MASS TRANSIT DEVELOPMENT AND EMISSIONS: HONG KONG CASE STUDY

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ABSTRACT

The air pollution and traffic congestion problems arising from urban transportation are widely acknowledged by policy-makers of metropolitan planning organizations (MPO), who usually set out proposals to constrain private car use and/or increase the availability of road space by roadway capacity expansion. However, these measures do not always ensure a decrease in travel congestion and exhaust emission in the long run, due to possible induced demand for travel. Hence, metropolitan transport management strategies often contemplate about developing a high capacity rail system as an efficient and environment-friendly way for urban transportation. However, such a shift in the urban transportation system involves large amounts of investments and social costs. This paper examines the role of urban rail transit in reducing vehicular exhaust emissions as compared with bus services. Using empirical data in Hong Kong, we show that urban rail transit, as compared with bus services, can lead to substantial reductions in emissions. To ascertain the environmental impact of the results obtained, we conduct sensitivity analyses to ascertain the outcomes under different operation scenarios.

Keywords: Environmental externalities, External cost, railway substitution, Exhaust emission, Monetary valuation

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1. INTRODUCTION

Exhaust emissions from vehicular sources have well been recognized to contribute substantially to urban air pollution and climate change problems, and will become even more so, with further increases in automobile ownership and usage. According to a US Environmental Protection Agency (2006) report, transportation sources accounted for 29% of the total U.S. greenhouse gas (GHG) emissions in 2006 and transportation is the fastest-growing source of GHG in the U.S., accounting for 47% of the net increase in total U.S. emissions since 1990. Transportation is also the largest end-use source of CO_2, which is the most prevalent GHG. In addition, the energy use due to transportation is expected to increase by 48% between 2003 and 2025, even with modest improvements in the efficiency of vehicular engines. Because of the negative effects of air pollution and climate change on human health and living conditions, public concerns about the environmental effects of vehicular traffic are reaching unprecedented levels, and governments around the world are giving attention to this problem as never before. Consequently, kinds of control measures ranging from vehicle emission standards to reducing vehicle kilometers travelled (VKT) have been adopted to help control vehicular emission and improve air quality.

Policy-makers of most metropolitan planning organizations (MPO) usually set out proposals to constrain private car use and/or increase the availability of road space. Many planners and traffic engineers argue that these sorts of measures are critical for both reducing traffic congestion and exhaust emissions. However, economic theory indicates that increases in road space and the consequent decreases in travel time and emission will tend to increase total vehicular travel and pollution in the long run, an effect known as induced travel (Noland and Quddus, 2006). Recent empirical studies of induced travel effects have established that travelers' behavioral reactions to road capacity enhancements will lead to an increase in total travel (Hansen and Huang, 1997; Noland and Cowart, 2000; Noland, 2001). Yin and Lawphongpanich (2006) also show that congestion pricing schemes aiming to constrain private car use do not necessarily lead to less traffic emissions. So promoting alternative forms of transport, particularly High Occupancy Vehicle (HOV), such as bus and urban railway transit, will be a possible way to solve both the air pollution and traffic congestion problems. However, the substitution of bus for car travel has a diverse impact on the total amount of exhaust emissions: although Carbon monoxide (CO), Carbon dioxide (CO_2) and volatile organic compounds (VOC, sometimes called Hydrocarbons (HC)) emissions are generally reduced, the total emissions of Nitrogen (NO_x), Sulphur dioxide (SO_2), and particulate matter (PM) are increased (Romilly, 1999). This is because buses have high emission factors for NO_x, SO_2 and PM per passenger kilometers relative to car as the substitution of diesel to petrol. Given the relative size of the damage from particles, the net reduction in pollution-related external cost created by switching travelers from cars to buses might not even be positive (Harford, 2006). The use of railways, which is believed to be more environmentally friendly, has become the back-bone of passenger transport systems of many metropolises. Hence, metropolitan transport management strategies often contemplate about developing a high capacity rail system as an efficient and environment-friendly way for urban transportation (Tang and Lo, 2008). However, such a shift of the urban transportation system involves large amounts of investments and social costs. Therefore, it is important to have an accurate evaluation of its effect on exhaust emissions.

The annual SO_2, NO_X PM and CO_2 emissions of Hong Kong in 2005 were 84,900 tons, 99,500 tons, 6,580 tons and 37,800 kilo-tons, respectively. For comparison purposes, based on the annual emission inventory (Streets 2003, U.S. EPA 2009 and HKSAR EPD 2009) and corresponding population (Japan Census Bureau 2007, U.S. Census Bureau 2010 and HKSAR Census and Statistics Department 2010), we estimate that the emissions per capita in Japan, the US and Hong Kong. The results are shown in Figures 1 and 2.

