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Article in *Research Journal of Applied Sciences, Engineering and Technology* · February 2014

DOI: 10.19026/rjaset.7.400

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Bus Rapid Transit (BRT) System Impacts to Environmental Quality

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Abstract: The aim of this research is to examine the mechanism and performance of Bus Rapid Transit (BRT) system and its impacts on environment quality. Environment quality is an indicator of regional quality of life, supporting the health and well-being of the public and sustainability of the urban and natural environment. Transit agencies are adopting vehicles with alternative fuels, propulsion systems and pollutant emissions controls. One of the ways to improve the transportation environment is through the reduction of BRT emissions to improve air quality. The primary advantage of Bus Rapid Transit (BRT) system is that it can be adapted to a multitude of operating environments, with sufficient scalability to deliver increased carrying capacity to meet future ridership growth. Moreover, the system will also likely reduce overall the noise levels by determining suitable noise management systems. The paper finds that a BRT system offers the greatest potential for greenhouse gas reductions primarily because BRT vehicles generally offer lower CO₂ emissions per passenger mile than other transportation system.

Keywords: Air pollutant, bus rapid transit, environmental quality, transportation, vehicular emissions

INTRODUCTION

Public transportation plays a social role in the urban environment: it improves access to workplaces and service infrastructures and at the same time reduces travel expenses. Moreover, within the context of reducing traffic congestion and greenhouse gas emissions, many people believe that public transportation must play a major role as an alternative to the private car (Brebbia, 2007; Dubé *et al.*, 2011; Rothenberg and Heggie, 1974). Most cities in the developing world are experiencing rapid urbanization, population growth and dispersal of amenities and activities (Zhao, 2010). These have caused an increased demand for and dependence on personal motorized transportation leading to problems such as congestion, accidents, environmental degradation, parking, pollution, stress, noise and urban sprawl (Abane, 2011). The development of sustainable transport options such as Bus Rapid Transit (BRT) systems has witnessed tremendous growth, most notably cities in developing countries. These large, city-wide transportation projects are often central to larger urban revitalization plans intending to foster economic growth and sustainable development (Delmelle and Casas, 2012). BRT is known for modern vehicles, established bus-way and implementations of Intelligent Transportation Systems

(ITS) technologies, is found to be increasingly a cost-effective method for the provision of a high-quality transport service (Deng and Nelson, 2011). BRT vehicles should be carefully selected and designed because of their impacts on travel times, service reliability and operating/maintenance costs; their impacts on the environment; and their identity and appeal to passengers. Bus propulsion systems should be “environmentally friendly” by minimizing air pollution and noise. Conventional diesel buses can reduce emissions by using catalytic converters and ultra-low-sulfur fuel. Other low-pollution options include Compressed Natural Gas (CNG) diesel-electric hybrids, electric trolley buses and dual mode trolley/diesel propulsion (Herbert *et al.*, 2003). Therefore, this research focuses on the reduction of emissions of air pollutants from Bus Rapid Transit (BRT) systems and its direct impact on urban environments.

ENVIRONMENTAL QUALITY

Environmental quality is an indicator of regional quality of life, supporting the health and well-being of the public and the attractiveness and sustainability of the urban and natural environment. There are three potential environmental improvement mechanisms as a result of the implementation of BRT in a corridor (Cham *et al.*, 2006):

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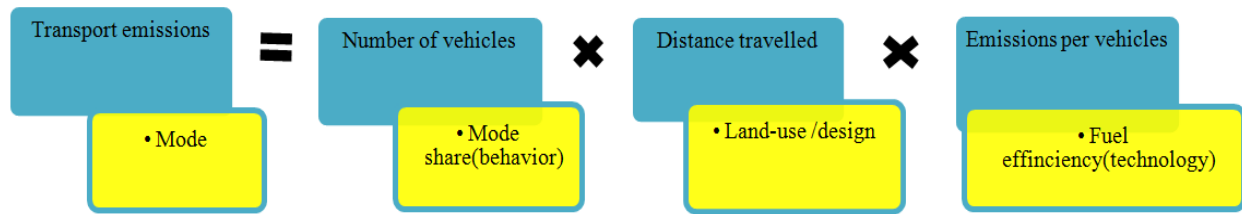


Fig. 1: Calculation of transport emissions for an individual mode

- **Technology effect:** Reduced corridor bus emissions due to the propulsion technology
- **Ridership effect:** Trips diverted from private vehicles which increase transit ridership
- **System effect:** Reduced vehicle emissions from reduced corridor congestion

