turn_l*
acc_h	0.025													
dec_m	0.045	0.987												
dec_h	0.398	1.263	0.734											
coast	2.243*	1.981	2.504*	1.058										
trv_s1	25.961#	9.889#	21.112#	11.719#	17.221#									
trv_s2	16.000#	6.398#	13.616#	7.107#	10.072#	-68.510#								
trv_s3	8.418#	3.752#	7.469#	3.705#	4.225#	-108.860#	-77.085#							
trv_s4	1.448	1.027	1.175	0.181	-1.556	-164.102#	-221.822#	-82.050#						
trv_s5	-5.819#	-1.680	-5.116#	-3.351#	-7.458#	-199.656#	-268.286#	-192.277#	-91.877#					
trv_s6	-13.160#	-4.348#	-11.180#	-6.743#	-13.215#	-265.923#	-509.343#	-287.439#	-247.667#	-141.268#				
trv_s7	-20.434#	-7.014#	-17.310#	-10.217#	-19.081#	-272.443#	-378.131#	-280.637#	-252.895#	-164.659#	-89.644#			
trv_s8	-25.156#	-11.278#	-30.816#	-16.083#	-30.771#	-89.654#	-82.825#	-69.143#	-54.685#	-40.845#	-29.140#	-16.582#		
turn_l	10.875#	6.101#	11.970#	7.144#	9.143#	-9.154#	1.300	8.766#	15.952#	23.930#	31.069#	37.768#	43.936#	
turn_r	10.163#	5.400#	9.778#	6.499#	7.100#	-10.594#	-0.330	6.765#	13.518#	20.980#	27.680#	34.589#	33.890#	-1.289

Note. # denotes the paired-samples T-test is significant at the 0.01 level (2-tailed). * denotes the paired-samples T-test is significant at the 0.05 level (2-tailed).

Table 4 shows the T-test results of fuel economy for each behavior pair. In summary, fuel economy increased with travel speed during nonacceleration behavior. The fuel economy of nonacceleration behaviors at 26–40 km/h was higher than that of medium/heavy acceleration, but lower than that of medium/heavy deceleration and coasting. The fuel economy of nonacceleration behaviors over 40 km/h was equivalent to that of medium/heavy deceleration and coasting. The fuel economy of nonacceleration behaviors at 11–25 km/h was equivalent to that of medium/heavy acceleration and lower than that of medium/heavy deceleration and coasting. The fuel economy of left/right turns was equivalent to that of medium/heavy acceleration or nonacceleration at 11–15 km/h or 16–20 km/h but higher than that of nonacceleration under 10 km/h and lower than the acceleration behaviors.

Correlations of fuel economy between each behavior pair

As shown in Table 5, the fuel economy of medium acceleration was highly associated with that of heavy acceleration ($p<0.05$). The following pairs of nonacceleration behaviors were highly correlated ($p<0.05$): travel speeds 1 and 2, travel speeds 2 and 3–5, travel speeds 3 and 4–6, travel speeds 4 and 5–7, travel speeds 5 and 6–8, travel speeds 6 and 7–8, and travel speeds 7 and 8. In addition, the fuel economy for left turns was highly associated with that of travel speeds 1–2 ($p<0.05$). All these highly associated behavior pairs showed linear relationships, explaining 51%–87% of the data variation. Figures 1 (a)-(b) show two examples of such linear relationships.

In summary, the following behavior pairs demonstrated positive linear relationships for fuel economy: 1) In nonacceleration behaviors over 10 km/h, the slower speed level and its next three higher speed levels. 2) Medium and heavy acceleration. 3) The nonacceleration behavior under 16 km/h and left turn behavior.

Correlations of mean speed and fuel economy for each behavior

Only the mean speed of heavy acceleration was highly associated with its own fuel economy ($p<0.05$) (Table 6). There was a linear relationship (Figure 1 (c)) between mean speed and fuel economy. Such a relationship can explain 64% of the data variation.

