Characteristics of Emissions and Vehicular Operations of Buses in Taipei's Exclusive Bus Lanes

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Abstract: The objectives of this research are to (1) investigate the emissions characteristics of bus operations in bus lanes and on regular city streets; (2) identify probable causes of excessive emissions, and (3) identify probable improvements. Emissions data were collected by using an On-board Emissions Measurement System (OEM) while the bus is in service. Study results show that a bus in an exclusive bus lane (1) is more emissions efficient than operated on regular city streets; (2) has high percent of idling time due to station and intersection delay; and (3) may overly expose bus passengers to high level of gas pollutants at busy stations. Improvements for enhancing health, environmental and operational efficiency may include redesign of traffic signaling, renovation of bus station design/operations, and setting an upper limit for bus volumes in a bus lane. Policies for using clean bus fleet and eco-drivers are also helpful.

Keywords: Emissions, Bus Lane, On-board Measurement System, Bus Operations

1. INTRODUCTION

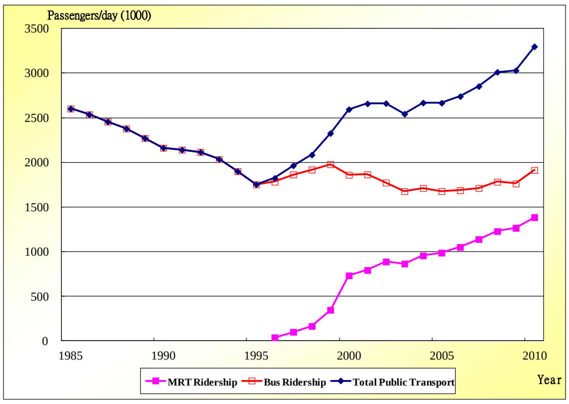
Prior to 1996, buses were the primary mode of public transport in Taipei, Taiwan. Private automobiles ownership increased at a fast rate, and bus patronage continued declining, as shown in Figure 1. In 1996, Taipei City Government implemented 41 kilometers of exclusive-bus-lane network on major arterials in Taipei. The bus-lane network was composed of 3 lines in the north-south direction, and 4 lines in the east-west direction. The bus-lane network upgraded bus services in terms of line speeds, safety and conveniences in making transfers. It attracted passengers back to the bus system, and subsequently provided convenient feeder services for the transit network, which was put in revenue service line by line, starting in 1997. Taipei's patronage for public transport system has drastically increased since then. Total public transport ridership almost doubled from that in 1995, with steady bus patronage, without losing riders to the rapid transit system.

The bus-lane network is characterized by the following features:

1) All bus lanes are in single-lane operations with variations in placement in the roadway to fit in traffic conditions and adjacent developments along the arterials;
2) Buses wait for green lights as other road traffic;
3) Traffic signaling is designed for all traffic, without special considerations and priorities for buses;
4) Buses wait in line at stations, without a by-pass lane; and

5) Stations located at the near-side of intersections, instead of mid-blocks, to facilitate transfers.

The bus-lane network was welcomed by city residents, and another 4 lines with a total length of 16 kilometers of bus lanes were added to the network in the following few years. Discount fare for transfers was also implemented as the ticketing system was automated. Currently about 60 percent of the bus patronage benefit from the use of a part or all of their daily trips in bus lanes. Bus operators consider those lines primarily in bus lanes as "gold lines", and are always interested in acquiring the right-of-ways for bus operations in the bus lanes.



Data Source: Department of Transportation, Taipei City Government

Figure 1 Historical Public Transport Ridership in Taipei Metropolitan Area

With all the benefits from the system, many questions are still raised today to inquire whether the system is being operated to its upmost efficiency and how it may contribute to the current issues on the cleanness of air and greenhouse gas emissions. The objectives of this research, therefore, are to (1) investigate the bus operations and emissions characteristics of buses in bus lanes relative to those on regular urban arterials; (2) identify probable causes of inefficiency, and (3) identify probable actions for further improvements.

2. DATA COLLECTION

The data used in this research came out of a project sponsored by the Institute of Transportation (IOT), Ministry of Transportation and Communications, to build a fuel and greenhouse gas (GHG) emissions model, while emissions of criteria pollutants of CO, THC and NOx were also collected. PM was not included as a part of the experiment. The data collection for this research is summarized below.