Documentation of the environmental impacts of BRT systems is rare. Experience has shown that there is improvement of environmental quality due to a number of factors. Ridership gains suggest that some former automobile users are using transit as a result of BRT implementation. Transit agencies are serving passengers with fewer hours of operation, potential reducing emissions. Most importantly, transit agencies are adopting vehicles with alternative fuels, propulsion systems and pollutant emissions controls (Hinebaugh and Diaz, 2009). BRT vehicles can be propelled by electricity, but more commonly utilize natural gas or clean diesel fuels. The amount of emissions from natural gas or clean diesel vehicles depends upon many factors including local geographic and topological features, fuel quality and driving behavior (Wright and Fjellstrom, 2003). All transit options produce environmental impacts when displacing journeys that would be otherwise taken by individual motorized transport. Thus, the amount of expected ridership and the number of persons switching from private vehicles to public transit is a significant determinant in calculating environmental benefits. The ability of mass transit systems to encourage private vehicle users to switch to transit depends on many factors, most notably cost and service performance. The convenience of private vehicle use gives a difficult competitive environment for transit. However, research in Bogotá indicates that approximately 10% of former vehicle users have now switched to the TransMilenio BRT system (Gleave, 2003). Public transport and non-motorized transport (walking and cycling) still command a dominant share of travel in developing cities. To understand the relative importance of behavioral (mode share) and land-use measures relative to technology measures in reducing greenhouse gas emissions, an appropriate analytical framework is needed. As noted in Fig. 1, all three elements (behavior,

land-use and technology) have a basic role to play in determining overall emission levels (Wright, 2004). Vehicle emissions are a major contributing factor to poor air quality. Key emissions from vehicles include Carbon monoxide (CO), unburned Hydrocarbons (HC) and Volatile Organic Compounds (VOC), Nitrogen Oxides (NO_x), Sulphur Oxides (SO_x) and Particulate Matter (PM). The potential indicators for evaluating the environmental impact of the system include: Levels of local air pollutants (CO, NO_x, SO_x, PM, Toxics), Emissions of greenhouse gases (CO₂, CH₄, N₂O), Noise levels, Number of older buses retired from service.

ENVIRONMENTAL PERFORMANCE

The main elements of environmental performance are emission standards and noise as explained below:

Emission standards: From an emissions standpoint, there is no one clear solution that is necessarily superior to another. In some instances, a fuel may emit less of one type of pollutant but more of another type of pollutant. For example, CNG may do well in terms of reducing particulate emissions, but can end up emitting more greenhouse gas emissions than even a diesel option. Some fuels may produce less local emissions but will produce more total emissions when the full fuel cycle is considered. For example, electric vehicles and hydrogen-fuelled vehicles may produce zero emissions at the tailpipe, but the emissions generated at the power-plant or through the hydrogen generation process can be quite substantial. Bio-fuels may seem to be net-zero producers of greenhouse gases, but agricultural practices can mean that soil-related emissions are quite high. Some fuels may work well in ideal conditions but are more polluting in circumstances when maintenance and road conditions are poor (Krzyżanowski *et al.*, 2005). The principal impacts of motorized vehicle emissions are: Health impacts, including respiratory illness, cardiovascular illness and cancer, Economic impacts, including absenteeism and reduced productivity, Impacts on the built environment (e.g., damage to buildings), Impacts on the natural environment (e.g., harm to trees and vegetation). Figure 2 to 4 illustrate that the propulsion technologies