Table 4: T-test of fuel economy for each behavior pair

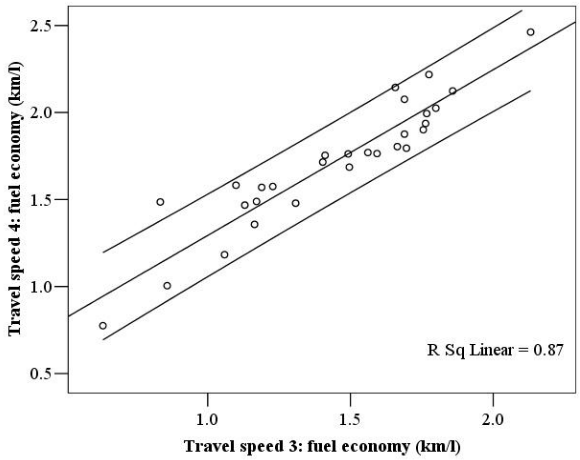
	acc_m	*acc_h*	*dec_m*	*dec_h*	*coast*	*trv_s1*	*trv_s2*	*trv_s3*	*trv_s4*	*trv_s5*	*trv_s6*	*trv_s7*	*trv_s8*	*turn_l*
acc_h	0.303													
dec_m	-9.082#	-6.742#												
dec_h	-7.839#	-6.102#	-0.485											
coast	-7.135#	-6.118#	-1.503	-0.949										
trv_s1	7.460#	3.838#	20.369#	14.372#	9.243#									
trv_s2	1.533	0.810	15.101#	11.218#	6.694#	-12.742#								
trv_s3	-0.287	-0.240	13.433#	10.298#	6.149#	-13.860#	-5.251#							
trv_s4	-3.041#	-1.752	11.216#	8.387#	5.309#	-19.989#	-12.881#	-11.121#						
trv_s5	-5.819#	-3.522#	8.733#	5.828#	4.474#	-21.198#	-15.830#	-13.045#	-7.673#					
trv_s6	-9.363#	-5.389#	5.086#	3.716#	3.516#	-20.738#	-16.532#	-14.946#	-10.491#	-7.251#				
trv_s7	-11.473#	-6.771#	2.768*	2.332*	2.706*	-22.217#	-18.454#	-15.715#	-12.432#	-10.033#	-6.306#			
trv_s8	-14.292#	-9.369#	-1.468	-0.693	0.722	-21.858#	-17.713#	-15.287#	-13.622#	-13.119#	-11.394#	-10.503#		
turn_l	2.022	1.278	12.583#	10.169#	6.977#	-9.147#	0.789	3.530#	7.956#	10.240#	12.977#	15.443#	16.073#	
turn_r	0.974	0.780	11.306#	9.987#	6.295#	-8.273#	-0.846	1.497	5.043#	6.984#	9.232#	10.878#	12.462#	-1.628

Note. # denotes the paired-samples T-test is significant at the 0.01 level (2-tailed). * denotes the paired-samples T-test is significant at the 0.05 level (2-tailed).

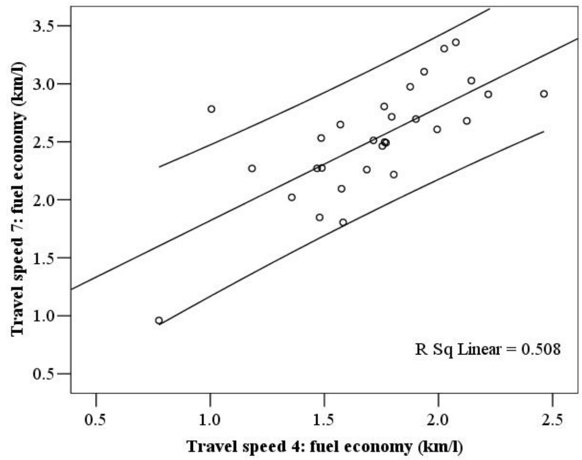
Table 5: Pearson correlation of fuel economy between each behavior pair

	acc_m	*acc_h*	*dec_m*	*dec_h*	*coast*	*trv_s1*	*trv_s2*	*trv_s3*	*trv_s4*	*trv_s5*	*trv_s6*	*trv_s7*	*trv_s8*	*turn_l*
acc_h	0.801#													
dec_m	-0.388*	-0.054												
dec_h	-0.052	0.113	0.511#											
coast	0.139	0.112	0.060	-0.377*										
trv_s1	0.306	0.289	-0.085	0.314	-0.475#									
trv_s2	0.313	0.372	0.174	0.395*	-0.582#	0.812#								
trv_s3	0.314	0.303	0.161	0.454*	-0.558#	0.611#	0.868#							
trv_s4	0.320	0.367	0.231	0.450*	-0.458*	0.676#	0.865#	0.933#						
trv_s5	0.295	0.354	0.323	0.275	-0.245	0.513#	0.770#	0.801#	0.849#					
trv_s6	0.457*	0.410*	0.252	0.193	-0.048	0.416*	0.673#	0.728#	0.745#	0.873#				
trv_s7	0.484#	0.463*	0.131	0.141	-0.033	0.476#	0.676#	0.670#	0.713#	0.836#	0.930#			
trv_s8	0.418*	0.403*	0.116	0.002	0.103	0.355	0.478#	0.415*	0.513#	0.721#	0.820#	0.898#		
turn_l	0.408*	0.423*	-0.141	0.159	-0.381*	0.758#	0.733#	0.625#	0.643#	0.470*	0.470*	0.522#	0.342	
turn_r	0.263	0.316	-0.064	0.337	-0.433*	0.609#	0.612#	0.538#	0.549#	0.264	0.255	0.290	0.105	0.689#