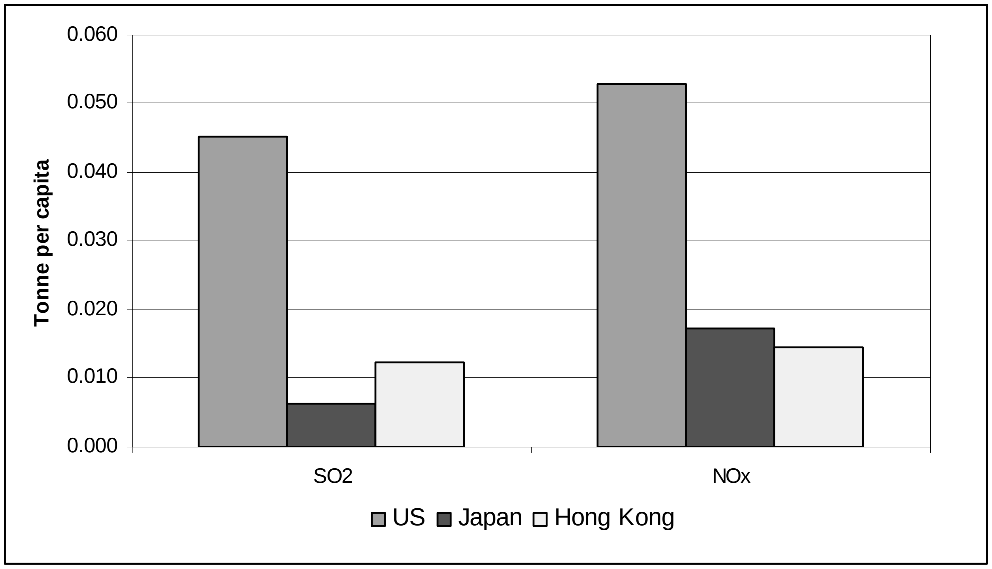

Figure 1 - Emission per capita in US, Japan and Hong Kong (SO_2 and NO_X)

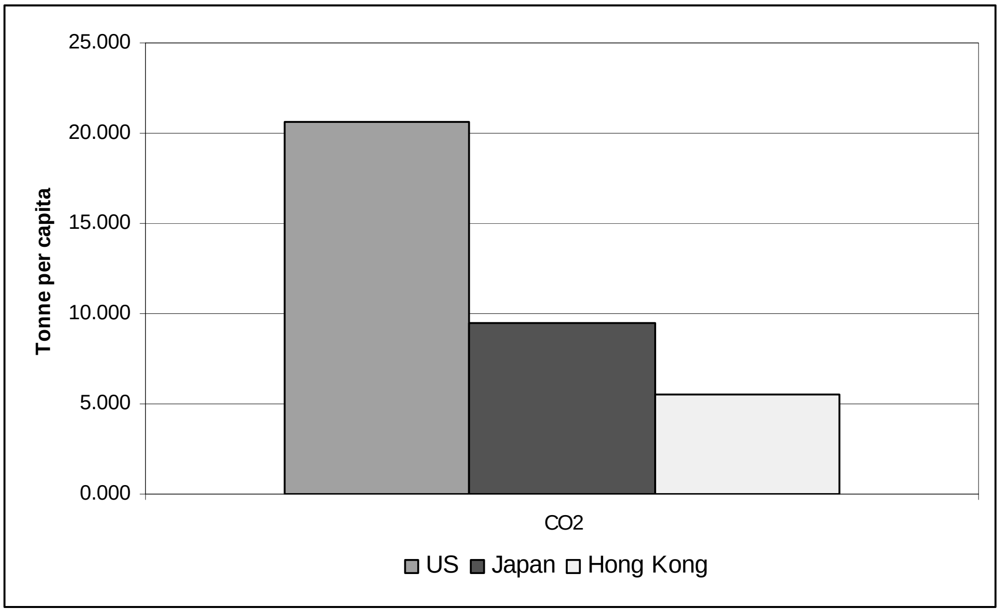

Figure 2 - Emission per capita in US, Japan and Hong Kong (CO_2)

According to Figures 1 and 2, on the basis of emissions per capita, generally, Hong Kong is below the US and Japan, except for SO_2 emission. Specifically, Hong Kong's emissions per capita are approximately 1/3 of those in the US and similar to but lower than those in Japan. This could be attributed to the low car-ownership and low private car usage as well as the lack of major industries with high emissions in Hong Kong.