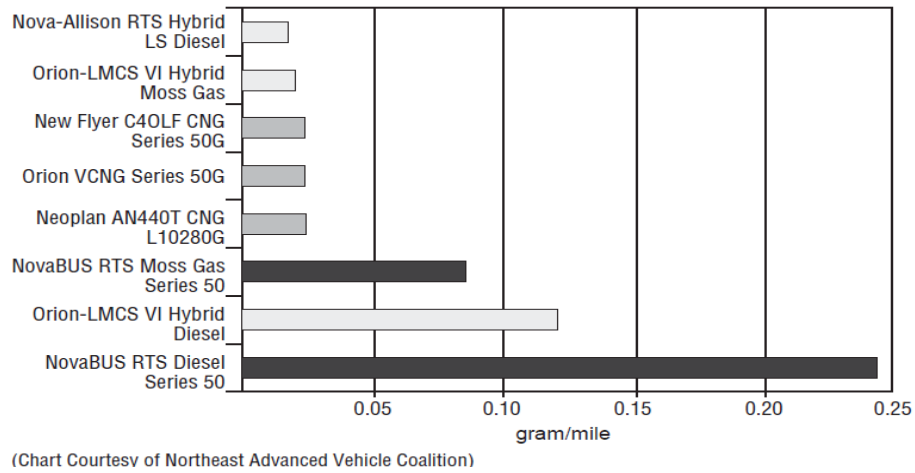


Fig. 2: Particulate emissions for various propulsion system types (Krzyżanowski *et al.*, 2005)

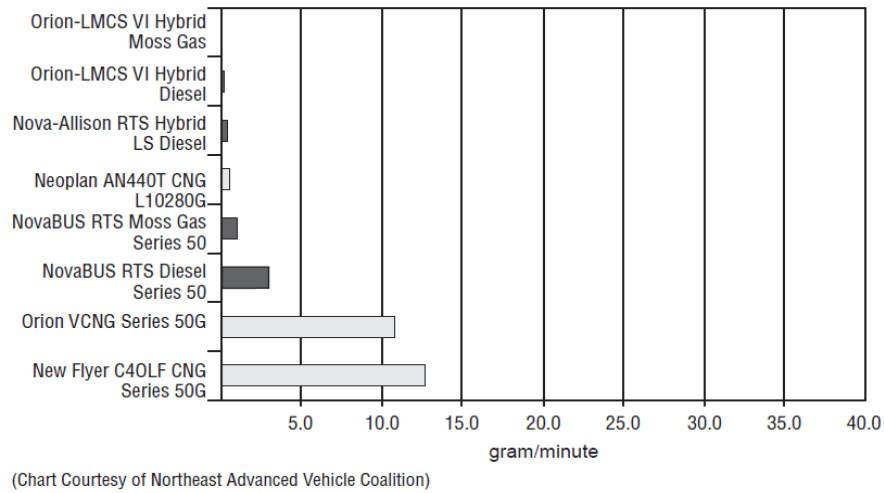


Fig. 3: Carbon monoxide emissions for various propulsion system types (Krzyżanowski *et al.*, 2005)

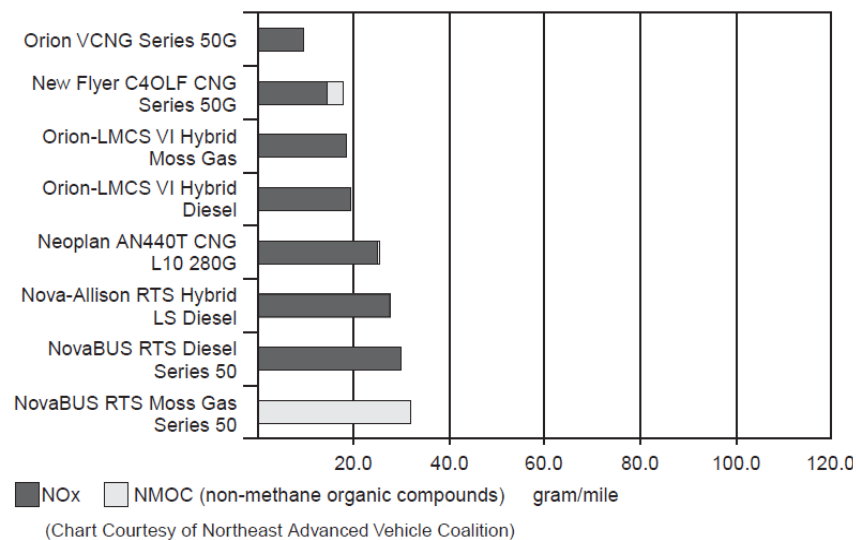


Fig. 4: Ozone precursor emissions (hydrocarbons, NO_x) for various propulsion system types (Krzyżanowski *et al.*, 2005)