2.1 Test Route and Test Bus

Route 226 of Taipei City was selected for the experiment. The route extends from Sanchong City in Taipei County, enters Taipei City from Taipei Bridge, runs through 4 major bus lanes and some city streets in Taipei, and terminates at Wuxing Street south of the New City Center. The total round-trip route length is 34 kilometers, with 33% of its length in exclusive bus lanes. Taipei City has a speed limit of 40km/hr for all buses, and therefore the data collected rarely exceed 40km/hr.

The test bus is a 2009 Daewoo BS120CN model, with a diesel engine displacement of 7640 c.c. The tare weight is about 12,000 kilograms, and it satisfies EU4 emission standard.

The driver has a clean driving record, and has a mild driving pattern.

2.2 On-board Emissions Measurement (OEM) System

The Horiba OBS-2200 system was used for collecting fuel consumption and emission data on roads. This system has been certified for Code of Federal Regulations (CFR) Part 1065 subpart J testing by the U.S. Environmental Protection Agency (EPA). It is also equipped with a Global Positioning System (GPS), which may be used to record vehicle positions over time, so that instantaneous speeds and acceleration rates may be recorded and related to emissions and fuel consumption. It is capable of measuring emissions of CO, CO_2, THC and NO_X. The fuel consumption is estimated by using a carbon balance methodology.

2.3 Sampling

The survey period of the IOT project extends from 6/17 to 6/24 in the year of 2011. For this analysis, the day of 6/21 (Tuesday) was selected. The first and last trips of the day were excluded, because they may not represent a typical run and passenger loading in a day. A total of about 32,397 seconds of samples were collected, which covers a travel distance of about 137.41 kilometers, or 4 full round-trips of the test bus throughout the weekday, as shown in the bottom part of Table 1. The data are segregated into four combinations of

1) peak period (7:00~9:00 and 17:00~19:00) and off peak period; and
2) bus-lane portion and regular-city-street portion of the same bus route.

Table 1 Total Sampled Time and Travelled Distances

	Bus lane, Peak	Bus lane, Off-peak	Regular Streets, Peak	Regular Streets, Off-peak	Total
Time in Samples (sec)	3,627	8,049	7,186	13,535	32,397
Travelled Distance (km)	14.06	34.41	29.86	59.08	137.41

3. CHARACTERISTICS OF VEHICLE OPERATIONS

3.1 Travel Time Distribution by Speed Intervals

Table 2 shows the percent of time spent in various speed intervals. The distributions are typical of buses, with high percent of time spent in idling, as well as the speed close to the speed limit. The following observations are made:

1) The percents of idling times are notably higher in bus-lanes or about 40% as compared with the 34% in the regular street portion. This is probably because (1) bus lanes are located on major arterials in the city center, where traffic congestion is more pronounced; (2) passengers volumes are much higher in bus lanes, requiring longer time for boarding and alighting; and (3) the large volumes of buses in a bus lane without a bypass may also add to stop time when waiting to get into bus stations.
2) The test bus spent similar percent of time idling during both peak and off-peak periods. Since the numbers of bus passengers are considerably less during off-peak

periods, the long idling time in off-peak periods may be caused by signal design that is not responsive to the current bus flows.

3) The combination of bus lanes in off-peak periods shows a considerably different distribution of time over speeds than the other three. The percent of time spent in speed above 35 km/hr amounts to 20.4%, while the other three only spend about 15~17% of time in the same speed interval. Moreover, the bus lanes in off peak period show about 4~5% of time in each of the 5 km interval below 25km/hr, as compared with the 5~8% of time spent in the same speed interval in the other three. This indicates bus lanes may operate more efficiently than the city-street portion when reasonable volumes of buses are in operations.

Table 2 Travel Time Distribution by Speed Interval

Speed Interval (km/hr)	Bus lane, Peak	Bus lane, Off-peak	Regular Streets, Peak	Regular Streets, Off-peak
0(Idling)	41.0%	40.4%	34.1%	34.3%
0-5	5.4%	4.7%	5.6%	5.1%
5-10	5.1%	4.8%	7.2%	5.6%
10-15	5.9%	5.0%	8.1%	6.8%
15-20	7.3%	5.1%	8.6%	7.9%
20-25	5.9%	4.5%	6.8%	6.9%
25-30	5.6%	6.3%	6.1%	7.9%
30-35	8.5%	8.9%	7.8%	8.2%
>35	15.3%	20.4%	15.7%	17.2%
Total	100.0%	100.0%	100.0%	100.0%

3.2 Acceleration Rates by Speed Interval

Fuel consumption rates are very much relevant to vehicular acceleration rates, but not so much to deceleration rates. Figure 2 shows the average acceleration rates, with deceleration excluded, of the test bus at various speed intervals. We can observe that:

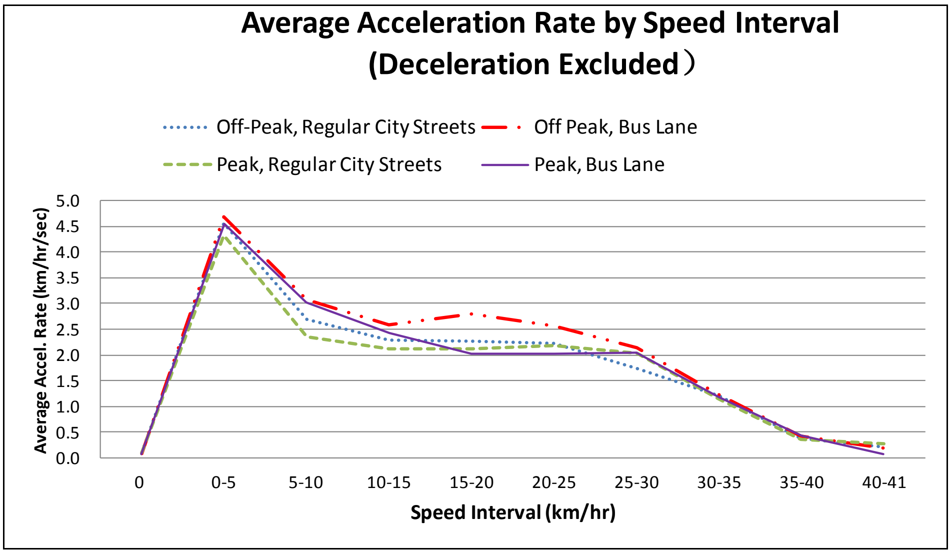


Figure 2 Average Acceleration Rates by Speed Interval

1) The test bus consistently applied much higher acceleration rates in bus lanes during off-peak period than the other three, indicating there may be (1) pressure from the buses behind to speed up; and/or (2) less disturbances from other road traffic in mid-blocks. The differences are most distinctive in the speed intervals between 10 and 25km/hr;
2) For all four combinations of bus-lane/regular-street and peak/off-peak periods, the average acceleration rates are highest when the test bus is operated below 5km/hr, and generally decrease as the bus approaches the speed limit of 40 km/hr; and
3) Off-peak operations show generally higher acceleration rates than those of peak operations, showing the preferred maneuvers of a good driver.

3.3 Travelled Distance Distribution by Speed Interval

Table 3 shows the travelled distances in various speed intervals. It shows that

1) During off-peak hours, the test bus can travel close to 70% of the distance at speeds above 30 km/hr in bus lanes, which is considerably longer than the 57~61% in the other three.
2) Below 10% of the distance was travelled by speeds between 10 and 20 km/hr in bus lanes during off-peak periods, as compared with the 14~17% in the other three. This is consistent with the observations for acceleration rates in Table 2. They show buses in bus lanes tend to be able to accelerate to speeds close to the speed limit, while they may be kept at much lower speeds for longer period of time on regular city streets and/or during peak periods.
3) As expected, off-peak periods show higher percent of distances travelled at high speed than peak periods.
4) Generally, bus lanes demonstrate higher operating speeds of 23 and 25 km/hr on line segments in peak and off-peak periods, respectively, as compared with the 22 and 23 km/hr on regular streets. This shows that the bus lane is functioning well in terms of reduction of disturbances from other roadway traffic in mid-blocks.

Table 3 Speed Distribution of Travelled Distance

Speed Interval (km/hr)	Bus lane, Peak	Bus lane, Off-peak	Regular Streets, Peak	Regular Streets, Off-peak
0-10	3.6%	3.0%	4.3%	3.3%
10-20	14.6%	9.9%	17.0%	14.4%
20-30	20.6%	17.9%	21.5%	23.9%
>30	61.2%	69.2%	57.2%	58.4%
Total	100.0%	100.0%	100.0%	100.0%
Average Operating Speed, Excluding Idling (km/hr)	23.00	25.14	22.10	23.31
Average Speed, Idling Included (km/hr)	16.31	17.91	16.48	17.36

4. CHARACTERISTICS OF EMISSIONS

In making comparisons between bus lanes and regular city streets, it should be noted that this paper can only compare the average emission rates of the two portions of the same bus route. The bus-lane portion and regular street portion of the bus route represent completely different traffic operating environment and passenger demands. The bus-lane portion of the route is on an arterial in city center, with generally much higher levels of traffic congestion and bus passenger demand, while the regular- street portion is partially in the suburb, or on secondary arterials. The traffic conditions along the arterials with bus-lane operations tend to be highly congested, and may be even less energy efficient if no bus lane was provided.