Hong Kong has one of the highest population densities in the world. The Environmental Protection Department of Hong Kong monitors emissions since 1990. Road transportation contributes a large proportion of NO_x, PM and CO_2 emissions, respectively, 21.5%, 29.8% and 16% (HKSAR Environmental Protection Department, 2009). Intended initially to contain congestion, which has the positive side effect of emission reduction, stringent demand management policies are in place to limit private car ownership in Hong Kong. Firstly, first registration tax and annual licensing fees make the purchase of and keeping a car expensive, for example, the first registration tax is about 50% higher than in New York, 100% higher than in Sydney, but less expensive that in Singapore. The end result is that car ownership rate is about one-tenth of the US's, at around 50 per 1000 persons. Secondly, fuels taxes, parking fees, road and tunnel tolls add to the operating cost. As a consequence, public transit trips make up about 90% of the motorized journeys in Hong Kong (Poudenx 2008). This figure has been stable for a long time. Generally, it is well accepted that once a person owns a car, it rapidly becomes a necessity and the feeling is reinforced over time (Cullinane and Cullinane 2003). That is, car ownership opens up the choice between transit and private car. For the majority of people in Hong Kong, without a car, the mode choice is really between different kinds of public transport modes. Therefore, it is reasonable to consider that private car journeys are relatively fixed in the current research, implying that there will be minimal mode shift between private car and public transit (bus and railway). On the other hand, the policy of Hong Kong is to develop different kinds of mass transit systems to allow for healthy competition and also to address the specific needs of communities located in different pars of Hong Kong, such as convenience door-to-door services, market size, etc. Therefore, the current research concentrates on the mode shift between different mass transit systems while induced travels are ignored at the moment. This assumption is supported by actual observations (Tang and Lo, 2010), which showed that despite a 300% increase in rail car-km per capita and another 150% increase in franchised bus vehicle-km per capita over the past 20 years, the combined rail and franchised bus passenger trips per capita only increased by a few percents. In other words, the induced demand from pubic transit service improvements is minimum, which could be attributed to the stringent demand management policies on private car ownership and usage.

The decision on the type of mass transit development for a metropolitan involves complicated issues, such as financial viability, prevailing transport policy, economic analysis of benefit and cost, supply and demand patterns, etc (Lo et al, 2008; Tang and Lo, 2010). Indeed most studies emphasize the financial and congestion aspects (Tang and Lo, 2008); few focus on the emission aspect of mass transit development. The objective of this paper is to add to the analysis with the emission impacts of mass transit development. An assessment of the external costs of air pollution is important for integrating environmental issues into transportation policies. Government policy-makers often use cost-benefit analysis, calculated in dollars per ton of emissions reduced for various emission control measures, to determine which control measures should be implemented to meet emission reduction requirements. The current paper identifies the net changes of four exhaust emissions arising from developing mass rail transit versus bus transit in Hong Kong. This study uses demand models calibrated for Hong Kong to estimate the ridership between these two modes, which are then used to estimate the emissions per day and per space-km carried by the respective mode. Lacking locally calibrated external costs per emission type, this study relies on monetary costs per emission type obtained in the UK. The remainder of the paper is structured as follows. Section 2 empirically analyzes the passenger shifts from bus to railway as a new railway is introduced into the urban passenger transportation system of Hong Kong. Section 3 provides an estimate for the exhaust emission factors and determines the changes in four individual exhaust emissions resulting from the addition of the new railway. Section 4 provides results for changes in the monetary cost in four individual exhaust emissions arising from the introduction of the new railway. Section 5 provides some concluding remarks.

2. DEMAND BETWEEN RAIL AND BUS SERVICES

The Hong Kong Special Administrative Region (HKSAR) comprises a densely populated city with land area of 1,104 km^2 and population of 7.06 million. It consists of three parts, namely, the Hong Kong Island, Kowloon, and New Territories. With such a densely populated area and limited land resource, the Hong Kong government formulates the transport strategy named “Hong Kong Moving Ahead” which focuses on five aspects (Hong Kong Transport Bureau, 1999): (1) Better integration of transport and land use planning, (2) Better use of railways as the back-bone of the passenger transport system, (3) Better public transport services and facilities, (4) Better use of advanced technologies in transport management and (5) Better environmental protection. Accordingly, the Hong Kong government started to expand the railway network. West rail, started operation in December 2003, provides a linkage between Tuen Mun in Northwest New Territories and downtown in Kowloon as shown in Figure 3. Before west rail commenced service, the majority of the trips between Tuen Mun and Kowloon were carried by bus services. After west rail started service in 2003, its market share gradually increases, at about 30% today. In this study, we analyze the ridership who took bus services from Tuen Mun to Kowloon before but now switched to west rail, and estimate the impact of this mode shift on exhaust emission.

Figure 3 - The newly introduced railway– west rail (pink line)

A pilot survey of the activity-travel patterns of North-west New Territories (i.e. Tuen Mun and Yuen Long) residents was conducted to examine the impact of the newly introduced railway by using the Computer Assisted Telephone Interview (CATI) system from October 18 to October 23 in 2004 after the operation of west rail, denoted as Survey2004. The telephone numbers were obtained from the phone book provided by one of the largest telecommunication corporations in Hong Kong, PCCW-HKT Telephone Ltd. This phone book contains telephone numbers of Hong Kong residents ordered by surname. Each entry contains the name, phone number and the residential district. In this survey, only Tuen Mun and Yuen Long residents' phone numbers were selected. Systematic sampling was used to select the potential interviewees. A random number was generated to select the beginning page of the phone book. On every 29th page all the telephone numbers of Tuen Mun and Yuen Long residents were selected (sample size required/average number of suitable telephone per page), starting from the beginning page. The questionnaire consisted of three parts. The first part collected the details of trips made by an individual on the interviewed day. The data included all the trips information made within the day such as the trip origin and destination, departure and arrival time, trip purpose and mode of transportation. The second part collected individuals' perceptions of the service quality of the transportation mode they used in the trips. The last section collected personal and household sociodemographic information. A total of 340 Tuen Mun and 319 Yuen Long residents were successfully interviewed and used for current analysis.