Table 1: Energy contents of fuels

| Fuels | Energy contents |
|-------------------------|-------------------------|
| Hydrogen | 11 MJ/m ³ |
| Ethanol | 21 MJ/L |
| Liquefied Petroleum gas | 24 MJ/L |
| Petrol | 32 MJ/L |
| Bio-diesel | 33 MJ/L |
| Natural gas | 33-38 MJ/m ³ |
| Diesel | 36 MJ/L |

increasingly being found on specialized BRT vehicles and high-end conventional buses (e.g., CNG and clean diesel hybrids) have lowered emissions for all pollutant types dramatically over the last 10 years. Diesel hybrids using low-sulphur fuels and continuously regenerating technologies (i.e., catalytic converters) reduce particulate emissions to virtually undetectable levels and hydrocarbon ozone precursors by 70%; they also provide significant improvement in fuel economy, upwards of a 30% increase. Clean diesels using low-sulphur fuel and catalytic converters are not expected to cost significantly more to purchase when they go into more widespread use. They will likely only cost a few cents more per mile to operate (slightly higher fuel costs) than current conventional diesel engines and have similar reliability levels. The low-sulphur diesel fuel needed for the cleanest clean diesel buses-those with after-burning, self-cleaning catalytic converters-is currently available only in some U.S. locations today. The energy contents of fuels as summarized in Table 1 (Krzyżanowski *et al.*, 2005; Schipper and Fulton, 2002).

Wöhrnschimmel *et al.* (2008) evaluate the BRT system's impact on commuters' exposure to these air

pollutants. The BRT system replaced conventional transport modes new articulated diesel buses. The implementation of the BRT system resulted in reductions in commuters' exposure to CO, benzene and PM 2.5 ranging between 20 and 70%. The results suggest that BRT systems could in general be an effective means of reducing human exposure to traffic related air pollutants and associated health impacts (Wöhrnschimmel *et al.*, 2008). In this globally important context, a preliminary analysis has been conducted by the Istanbul Public Transport Authority to estimate the CO₂ emission and fuel consumption reduction achieved by the Metrobüs system as listed below (Alpkokin and Ergun, 2012):

- Reduced vehicle-km by the removal and re-organization of the conventional buses amounts to 125 ton CO₂/day
- Reduced vehicle-km by the removal and re-organization of the intermediate forms of public transportation amounts to 42 ton CO₂/day
- The average daily fuel consumption saving amounts to 242 ton-L/day

Imam and Jamrah (2012) investigated in their research twenty case studies from fifteen cities, in both Northern and Southern Europe, who have adopted BRT as a transport mode. Figure 5 emphasizes the gap between the two emission values estimated. Overall, the BRT emissions ranged between 11 and 85% of the passenger car emissions.

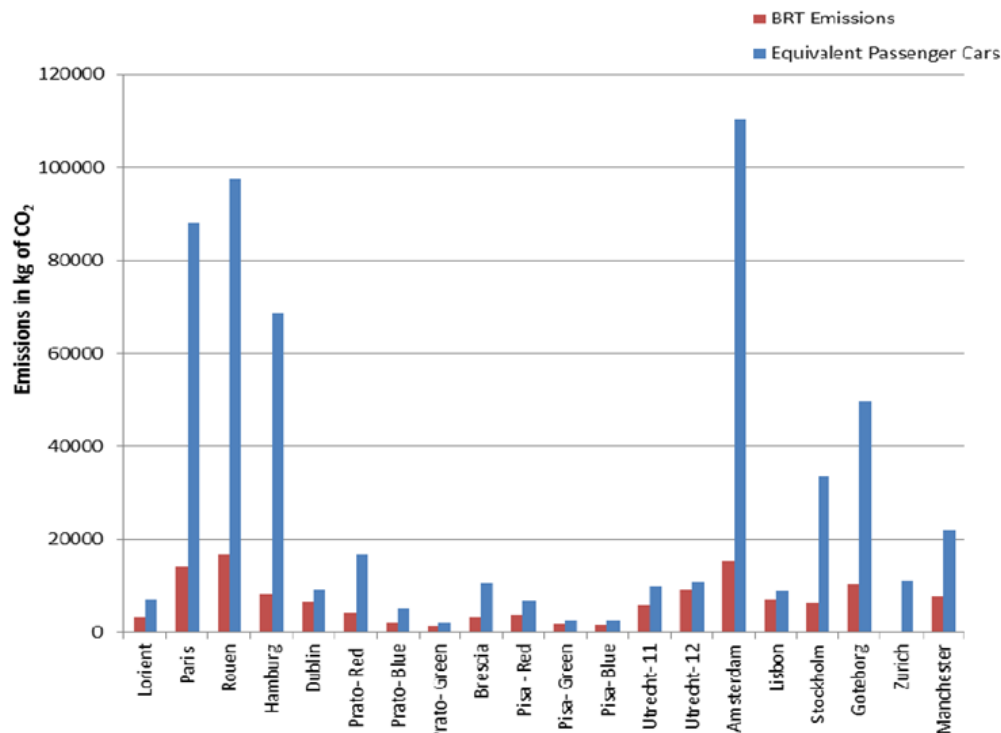


Fig. 5: Daily emissions of the BRT and the equivalent passenger cars (Imam and Jamrah, 2012)