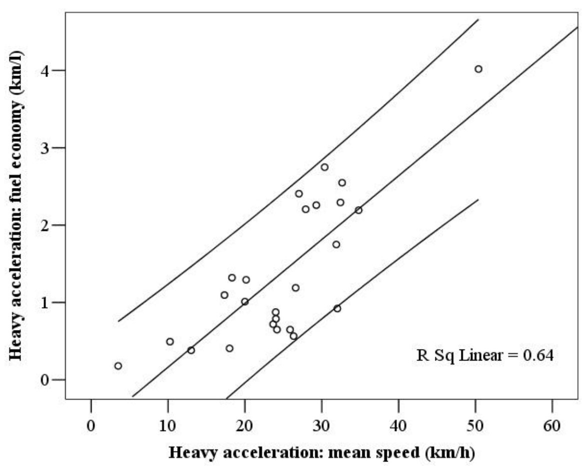
Note. # denotes the correlation is significant at the 0.01 level (2-tailed). * denotes the correlation is significant at the 0.05 level (2-tailed).



(a) Linear relationship between travel speeds 3 and 4 on fuel economy (R^2=0.87)



(b) Linear relationship between travel speeds 4 and 7 on fuel economy (R^2=0.51)



(c) Linear relationship between mean speed and fuel economy of heavy acceleration

Figure 1: Examples of linear relationships

Table 6: Pearson correlation between mean speed and fuel economy of each behavior

	Pearson correlation
acc_m	0.210
acc_h	0.800#
dec_m	-0.147
dec_h	0.366
coast	0.642#
trv_s1	-0.136
trv_s2	0.016
trv_s3	-0.202
trv_s4	0.288
trv_s5	-0.166
trv_s6	0.355
trv_s7	0.151
trv_s8	0.009
turn_l	0.485#
turn_r	0.061

Note. # denotes the correlation is significant at the 0.01 level (2-tailed).

DISCUSSION

For nonacceleration and acceleration behaviors, fuel economy was influenced by speed and acceleration/deceleration. In the nonacceleration behaviors, higher speeds yielded higher fuel economies. For the acceleration behaviors, deceleration and coasting (engine braking, $G < 0.6$) yielded higher fuel economy than did accelerations. These findings mean that when buses were not turning, higher travel speed and deceleration behaviors would cause vehicles to consume fuel in an economical way. Nevertheless, an acceleration behavior would follow a deceleration behavior during a whole route. Accordingly, fuel consumption in a whole travel route may increase with frequent brakes (decelerations), as that has been known previously.

During nonacceleration behaviors, our data suggest that fuel economy increased with travel speed. However, a peak did not appear; therefore, Taiwan's city buses, which were investigated in the present study, may not be operating in the most fuel-efficient manner possible. Taiwan's city buses are required to travel at 40 km/h, in general. The regulated speed limit of the city roads on which the city buses traveled is 50 km/h. The fuel consumption rate per unit distance appears to be optimum in the speed range of 50–70 km/h (Wang et al., 2008).

During acceleration behaviors, the influence from acceleration seems to be larger than that from the mean speed. Our data indicated that there was a higher fuel economy for deceleration, but a lower fuel economy for acceleration. Other studies have found that fuel consumption rates increase significantly when vehicles accelerate but not when they decelerate (Wang et al., 2008). Our data demonstrated that the mean speed of medium acceleration/deceleration was higher than that of coasting, yet the fuel economy of medium acceleration was lower than that of coasting, and the fuel economy of medium deceleration was equivalent to that of coasting. These data indicate that the three acceleration behaviors had an effect on the mean speed. However, the relationship between mean speed and fuel economy may differ for nonacceleration behaviors. Moreover, the poor fuel economy of turning behaviors seemed to be caused by low speed. Our data suggest that travel speeds were lower during left and right turns; therefore, fuel economy was also lower. Generally, the evidence of coasting and increased fuel economy may promote the creation or use of bus ways where longer routes could be streamlined with roads for only to travel on. The low-speed turning effects on fuel economy may give some implications in the planning of bus routes.