The mode choice between railway and bus is modeled by using standard binary logit model. The choice of independent variables for potential inclusion in the models was guided by the findings from previous mode choice research and the available variables from the data source. The variables considered in the specifications included household socio-demographics (residential district, household monthly income, number of household members, presence and number of children/workers/elders) and individual socio-demographics (age, gender, marital status and education level). It was also believed that when an individual chooses a particular mode to reach a destination for a particular activity, he/she will consider the travel time, cost and number of transfers to the destination. These variables are specified in Table 1 along with their definitions

Table 1 - Independent variables used in the mode choice analysis

Variable	Definition
Individual socio-demographics	
Age	1= 12-39, 2=40-59, 3=60 and above
Gender	1=Male, 0=Female
Marital_status	1=Single, 2=Married
Education_level	1=Primary school, 2= Others
Household socio-demographics	
District	Residential district, 1= Tuen Mun, 2= Yuen Long
Income (HK$ monthly)	1=No income, 2=less than 15 000, 3=15 000 – 39 999, 4=more than 40 000
Nhousemembers	Number of household members
Nchildren	Number of children
Nelders	Number of elders
Nworkers	Number of workers
Transportation characteristics	
Ntransfers	Number of transfers
Travel_fee	Travel fee to the destination
Travel_time	Travel duration to the destination

The final model specification was developed through a stepwise variable selection method, which is a systematic process of adding statistically significant variables and eliminating statistically insignificant variables based on a likelihood ratio test. The empirical result is shown in Table 2.

Table 2 - Empirical results of a binary logit model for bus and railway choice

Parameters	B	S.E.	Wald	Sig.	Exp(B)
District	3.596	1.316	7.465	0.006	36.455
Travel_fee	-0.284	0.154	3.404	0.035	0.753
Travel_time	-2.997	1.664	3.243	0.042	0.050
Age	2.318	0.989	5.486	0.019	10.151
Constant	-130.466	45.416	8.252	0.004	0.000

This model is statistically significant with all the variables having logical signs and magnitudes. According to a Population By-census conducted in 2006 (HKSAR Census and Statistics Department 2006) denoted as Census2006, there are 445853 Tuen Mun residents and 455466 Yuen Long residents respectively and in general there will be 42.6% of Tuen Mun and Yuen Long residents will leave local district to downtown. Then, the mode choice probabilities between bus and rail can be predicted using the average values of the corresponding explanatory variables of Northwest New Terrorist residents. That is, substituting the explanatory variables of mode choice model with the average means from Census2006, we can estimate that the amount of travelers who shift from bus to west rail is 99,896, or about 100,000 per day.

3. EMISSIONS FROM RAIL AND BUS SERVICES

The major air pollutants, emitting from vehicular traffic, are oxides of Nitrogen (NO_x), Carbon dioxide (CO_2), Carbon monoxide (CO), volatile organic compounds (VOC), particulate matter ($PM_{2.5\text{-}10}$) and Sulphur dioxide (SO_2). It is well known that CO_2 is the most prevalent GHG which is one of the major causes for global warming concerned by the public. The Kyoto Protocol, validated in Feb 2005 and ratified by 142 countries and locations including 30 industrialized countries up to Aug 2005, sets binding targets to reduce GHG emissions. With the intention of providing flexibility to achieving these targets, Clean Development Mechanism (CDM) and Joint Implementation (JI) are included in the Protocol, which allow nations to achieve their GHG emission targets by purchasing "Carbon Credits" from other nations. Therefore, an accurate analysis of environmental externalities of exhaust emissions resulted from the mode shift from bus to rail services will also have great potential economic benefits.