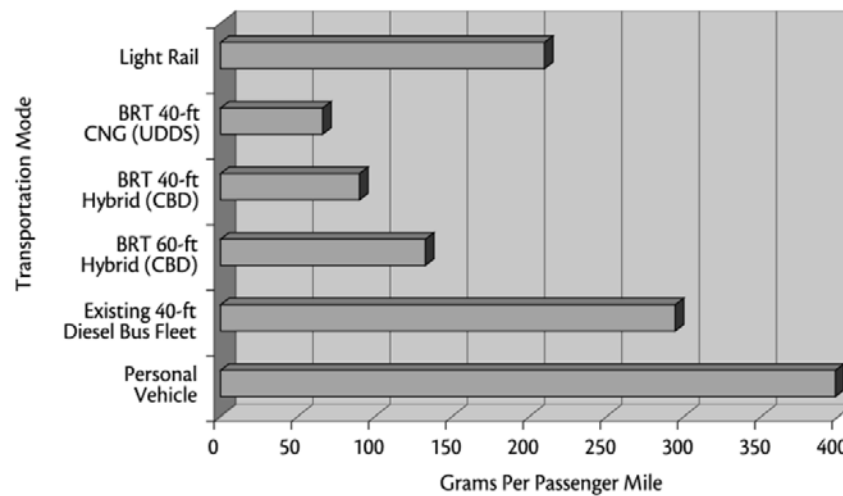


Fig. 6: CO₂ emissions per passenger mile for all transportation modes (Vincent and Jerram, 2006)

Vincent and Jerram (2006) compared the expected CO₂ emissions from three scenarios by 2011: a no-build option that relies upon private automobiles and a diesel bus fleet; building a Light Rail (LRT) system; and building a BRT system using 40 or 60-ft low emission buses. Figure 6 shows the effects of CO₂ Emissions per Passenger Mile for All Transportation Modes.

Noise: Acceptable noise levels should also be specified within the bus procurement specifications. Excessively loud vehicles are both a health hazard as well as a detriment to the marketing image of the transit service. Noise levels are determined by several variables including: Fuel and propulsion system technology, Design of propulsion system, Size of vehicle relative to engine size, Dampening technologies and exhaust system employed, Quality of road surface and Maintenance practices. BRT helps reduce vehicle noise by: replacing 4 to 5 mini-buses with a larger transit vehicle; using quieter engine technologies; managing the system to produce “smoother” vehicle operations; Employing noise dampening devices; and, encouraging mode shifting from private vehicles to public transport.

ENVIRONMENTAL IMPACTS

The true impact of BRT is not simply the physical system but rather the improvements that it creates in people’s lives. Evaluating the expected impacts on traffic levels, economic development, environmental quality, social interactions and urban form all help determine whether the BRT system will add real value. Public transport projects typically bring positive environmental impacts through the reduction of private vehicle use and subsequent associated emissions.

Quantifying the expected environmental benefits of the BRT project can help to justify the project as well as strengthen the image of the initiative with the public. As a major project, an Environmental Impact Assessment (EIA) is likely to be required. The expected reduction in vehicle emissions will likely be the principal benefit. However, the system will also likely reduce overall noise levels as well as the release of both liquid and solid waste products. The construction process itself can be disruptive and lead temporarily to some increases in emissions. However, by calculating emission reduction benefits across the life of the BRT project, the overwhelming evidence to date suggests that BRT can markedly improve the state of the urban environment.

One of the main elements of BRT system is Running Way (RW). RW should allow rapid and reliable movement of buses with minimum traffic interference and provide a clear sense of presence and permanence. The basic goal of a running way is to give BRT an operating environment where buses are free from delays caused by other vehicles and by certain regulations and to provide transit riders with better, more reliable service. BRT systems should therefore be considered as a cleaner and less hazardous alternative (from the health point of view) to conventional public transport systems, especially in the quickly growing cities of developing countries. At the same time, a proper maintenance of conventional transport modes should be ensured to reduce commuters’ exposures (Wöhrnschimmel *et al.*, 2008).