4.1 Emission Rates during Idling

Table 4 shows the emission rates during idling. The observations are summarized below,

1) Diesel engines generally emit very limited amount of THC during idling.
2) Idling emission rates are generally higher during peak periods than off-peak periods. This may be caused by the larger passenger volumes boarding and alighting in peak periods, which raises the energy demand for air-conditioning, induces considerable incomplete combustion, and thereby raising the idling fuel rates and emission rates of all four pollutants.
3) CO shows a 17~22% higher idling emission rates in peak periods than those of the off-peak periods, which may be caused by the incomplete combustion cycles during idling. This is followed by NOx and CO_2. THC shows a difference of 2~3%, and is the most insensitive to the different operating environment of buses, as compared with other three pollutant emissions.
4) Idling emission rates are generally slightly higher as measured on regular city streets than in bus lanes, with the exception of THC. CO shows the largest difference or about 8 to 12 % higher emission rates on city streets than in bus lanes. CO_2 shows about 4% higher emission rates on regular city streets than in bus lanes, while the discrepancies of NOx are about 1% or less.

Table 4 Emission Rates during Idling

Pollutants	Bus Lane			Regular Streets		
	Peak (g/sec)	Off-peak (g/sec)	Peak/off-peak (%)	Peak (g/sec)	Off-Peak (g/sec)	Peak/off-peak (%)
CO	0.0357	0.0304	117.4%	0.0400	0.0327	122.3%
THC	0.000153	0.000149	102.7%	0.000145	0.000142	102.1%
NOx	0.0591	0.0530	111.5%	0.0598	0.0529	113.0%
CO2	2.7056	2.5292	107.0%	2.8020	2.6239	106.8%

4.2 Emission Rates by Speed Intervals

The emission rates for the four pollutants generally decrease with respect to the increase of speed, and thus form convex relationships with respect to speeds. That is to say, the rates are large at low speeds, and gradually reduce at their respective decreasing rates as speeds increase, as shown in Figure 3. Figure 3 also compares the emission rates during peak and off-peak periods while operated in bus lane and on regular city streets. The following observations are made regarding the change of emissions rates relative to the operating speed of the test bus.

1) Unlike idling emission rates, off-peak periods generally show higher emission rates than their peak-period counterpart. In driving between bus stops, the driver tends to accelerate as much as allowable by the traffic conditions to reach the speed limit, or 40 km/hr, as early as possible. Off-peak periods generally offer better operating environment for acceleration because of less traffic disturbances. This is supported by Figure 2 in Section 3.2, where higher acceleration rates are used when the test bus operates at low speeds, which in turn increases emission rates at low speeds. The discrepancies between emission rates become less distinctive when speeds are above 25 km/hr, because acceleration rates tend to be about the same for both bus-lane and regular-street operations, as also shown in Figure 2.
2) In an exclusive bus lane, traffic disturbances are considerably reduced. In an off-peak period, the number of buses in a bus lane is well below the bus lane capacity. Therefore, a bus may quickly accelerate and maintain steady driving for longer period of time, as discussed in Sections 3.1 and 3.2.
3) CO shows the most distinctive differences in the bus' emission rates between peak and off-peak periods.

4.3 Sensitivity to Variation of Bus Operating Speeds

Figure 4 compares the sensitivity of emission rates to speeds of the four pollutants. Since the emission rates vary considerably between pollutants, they are all normalized with respect to the emission rates in the speed group of 25~30km/hr, and represented by %. This speed group is selected because the emission rates have generally stabilized as the bus accelerates to its full operating speed, and the driving patterns are probably not yet affected by the speed limits of 40 km/hr. From the figure,

1) When comparing with other pollutants, CO emissions appear to be the most sensitive to speed variation, with the highest percent in low speed and lowest percent in speeds above 25 km/hr, as shown in Figure 4.
2) With the most level curve out of the four pollutants, THC emission rates appears to be the least sensitive to speed variation.
3) A hump exists in the speed interval of 20-25 km/hr in bus lanes for all pollutants, with CO showing the most distinctive figures. For regular streets, however, the humps are hardly noticeable. This may be caused by the gear shift operation of the test bus in bus lane. The difference in driving pattern may have been caused by the queuing formation and bus following behavior while operating in bus lanes.