The vehicle emission factors depend on a number of parameters, including vehicle type, engine fuel, vehicle speed and the emission standards in force when the vehicle is registered. Test results for exhaust emissions show considerable variability, even for the same model of vehicle. No two vehicles are ever identical, and driving conditions cannot be exactly replicated over different tests. In general, buses are assumed to be powered by diesel engines and driven on urban conditions. In addition, buses in a city usually registered with different kinds of emission standards. Table 3 shows the urban emission factors for buses currently used in Hong Kong, which are based on four sets of European emission standards with their proportions: Pre-Euro I (before October 1992), Euro I (October 1992), Euro II (October 1996) and Euro III (October 2000). Note that the emission factors in Table 3 are not the legislative limits set for each European emission standards, but are the calculated values from European Environment Agency (2009) within each standard. In general, there are significant reductions in the emission factors of NO_x and PM as the introduction of stricter emission standards, which are regulated by European standards. The exceptions are for SO_2 and CO_2, where emissions are determined mainly by fuel consumption

Table 3 - Urban exhaust emission factors (g per km) from buses[a] (37km/h)

Standard	Proportion	CO_2	SO_2	NO_x	$PM_{2.5}$[b]
Pre-Euro	0.13	974.14	0.56	14.60	0.69
Euro I	0.23	828.84	0.47	8.89	0.39
Euro II	0.46	812.13	0.46	9.44	0.18
Euro III	0.18	840.34	0.48	7.76	0.17

a. Double deck buses in Hong Kong are approximated by articulated buses in Europe
b. Particulate emissions in the vehicle exhaust mainly fall in the $PM_{2.5}$ size range, as the coarse fraction ($PM_{2.5-10}$) is negligible in vehicle exhaust

The calculation methodologies of emission factors from European Environment Agency (2009) are categorized into Tier 1, Tier 2 and Tier 3 methods. Tier 1 and Tier 2 are “Simpler methodology” whereas Tier 3 is “Detailed methodology”. Tier 1 and Tier 2 emission factors are derived by combining the Tier 3 method or Copert 4, an emission calculation software program, and data from Tremove 2.52, a fleet activity database. Tier 1 and Tier 2 emission factors can be applied to vehicular gasoline consumption and vehicle mileage information, while mean travel speed per mode and vehicle technology are necessary for using the Tier 3 emission factors. A procedure for deciding which method is suitable for vehicular exhaust emission calculation with the available information is shown in Figure 4. In this paper, we adopt the Tier 3 approach. In the Tier 3 method, exhaust emission is calculated with consideration of engine temperature and operation condition. The corresponding emission factors originate from Corinair Working group, Artemis project, MEET project and various DG Enterprise studies. They are derived for different vehicle types (i.e. passenger car, LDV, HDV & Bus and Two Wheelers), fuel (i.e. Gasoline, Diesel, LPG and CNG), vehicle technology (i.e. pre-Euro, Euro 1, Euro 2, Euro 3 and Euro 4) and engine capacity or weight. Tier 3 emission factors can be generally separated into 2 classes according to the pollutants: CO, VOCs, NO_x, PM and fuel combustion are in the first class which are necessary for detailed estimation; whereas SO_2. NH_3, Pb, CO_2, N_2O, and CH_4 are in the second class, which involves simpler “bulk” emission calculations.