ENVIRONMENTAL IMPROVEMENT MECHANISMS

BRT system improves environmental quality by reducing pollution caused by the transportation system

Table 2: Environmental improvement mechanisms

| Pollution reduction mechanism | Sources of pollution reduced | Objective | Significance of impact |
|-------------------------------|--|--|--|
| Technology effect | BRT vehicle emissions | Reduce direct BRT vehicle pollution by using: <ul style="list-style-type: none"> • Larger (and fewer) vehicles • Propulsion systems, fuels and pollution control systems with less emissions | Moderate and immediate |
| Ridership effect | Emissions from trips using automobiles rather than transit | Attract riders to BRT through improved performance: <ul style="list-style-type: none"> • Travel time savings • Reliability • Brand identity • Safety and security | High-on a passenger-mile basis, public transportation produces approximately 90% less volatile organic compounds, 95% less carbon monoxide, and nearly 50% less nitrogen oxides and carbon dioxide than identical trips using private automobiles (Shapiro <i>et al.</i> , 2002) |
| System effect | Vehicle emissions from congestion | Direct-reduce conflicts between BRT vehicles and other traffic to reduce emissions from all vehicles Indirect-attract riders to BRT to reduce overall system congestion | Moderate-models have estimated the reduction of overall regional vehicular emissions from reducing both transit emissions and vehicle emissions through reduced congestion to be on the order of several percent (Darido, 2001) |

| BRT Element | Design Variables | Technology Effect | Ridership Effect | System Effect |
|-----------------------------|-----------------------------------|-------------------|------------------|---------------|
| Running Ways | Running Way Segregation | | X | X |
| | Running Way Marking | | X | |
| | Guidance | | X | |
| Stations | All | | X | |
| Vehicles | Vehicle Configuration | X | | |
| | Aesthetic Enhancements | | X | |
| | Passenger Circulation Enhancement | | X | |
| | Propulsion System | X | | |
| Fare Collection | All | | X | |
| ITS | Vehicle Prioritization | | X | X |
| | Driver Assist and Automation | | X | |
| | Operations Mgmt. | | X | X |
| | Passenger Information | | X | |
| | Security Monitoring | | X | |
| Service and Operations Plan | Route Length | | X | X |
| | Route Structure | | X | X |
| | Service Span | | X | X |
| | Service Frequency | | X | X |
| | Station Spacing | | X | X |

Fig. 7: Potential environmental impact of BRT elements (Hinebaugh and Diaz, 2009)

through three distinct, yet cumulative, mechanisms, which are presented in Table 2.

BRT system design effects on environmental quality:

In Exhibit 5, each BRT design variable is classified according to which mechanism of pollution reduction it affects (Fig. 7).

CONCLUSION

The emission calculations highlight the huge savings achieved when using the BRT, as opposed to individual motorized transport in the form of passenger cars. Overall, the BRT emissions of the systems considered ranged from 11 to 85% of their corresponding equivalent passenger car emissions. In conclusion, with the continuing rise in traffic congestion levels, a backlog of infrastructure needs and renewed environmental concerns, more and more focus is given to public transportation and new technologies that enhance the performance of transit systems. BRT is

considered one of the promising high-performance, cost effective solutions that provide high quality services to the users. From these findings we conclude that commuters' exposures to air pollutants during commuting could be effectively reduced by BRT systems, mainly by reducing the penetration of emissions from surrounding traffic. Other possible areas for further analysis would be to calculate non-CO₂ emissions which are the main contributors to climate change; like Nitrogen Oxides (NO_x), Sulphur Oxides (SO_x) and particulate matter. An area for further research would be to add an exposure model that includes not only the absolute amounts of emissions but also the exposure of these emissions to the population. Measurements of gaseous pollutants and particulate matter could be taken at different distances from the BRT corridors for development of exposure models for these emissions. The paper finds that BRT offers the greatest potential for greenhouse gas reductions, primarily because BRT vehicles generally offer lower CO₂ emissions per passenger mile than other

transportation system. Lower capital costs for BRT infrastructure would enable cities to build more BRT for a given budget, increasing opportunities to shift commuters to public transit.

ACKNOWLEDGMENT

The authors would like to express appreciation to the UKM's Sustainable Urban Transport Research Centre (SUTRA) /Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia for providing facilities to conduct this study.

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