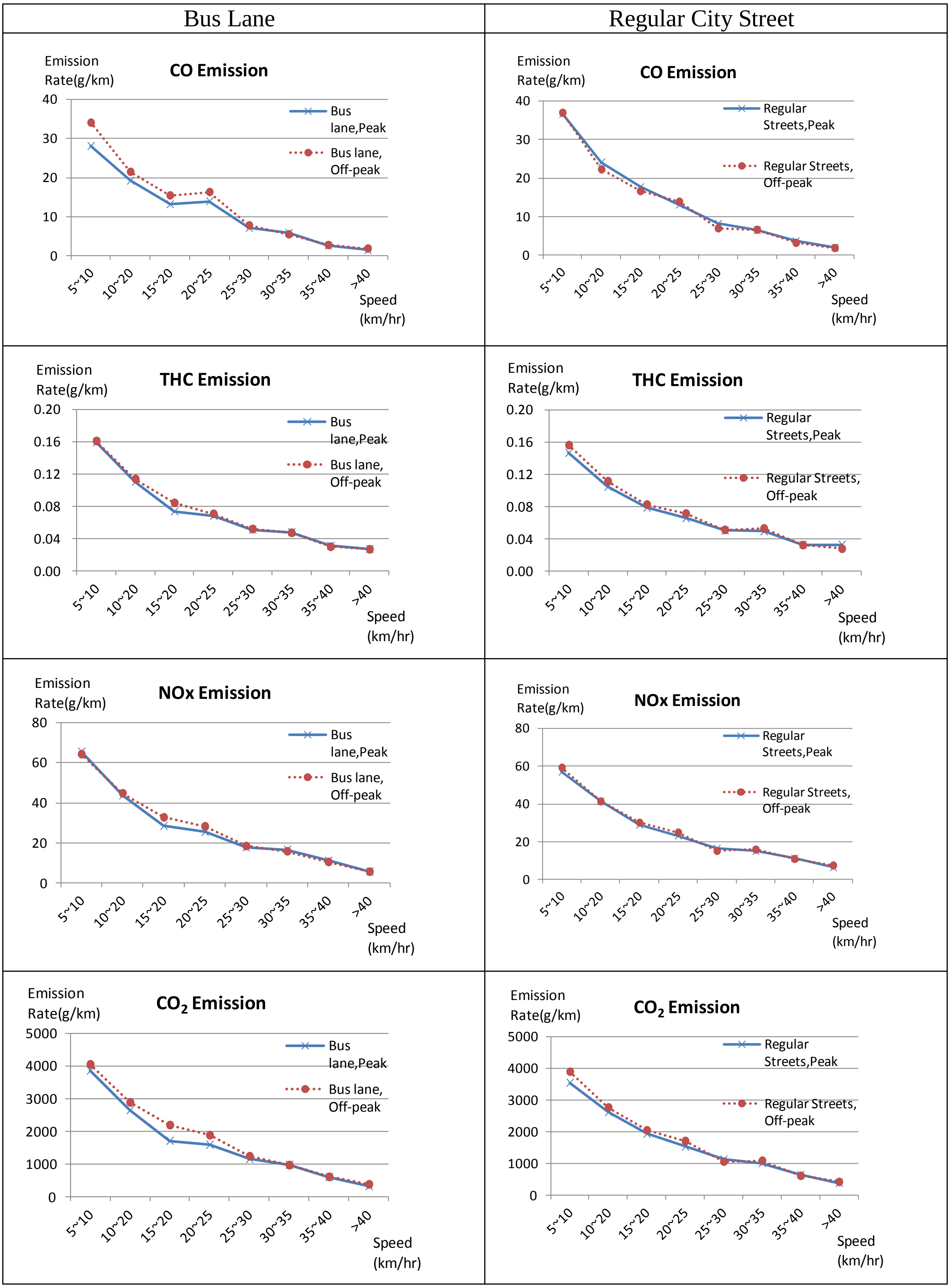


Figure 3 Emission Rates Relative to Speeds during Peak and Off-peak Hours

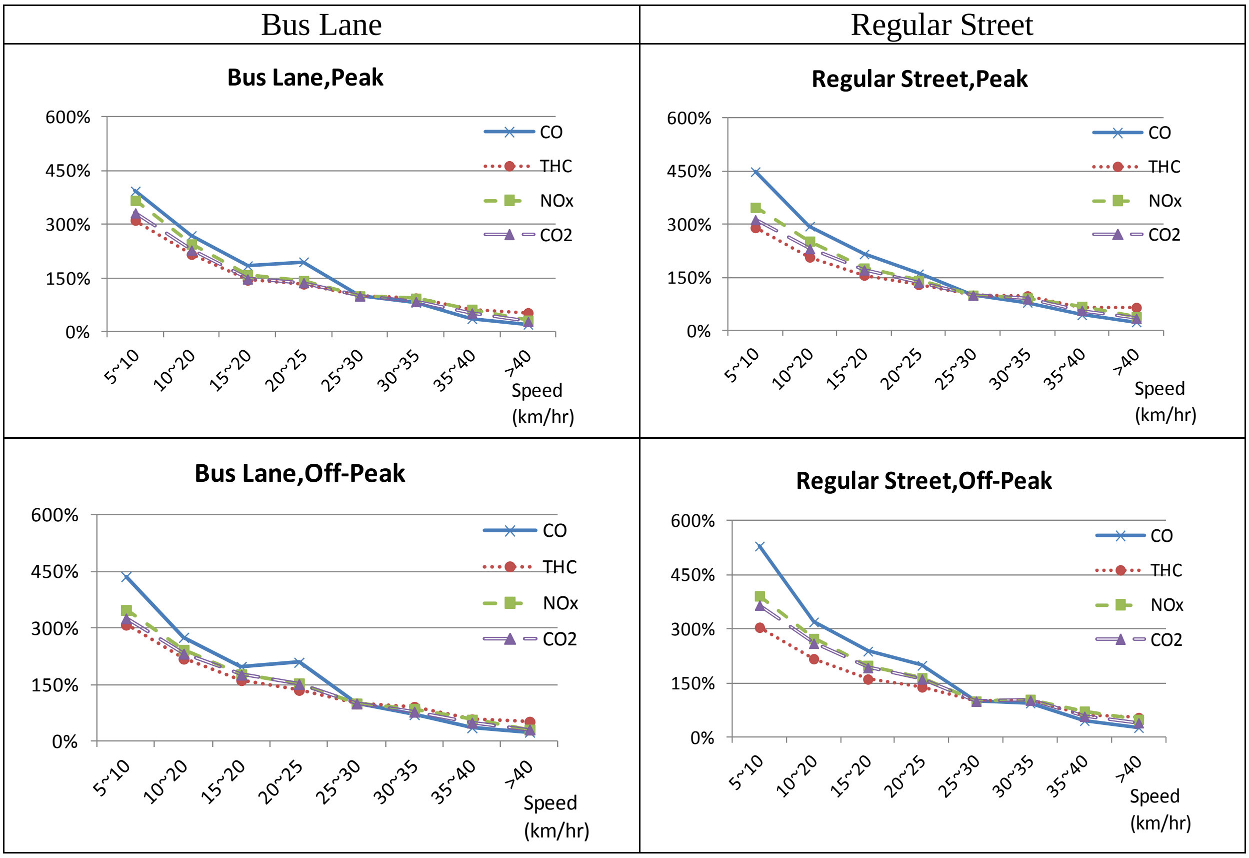


Figure 4 Sensitivity of Emissions to Speed (Normalized by the rate at 25~30 km/hr)

4.4 Distribution of Distance Travelled vs. Distribution of Emissions

Tables 5(a) and 5(b) compare the percent distributions of emissions of various pollutants and of distance travelled in each speed interval for bus lanes and for regular streets, respectively. This comparison would demonstrate the level of contribution of pollutant emissions by speed group. If the emission percentage is larger than the distance percentage, it means the emissions per unit distance tend to be high, and should be the focus of attention when trying to improve air quality. Since CO is the most sensitive to speed variation, it is used to describe how Tables 5(a) and 5(b) may be interpreted, as below.

1) About 36% and 31% of the CO emissions in bus lanes are produced during peak and off-peak periods, respectively, when the test bus is idling. The percentages may be compared with those for bus operations on the regular street portion, which are about 27% and 25% for peak and off-peak periods, respectively. Bus idling are generally caused by (a) stopping at traffic signals; (b) stopping at bus stations or bus stops for boarding and alighting and (c) stopping in mid-block due to traffic disturbances. In the case of bus lane, buses may be idled while in queue to enter stations, where the buses at front are in boarding and alighting operations. This may be observed immediately upstream of a busy station in bus lanes, especially during peak hours, when bus volumes become too large to be accommodated by the station platform. Whatever the causes, it is understandable that reducing idling time for buses would considerably lower the overall emission rates and would improve the emissions produced by buses.
2) Between 3% and 4% of the distances are travelled by the bus operated below 10

km/hr. The CO emissions, however, amount to more than 46% and 44%, respectively for bus lanes and regular streets, of the total emission level, if emissions in idling are also included. In the extreme case, almost a half, or 49%, of CO emissions in bus lanes during peak hours, occurs when the test bus is either standing or travelling below 10 km/hr. These figures show the air quality effects of buses in stop/acceleration/deceleration operations.