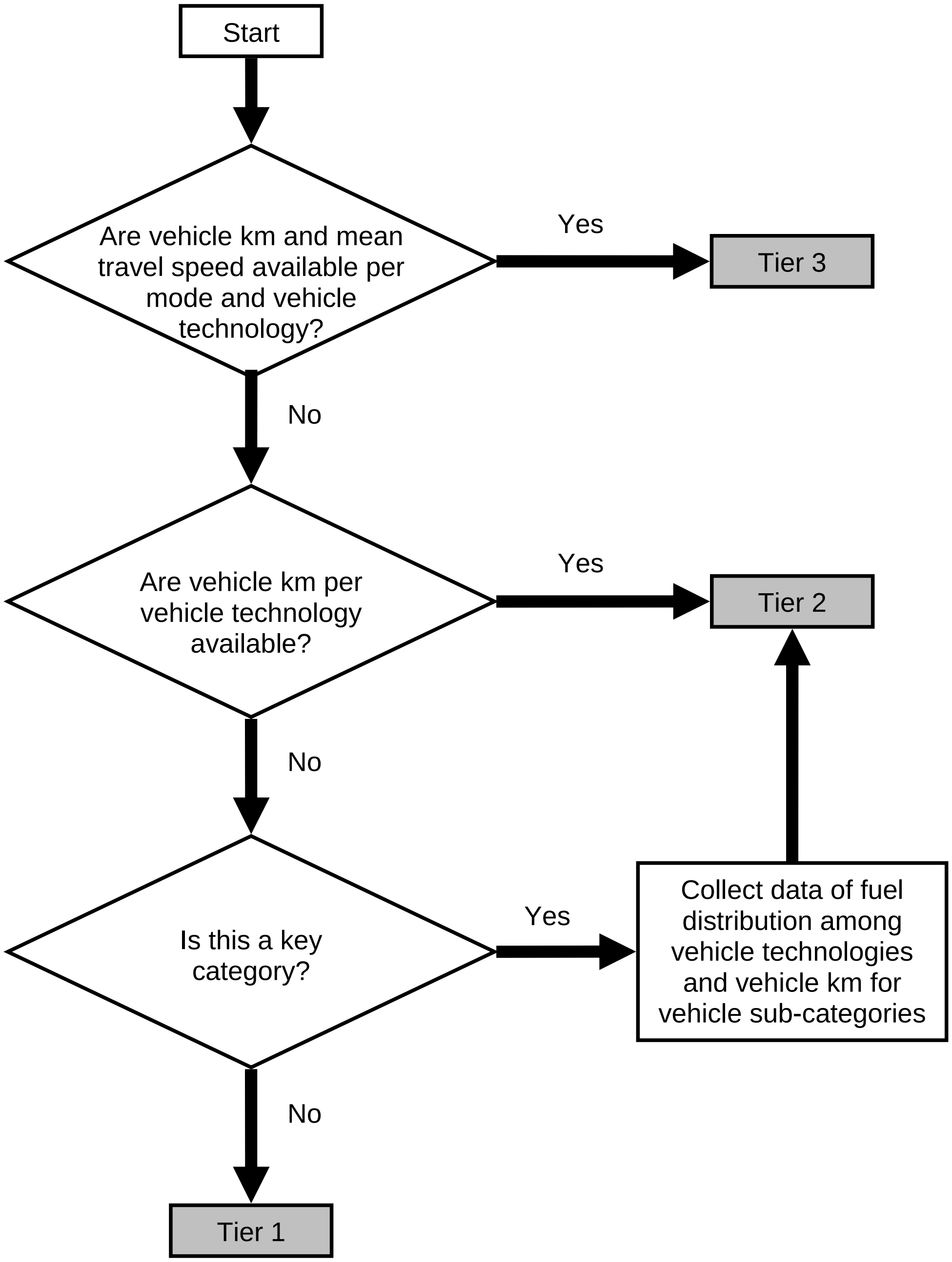

Figure 4 - Decision tree for choosing vehicular exhaust emission method

Most urban railway uses electric traction, whose emissions are mainly determined by the power plants that generates the electricity. Therefore, the mix of pollutants from rail is somewhat distinct from pollutants from buses and they are not related to the location where a train is running, but to the locations of the power plants. Pollution-related externalities are not given per kilometer but per kWh of power used by train. It is assumed that emissions from electricity production plants have the same environmental impact as vehicle emissions in urban areas. Table 4 shows the typical emission factors from a major power plant in Hong Kong, namely, the CLP Group (2005).

Table 4 - Typical emissions (g/kWh) from a major power plant in Hong Kong

Emission	g/kWh
CO_2	708.56
SO_2	1.85
NO_x	1.12
PM_{10}	0.08

The change in net emission per day is calculated based on the scenario of 99,896 passengers shifting from bus to west rail, a figure determined in section 2. Given the average bus occupancy rate and the roadway distance between Tuen Mun and Yuen Long in Northwest New Territories and downtown in Kowloon, and the actual composition of the bus fleet as according to European emission standards, the daily exhaust emissions of the bus fleet are estimated to be as shown in Table 5. Also in Table 5 are the sensitivity results of varying the occupancy rate and speed of the bus services. Generally, the exhaust emissions change proportionally with the occupancy rate. On the other hand, for the range of speed evaluated (i.e. from 30 km/h to 45 km/h), the exhaust emissions generally reduce with the increases in speed. In general, it is known that a nonlinear, non-monotone relationship exists between speed and exhaust emissions. But for the speeds tested, it seems that speed increases, perhaps arising from congestion reduction, are beneficial as far as emissions are concerned. In order to facilitate the comparison with other regions, we also calculate the bus emission factors per seat-kilometer, denoted as per space-km, as shown in Table 6.

As for the rail services, given the electricity consumption per west rail trip and the service's daily frequency (MTR Corporation, 2009), it is possible to estimate the daily exhaust emissions and emission factors per space-km for west rail. The results are shown in Table 7. Comparing the bus and rail emissions, we can estimate the net emission change due to the introduction of west rail. Such results are shown in Tables 8, 9, 10, together with the sensitivity analyses.

Table 5 - bus daily exhaust emissions

Emission	Occupancy rate (Speed: 37km/h)			Speed (Occupancy rate:43/130)		
	43/130	65/130	90/130	30km/h	37km/h	45km/h
CO_2 (kg)	56734.46	37532.03	27106.47	64048.15	56734.46	51698.9
SO_2 (kg)	32.48	21.48	15.52	36.66	32.48	29.59
NO_x (kg)	652.76	431.83	311.88	732.92	652.76	596.56
$PM_{2.5}$ (kg)	19.64	12.99	9.39	23.33	19.64	16.85

Table 6 - bus emission in g per space-km by speed

Emission	Speed		
	30km/h	37km/h	45km/h
CO_2 (g/space-km)	30.07	26.58	24.19
SO_2 (g/space-km)	0.02	0.02	0.01
NO_x (g/space-km)	0.35	0.31	0.29
$PM_{2.5}$ (g/space-km)	0.013	0.01	0.01