In the future, medium acceleration/deceleration and coasting could be further classified by travel speed to intensively investigate the influence of speed and acceleration on fuel economy. Furthermore, it may merit in comparing fuel economy across bus routes based on turns and posted speeds for a fixed distance of travel or fuel economy across drivers for a fixed route to demonstrate the safe driving behaviors and how much fuel economy performance improves as a result.

Individual behaviors

Our data indicated that there was a positive linear relationship for fuel economy between the nonacceleration behaviors of higher speed and lower speeds within an approximately 20 km/h range. Such a linear relationship is a typical operation characteristic of the vehicle. Nevertheless, there were thirty different buses used in the present study, so to some extent, vehicle factors have been excluded. Therefore, on average, such a linear relationship seems to hold for a bus fleet.

During heavy acceleration behavior, the positive linear relationship between mean speed and fuel economy seems to indicate that heavy acceleration is fuel efficient at high travel speeds but not at low travel speeds. Furthermore, a weak association between mean speed and fuel economy for medium acceleration behavior might imply that smooth acceleration has only a marginal impact on the fuel economy of the vehicles. In addition, the weak association between mean speed and fuel economy for all the nonacceleration, nonturning behaviors at different travel speeds might imply that the classified range of travel speeds needs to be larger than 5 km/h. For the heavy acceleration behavior, travel speed ranged from 3–50 km/h.

The ways people drive, accelerate, and turn has a strong influence on the fuel consumption of a vehicle. Experiences from Europe and Japan have shown that training bus drivers on ecodriving styles can yield fuel economy improvements on the order of 2%–20% during the training period and in the short- or long-term after training (reviews in Barth and Boriboonsomsin, 2009; af Wåhlberg, 2007 and reviews).

Acceleration behaviors and safety

Deceleration behavior yielded higher fuel economy than acceleration behavior; however, deceleration behavior is frequently the result of unsafe driving. In particular, excessive deceleration may be partly caused by a short following distance. In fact, our devices clearly recorded such unsafe situations. As shown in Figure 2, excessive deceleration resulted from insufficient time for stopping. Specifically, a car in front of the bus stopped at a red light, but the bus driver did not show any initial stopping behavior. In the next second, the bus driver started strongly pressing on the brake pedal, resulting in rapid deceleration. In the third second, longitudinal acceleration continued decreasing and lateral acceleration started changing. At the same time, an avoidance behavior can be observed from the video camera images, i.e., the bus veered to the right. In the fourth second, longitudinal acceleration reached a minimum value and lateral acceleration increased. At the same time, the image recorded in the video camera showed the bus continuing to veer to the right.

The fuel economy of turning behaviors was equivalent to that of acceleration behavior. However, there may be excessive unsafe acceleration during turning. A selected case, shown in Figure 3, indicates that excessive lateral deceleration resulted from initiating a right turn at too high a speed. In the first second, the image in the video camera showed that the bus was turning right at a speed of over 35 km/h, recorded by the logging devices. In the third second, the bus driver started pressing the brake pedal strongly, which resulted in a rapid decreasing of longitudinal acceleration. At the same time, the instrumented bus continued turning right, as observed from the video camera image. In the fourth second, the longitudinal acceleration continued decreasing and the lateral acceleration increased suddenly. At the same time, the video camera image showed that the bus was very close to a traffic island. In the fifth second, longitudinal acceleration reached a minimum, lateral acceleration continued increasing, and the speed decreased to 20 km/h. In the sixth second, longitudinal acceleration returned to 0 G, lateral acceleration reached a peak, and the bus turned to the right side of the traffic island (seen in the video camera image).