3) Traffic management measures should be focused on ways for reducing the emission levels during idling and low speed operations. This is especially important for bus lanes because of the large number of buses making stops at the bus stations on bus lanes, which largely increase intensities of CO, as well as other pollutants in station areas. Facility-wise, the design of station platforms and bus shelters should be elaborated to provide some relief or shelter for passengers' health and comfort.
4) At the high-speed end, or above 30 km/hr, the distances travelled amount to 57~69%, while the CO emission levels only amount to 17~21% of the total, with CO showing the lowest percentages of the four pollutants. This is the speed group that provides the emissions efficiency.
5) Similar trends may be observed for other pollutants, such as NOx. 31~37% of NOx emissions are produced when the bus is operated below 10 km/hr or idling, while 27~34% when the bus is operated above 30 km/hr.

4.5 Average Emission Rates

Average emission rates are calculated by dividing sub-total emissions by sub-total distance travelled in bus lane or on regular city streets, respectively, as measured throughout the sampled bus trips. Two average rates may be calculated by including and excluding idling emissions in the abovementioned emissions calculation. The results are shown in Table 6. The following observations are made:

1) In all cases, average emission rates are higher in peak periods than in off-peak periods. Bus lane operations in off-peak period consistently show the lowest average emission rates for all four pollutants. It shows that traffic disturbances tend to cause adverse effects to air quality. Thus, the driving pattern in bus lane during off-peak period may be considered as an ideal pattern for bus operations, except the inefficient idling part.
2) An emission-saving strategy for driving is to try to reach a steady high speed and maintain it as much as possible. Although the emission rates at low speeds tend to be high due to high acceleration rate, the longer distance travelled by using steady high speed close to the speed limit of 40 km/hr will pay off.
3) If idling is included, the average emission rates become more distinctive than if excluded.
4) Generally, the average emission rates are lower in bus lanes than on regular streets in the case of the test bus route. Although the bus lanes and regular streets in the test bus route are of completely different operating environment, and their comparisons may not be meaningful, we can still try to assess whether the exclusive bus lane system improves air quality after all. Since city center in most cases represents an area with longer delay and lower speeds than in the suburb, regular streets in the city center are probably causing more emissions than those in the suburb. Bus lanes appear to have achieved the objective of overall air quality improvement in the exclusive bus lane system on a bus-by-bus comparison. The number of buses, however, would also be a factor to be considered in dealing with

passenger exposure to air pollutants.

Table 5(a) % Distributions of Emissions vs. Distance Travelled (Bus Lane)

Speed Group (km/hr)	Peak Period					Off-Peak Period				
	% Dist-ance	% Emission				% Dist-ance	% Emission			
		CO	THC	NOx	CO2		CO	THC	NOx	CO2
0	-	35.8%	23.8%	24.5%	20.7%	-	31.0%	22.8%	22.4%	18.7%
0-10	3.6%	13.2%	11.3%	12.8%	13.1%	3.0%	15.0%	10.3%	11.7%	12.0%
10-20	14.6%	17.2%	17.2%	17.8%	19.1%	9.9%	15.6%	14.5%	15.5%	17.0%
20-30	20.6%	16.5%	16.8%	16.1%	18.2%	17.9%	17.2%	16.0%	16.4%	18.4%
>30	61.2%	17.3%	30.9%	28.8%	28.9%	69.2%	21.2%	36.4%	34.0%	33.9%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 5(b) % Distributions of Emissions vs. Distance Travelled (Regular Street)

Speed Group (km/hr)	Peak Period					Off-Peak Period				
	% Dist-ance.	% Emission				% Dist-ance.	% Emission			
		CO	THC	NOx	CO2		CO	THC	NOx	CO2
0	-	27.3%	18.2%	20.6%	16.8%	-	25.1%	17.4%	18.8%	15.6%
0-10	4.3%	16.5%	12.3%	13.8%	13.8%	3.3%	16.7%	10.4%	12.0%	12.2%
10-20	17.0%	23.5%	21.5%	22.3%	24.0%	14.4%	20.9%	19.4%	20.4%	22.0%
20-30	21.5%	15.4%	17.5%	16.2%	18.1%	23.9%	18.3%	20.6%	19.0%	21.1%
>30	57.2%	17.3%	30.5%	27.1%	27.3%	58.4%	18.9%	32.3%	29.8%	29.1%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 6 Average Emission Rates, with and without Idling