Table 7 - Daily exhaust emissions and emission factors per space-km from west rail

Emission	Amount
CO_2 (kg)	18127.99
SO_2 (kg)	47.39
NO_x (kg)	28.68
PM_{10} (kg)	1.95
CO_2 (g/space-km)	0.9268
SO_2 (g/space-km)	0.0024
NO_x (g/space-km)	0.0015
PM_{10} (g/space-km)	0.0001

Table 8 - Changes in total emissions due to the mode shift from bus to west rail with the bus services operating at different rates of occupancy

Emission	Occupancy level					
	43/130	% change	65/130	% change	90/130	% change
CO_2 (kg)	-38606.47	-68.05%	-19404.04	-51.70%	-8978.48	-33.12%
SO_2 (kg)	14.92	45.93%	25.91	120.59%	31.88	205.43%
NO_x (kg)	-624.08	-95.61%	-403.15	-93.36%	-283.19	-90.80%
PM (kg)*	-17.69	-90.06%	-11.04	-84.97%	-7.43	-79.19%

*PM_{10} is regarded as $PM_{2.5}$ in the calculation of PM emission change

Table 9 - Changes in total emissions due to the mode shift from bus to west rail with the bus services operating at different speeds

Emission	Speed					
	30km/h	% change	37km/h	% change	45km/h	% change
CO_2 (kg)	-45920.16	-71.70%	-38606.47	-68.05%	-33570.91	-64.94%
SO_2 (kg)	10.73	29.26%	14.92	45.93%	17.80	60.14%
NO_x (kg)	-704.24	-96.09%	-624.08	-95.61%	-567.88	-95.19%
PM (kg)*	-21.38	-91.63%	-17.69	-90.06%	-14.90	-88.41%

*PM_{10} is regarded as $PM_{2.5}$ in the calculation of PM emission change

Table 10 - Changes in emissions per space-km due to the mode shift from bus to west rail with the bus services operating at different speeds

Emission	Speed					
	30km/h	% change	37km/h	% change	45km/h	% change
CO_2 (g/space-km)	-29.14	-96.92%	-25.65	-96.51%	-23.26	-96.17%
SO_2 (g/space-km)	-0.02	-85.92%	-0.01	-84.08%	-0.01	-82.50%
NO_x (g/space-km)	-0.35	-99.58%	-0.31	-99.53%	-0.29	-99.49%
PM (g/space-km)*	-0.01	-99.24%	-0.01	-99.09%	-0.01	-98.93%

*PM_{10} is regarded as $PM_{2.5}$ in the calculation of PM emission change

Comparing Tables 6 and 7, on the basis of emissions per space-km, the advantage of west rail is clearly evident. Each type of emission has a substantial reduction, of the order 80-90%, as confirmed in Table 10. Of course, the operation of west rail is nowhere near its capacity yet. The per space-km emission measures may over-estimate the actual benefit of west rail for now, and may serve as future measures when the market share of west rail further increases to its capacity. The results, in Tables 8 and 9 together with sensitivity analyses of bus occupancy and speed, show substantial decreases in the emissions of CO_2, NO_x and PM, but increases in the emissions of SO_2. So the modal shift induced by west rail does involve a tradeoff between emission types. To conduct an overall comparison between the two types of public transit services, in the next section, based on studies in the UK, we place monetary valuation for each type of emission, and determine the overall net benefit of introducing west rail as far as emissions are concerned.

4. EMISSION COSTS: RAIL VERSUS BUS SERVICES

There are a number of ways to estimate the monetary costs of exhaust emissions from passenger vehicles. Romilly (1999) summarizes that they can be estimated directly by tracing the links between emission sources and their effects on human health and climate change, then placing a value on these effects; alternatively, they can be estimated through techniques such as hedonic pricing, where emission costs are inferred from observed price in markets such as already existing European Union carbon market, or the revealed preferences of policy-makers, where the inference is based on the costs of meeting emission standards. In practice, data limitations mean that studies of emission costs tend to use a variety of estimation methods, e.g. Small (1977), Krupnik and Portney (1991), Hall et al. (1992), Small and Kazimi (1995), Mayeres et al (1996), Pretty et al (2000), Delucchi et al.(2002), Jensen et al.(2008). In spite of the extensive literature on the monetary costs of air pollution, many empirical results are not appropriate for the purpose of this paper because they are insufficiently disaggregated. The European Commission (2008) recently released a handbook with estimates of external costs in the transport sector. The handbook, jointly prepared by several transport research institutes, summarizes the state of the art as regards the valuation of external costs. However, there is much variation in these external costs among different countries and time scales. For consistency, this paper adopts the external costs used at UK in 2010, which are similar to Hong Kong and disaggregated suitably for the purpose of this study. The external cost used is composed of “Air pollution cost” for NO_x, $PM_{2.5}$, PM_{10} and SO_2 and “Climate change cost” for CO_2. Air pollution cost is generated with consideration of health costs, building and material damages, crop losses in agriculture and impacts on the biosphere, and impacts on biodiversity and ecosystems incurred by pollutant emission. Climate change cost adopted for CO_2 is generated based on avoidance costs, which is the cost required for emission reduction to meet Kyoto targets. These external costs are shown in Table 11.