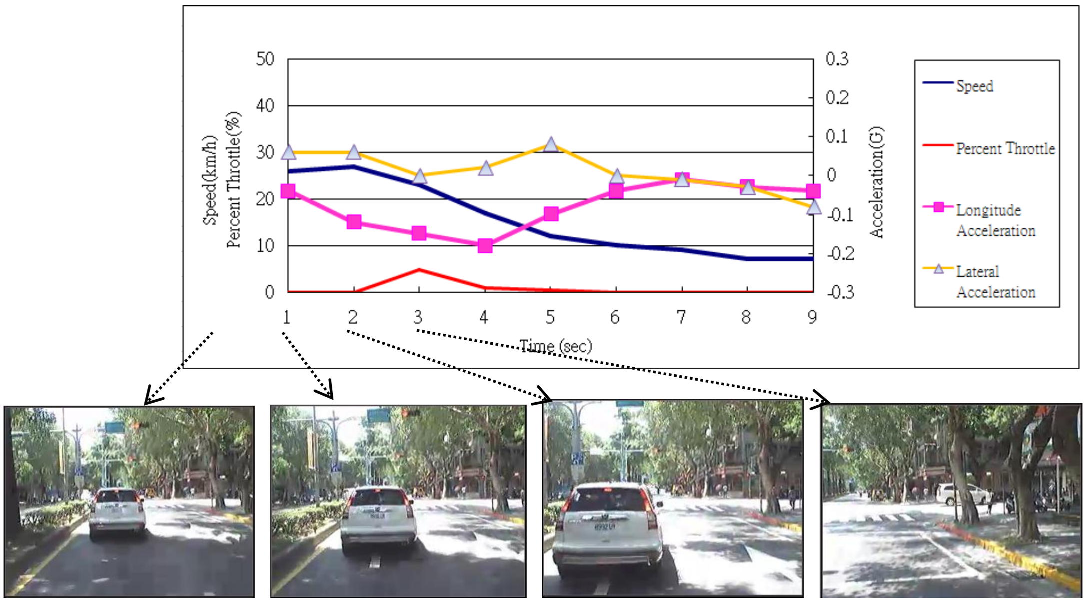


Figure 2: A case of unsafe driving behavior: excessive longitudinal acceleration

Driver acceleration behavior may be a predictor of accidents (af Wåhlberg, 2004). For example, fast lane changing (Gully et al., 1995), speed (Kloeden et al., 1997), and short headways (Evans and Wasielewski, 1983) have been shown to be associated with accidents. These behaviors all give rise to accelerations or decelerations, in either lateral or longitudinal directions. However, such potentially unsafe acceleration/deceleration behaviors, both during straight driving and turning, could be reduced by training. It has been reported that training can reduced the percentage of time spent in heavy acceleration or deceleration by 0.26% and 0.22%, respectively (Beusen et al., 2009).

CONCLUSIONS

The driving data reported in this study indicated that the ways people drive, accelerate, and turn strongly influence the fuel consumption of a vehicle. In addition, unsafe driving behavior has been observed in the recorded video images in the current study. Abnormal driving behaviors can be analyzed using the video camera images to evaluate whether a particular driving behavior was unsafe.

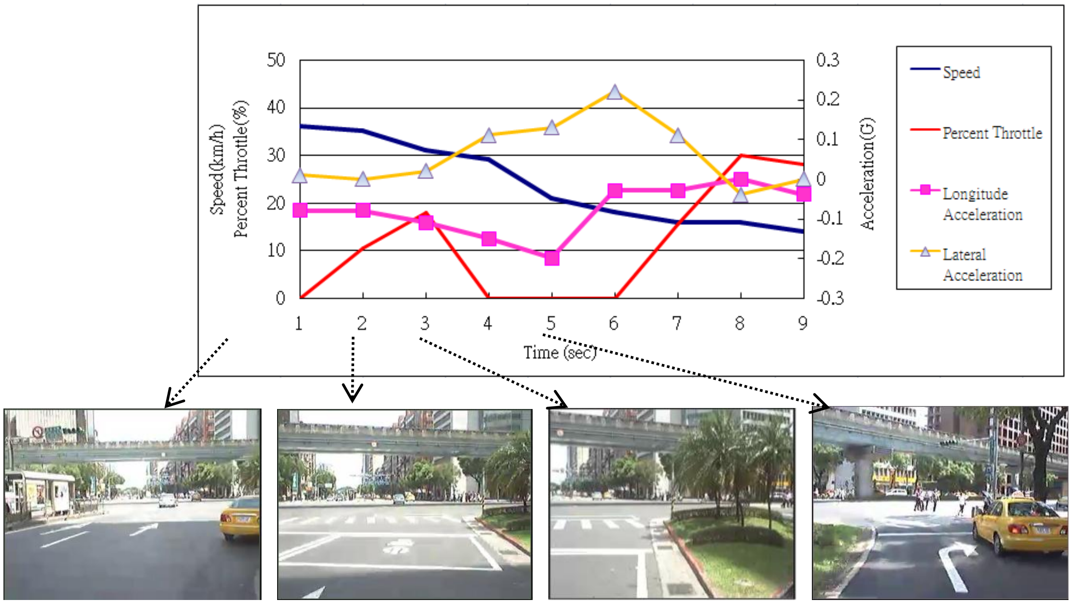


Figure 3: An example of an unsafe right-turn: excessive lateral deceleration

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