Pollutants		Bus Lane Peak (g/km)	Bus Lane Off-peak (g/km)	Bus Lane Peak/offpeak (%)	Regular Streets Peak (g/km)	Regular Streets Off-Peak (g/km)	Regular Streets Peak/offpeak (%)
CO	Avg. Emission Rate, w/o Idling	9.25	8.65	106.9%	11.57	10.42	111.0%
	Emission Rate, with Idling	12.88	11.41	112.9%	14.67	12.87	114.0%
THC	Avg. Emission Rate, w/o Idling	0.0574	0.0526	109.1%	0.0596	0.0588	101.4%
	Emission Rate, with Idling	0.0729	0.0661	110.3%	0.0709	0.0695	102.0%
NOx	Avg. Emission Rate, w/o Idling	21.48	19.32	111.2%	21.31	20.20	105.5%
	Emission Rate, with Idling	27.48	24.13	113.9%	25.96	24.15	107.5%
CO2	Avg. Emission Rate, w/o Idling	1274.55	1213.25	105.1%	1353.07	1318.46	102.6%
	Emission Rate, with Idling	1549.07	1442.55	107.4%	1570.58	1514.60	103.7%

5. CONCLUSIONS AND RECOMMENDATIONS

The study reaches the following conclusions and recommendations:

1) Taipei's exclusive bus lane system has been very successful and effective in improving bus efficiencies and attracting bus passengers in past decades. It is effective in sheltering buses from disturbances caused by other road traffic, and it enables buses to reach speeds of low fuel rates and low emission rates more easily than regular city streets.
2) The percents of idling time appear too high for the bus-lane operations in both peak and off-peak periods. Excessive idling reduces both operational and environmental efficiencies. For reducing idling time in the bus lanes, it is necessary to (a) upgrade traffic signaling systems by, e.g., bus-pre-empt or bus-priority signaling; (b) establish and enforce upper limits to the number of buses allowed in bus lanes, especially during peak periods; (c) where possible, redesign stations and platforms to better accommodate the allowed number of buses in bus lanes; and (d) streamline the fare-collection mechanism by providing fare card readers at both bus doors. More detailed analyses are required to identify the most effective way for improvements.
3) Bus emissions vary considerably by operating speeds, especially in an urban environment. The traditional approach of measuring vehicular emissions on a per-kilometer basis may not be effective in assessing air quality or passenger exposure effects relative to detailed bus lane design.
4) The exclusive bus lane system in Taipei does generally improve air quality in Taipei City. Bus lane operations in off-peak period consistently show the lowest average emission rates for all four pollutants. Thus, the driving pattern in bus lanes during off-peak period may be considered as an ideal pattern for bus operations, except the

inefficient idling, which needs to be improved.

5) Like the operations in bus lanes during off-peak periods, an emission-saving strategy for driving is to try to reach a steady high speed and maintain it as much as possible. Although the emission rates at low speeds tend to be high due to high acceleration rate, the longer distance travelled by using steady high speed close to the speed limit of 40 km/hr will pay off. To some extent, too many buses in bus lanes would degrade both operational efficiencies and environmental performances
6) City bus operations require frequent stops, acceleration and deceleration. The buses with regenerative brake systems, hybrid technologies, or other efficient stop/go features may stand out in energy and emission performances for their effective management of low speed operations.
7) Electricity-powered air conditioning system would be effective in reducing emission rates during idling. An independent electric air conditioning system would also be useful if a stop-engine-during-idling is to be implemented.
8) Bus station areas in a bus lane may be exposed to considerably high level of pollutant emissions. For example, close to a half of CO emissions are produced when the bus is operated below 10 km/hr or idling. The high emissions per bus and high number of buses in a bus lane may cause high concentration of pollutants at station of large passenger demands. Special bus shelter design and station operations should be considered to maintain health, environmental and operational efficiencies.
9) Since bus operators favor operations in the bus lanes because of their high patronage and high operating efficiencies, a policy for prioritizing right-of-way assignment to those operators providing "Green Buses" and "eco-drivers" to operate on the bus lane system may help the overall energy performances of the entire bus-lane system.
10) Particulate matters (PM) were not included in this research because the lack of funding for measuring instruments. Taiwan's Environmental Protection Agency (EPA) has recently required the air quality standards be extended to $PM_{2.5.}$ More research is needed in characterizing $PM_{2.5}$ emissions.

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