Table 11 - External cost of vehicle-related emissions (United Kingdom)

Emission	NO_x	$PM_{2.5}$	PM_{10}	CO_2	SO_2
US$/kg	3.12	311.28	124.56	0.02	5.28

Of the emissions accounted for in Table 11, the biggest single source of exhaust emission costs per unit of emission is PM, which is responsible for hundreds of thousands of premature deaths a year. CO_2 emissions have indirect effects on health and the environment via the induced change in global temperature. Although estimates of the monetary costs of CO_2 emissions are subject to considerable uncertainty, the previous studies provide monetary valuations which are of approximately the same magnitude of hundreds of US dollars per ton of carbon. Table 12 shows the net change per day in monetary costs based on the actual emission changes from Tables 8 and 9, while Table 13 shows the net change per space-km at different bus speeds.

Table 12 Daily net change in external cost (US$) by shifting from bus to west rail

Emission	Occupancy level			Speed		
	43/130	65/130	90/130	30km/h	37km/h	45km/h
CO_2 (kg)	-772.13	-388.08	-179.57	-918.40	-772.13	-671.42
SO_2 (kg)	78.75	136.79	168.30	56.65	78.75	93.97
NO_x (kg)	-1,947.13	-1,257.82	-883.57	-2,197.24	-1,947.13	-1,771.78
PM (kg)*	-5,871.05	-3,801.58	-2,678.01	-7,019.01	-5,871.05	-5,001.15
Total	**-8,511.56**	**-5,310.69**	**-3,572.84**	**-10,078.00**	**-8,511.56**	**-7,350.37**

* PM_{10} and $PM_{2.5}$ is distinguished in the calculation of External Cost

Table 13 Net change in external cost (US$) per space-km by shifting from bus to west rail by bus speed

Emission	Speed		
	30km/h	37km/h	45km/h
CO_2 (g/space-km)	-5.83E-04	-5.13E-04	-4.65E-04
SO_2 (g/space-km)	-7.81E-05	-6.75E-05	-6.03E-05
NO_x (g/space-km)	-1.09E-03	-9.72E-04	-8.88E-04
PM (g/space-km)*	-4.07E-03	-3.40E-03	-2.89E-03
Total	**-5.82E-03**	**-4.95E-03**	**-4.30E-03**

* PM_{10} and $PM_{2.5}$ is distinguished in the calculation of External Cost

Table 12 and Table 13 show that the monetary costs decrease substantially as a result of the modal switch from bus to west rail. There are great benefits from PM reduction as PM is regarded as the biggest threat, among the four types of emissions, to human health. However, it seems that the potential damage of GHG (CO_2) is greatly underestimated. The empirical results suggest that the development of railway can lead to substantial reductions in exhaust emissions, especially in the long run, on a space-km basis. Based on the current level of operation of west rail, the rail service led to reductions in CO_2 (kg), NO_x (kg), and PM (kg) but increases in SO_2 (kg). Overall, converting emissions to monetary terms, west rail contributes to an additional benefit of about US$5,000-10,000 per day, or around US$3,000,000 per year. This number may seem small now, relative to the other potential benefit of rail service, such as reductions in traffic congestion, road accidents, etc, but with a higher utilization rate of the rail service, the benefit of rail over bus services will be much more prevalent, as shown in their potential emission reductions on the per space-km basis.

5. CONCLUDING REMARKS

Based on the results of this study, it can generally be concluded that urban rail transit plays an important role in reducing exhaust emissions. Substitution of rail for bus travel in urban areas yields significant monetary benefits, especially in CO_2, NO_x and PM. However, the conclusions reached in this paper are subject to further refinements, especially in the estimation of exhaust emissions and their external costs. The current research however does not consider the investment costs, and the cost-effectiveness of the rail link in reducing emissions. There are definitely other benefits for spatial economy and communication as the introduction of new rail link. It will be a very expensive measure if the only goal was to reduce emissions. There is a need for further research into these issues: Firstly, there in general will be induced trips as the introduction of railway. How do the induced trips affect exhaust emissions? For the time being, the difference in total emissions between west rail and the additional bus services that would be needed to carry the same amount of passengers is a reasonable estimation of the environmental benefit of west rail. Secondly, what are the changes of the occupancy rate and average speed of buses after the introduction of railway? Thirdly, what is the optimal speed for buses if the pollution cost and congestion cost is considered simultaneously? And In a broader framework, how the planning of the urban form and development of mass transit systems would imply on exhaust emissions? These are broader research questions that our further researches focus on.

ACKNOWLEDGMENT

We appreciate the constructive comments of the two referees.

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