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Terrianna O'Briette Christia Selby

Congestion, Kingston and Rio de Janeiro: Methods for Understanding and Estimating

Dissertação de Mestrado

Dissertation presented to the Programa de Pós-Graduação em Engenharia Urbana e Ambiental of PUC-Rio in partial fulfillment of the requirements for the degree of Mestre em Engenharia Urbana e Ambiental

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Advisor: Prof.Celso Romanel

Coadvisor: Prof. Fernando Mac Dowell da Costa

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Prof. Celso Romanel
Advisor
Departamento de Engenharia Civil e Ambiental – PUC-Rio

Prof. Nelio Domingues Pizzolato
Departamento de Engenharia Industrial – PUC-Rio

Prof. Paulo Cezar Martins Ribeiro
Universidade Federal do Rio de Janeiro

Izabella Kraichete Lentino
Ministério Público do Estado do Rio de Janeiro

Rio de Janeiro, December 17th, 2019

Terrianna O'Briette Christia Selby

Bachelor of Science in Environmental Sciences by the University of Guyana, 2011 and Post Graduate Diploma in Urban Planning and Management, by the university of Guyana, 2013; Currently works at the Embassy of Brazil in Jamaica, as a "Commercial and Trade Promotion Officer" in charge of sourcing, logistics and research.

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Abstract

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The paper identified and assessed methods to quantify and model congestion, emissions of pollutants and exposure through literature reviews, interviews and estimations. Focus was placed on studies by Toledo. (2011), and Linton et.al, (2015), models like COPERT and MOVES (USEPA) and on methodologies like the IPCC guidelines, which can be modified and applied to Latin American and Caribbean (LAC) countries. Molynes Road in Kingston, Jamaica and the Lagoa-Barra Highway to Zuzu Angel Tunnel complex in Rio de Janeiro city, Brazil, were compared to assess congestion and emissions. Total emissions of CO_2 and CO_2 per passengers, were calculated for Jamaica under three assumed scenarios, at emission totals of 2.62×10^9 kg of CO_2 (gasoline) and 3.09×10^9 kg of CO_2 (diesel), based on data extrapolations and work by Abbas. (2014). Time lost as a result of congestion, expressed as USD/hr was calculated for both thoroughfares under four speed scenarios and utilising the free-flow form of the thoroughfares for comparison. As expected, results indicated higher incurred costs with reduced travelling speeds (-731.7 USD/hr for Molynes Road and -1,131.2 USD/hr for the Lagoa-Barra Highway into the Zuzu Angel Tunnel Complex at 10km/hr). Interviews were conducted with operators of the transportation sector, including informal actors; social repercussions of urban transportation policies were discussed and social costs were calculated and described. Critiques and calculations allowed for the identification of weaknesses within the transportation sector and provided the basis for predictions and recommendations to be made.

Keywords

Congestion; Urban Transportation; Air Pollution; Emissions; Informality.

Resumo Estendido

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INTRODUÇÃO

Em cidades e centros urbanos do mundo, em especial nos países em desenvolvimento, existem tendências ao forte crescimento da população, que se transfere para esses centros em busca de melhores condições de vida. Nas últimas décadas, entretanto, esse crescimento tem sido acompanhado pela expansão excessiva do número de veículos automotores, o que gera cada vez maiores congestionamentos em suas precárias infraestruturas viárias, em especial nas horas de pico. Kunzli et al. (2000) observaram que, como fonte principal de emissões de partículas primárias (PM) e precursores de PM secundário, o tráfego contribui substancialmente para o impacto geral da poluição do ar. Essa alta contribuição deve-se ao fato das densidades de emissão do tráfego serem, em média, mais altas nas áreas povoadas. A combinação de áreas densamente povoadas e a alta poluição do ar exterior são motivo de preocupação.

A USEPA (United States Environmental Protection Agency) observou, em seu estudo para caracterizar PM2.5 (material particulado fino com diâmetro 2,5µm), que um dos problemas mais prementes enfrentados por áreas urbanas é o da deterioração da qualidade do ar, com as fontes móveis sendo as principais contribuintes para emissões gasosas liberadas para a atmosfera em centros urbanos. Além disso, os poluentes como o monóxido de carbono (CO), dióxido de carbono (CO2), óxidos de nitrogênio (NOx), compostos orgânicos voláteis (COV) e óxidos de enxofre (SOx) são de extrema importância por causa dos seus impactos ambientais e impactos na saúde. Dos poluentes emitidos por fontes móveis, partículas finas têm grandes impactos na saúde, clima e visibilidade.

A poluição atmosférica contribui para aumento da morbidade e mortalidade humanas. Porém é necessário estudar a extensão dos efeitos na saúde, especialmente considerando as variações entre centros urbanos (Kunzli et al., 2000; Shabbar Ali et al., 2013). Alguns efeitos negativos se manifestam com exposição a curto prazo, como falta de ar, olhos ardentes, sonolência, tosse, entre outros, ou com exposição a longo prazo, que apresentam maiores complicações e uma variedade de sintomas. A avaliação da exposição individual a poluentes pode representar um desafio para estudos epidemiológicos. Dessa forma, tornam-se necessárias abordagens alternativas para ilustrar os relacionamentos e incentivar pesquisas futuras.

Modelos são excelentes quando estimar todas as facetas de exposição a um evento torna-se inviável ou impossível. Modelos que correlacionem poluentes e emissões a efeitos na saúde podem ser classificados como de proximidade, de interpolação, de regressão do uso da terra, de dispersão, integrados de emissão meteorológica e híbridos (Jerrett et.al, 2005), em ordem crescente de complexidade.

Os modelos híbridos exigem idealmente o uso de tecnologias de monitoramento pessoal juntamente com outras técnicas para modelar emissões e exposição e identificar possíveis problemas adversos de saúde. Este tipo de modelo permite investigar a exposição que um indivíduo pode sofrer ao longo de uma trajetória. Além disso, como emissões e poluição em túneis podem ser negligenciadas, o uso desses dados como linha de base é essencial para entender o que pode resultar de estradas congestionadas e uma melhor compreensão dos efeitos de um túnel congestionado.

Atualmente, pelo conhecimento desta autora, não há estudo comparando congestionamento e emissões entre uma grande cidade sul-americana e uma grande cidade caribenha. Embora seja um documento introdutório para futuros estudos comparativos mais aprofundados, procurou-se nesta dissertação delinear semelhanças entre essas cidades (Rio de Janeiro e Kingston), questionar sistemas e políticas e alertar futuros pesquisadores quanto a possíveis bloqueios rodoviários na aquisição de dados.

OBJETIVOS

O objetivo central do estudo foi comparar o setor de transporte urbano do Rio de Janeiro, RJ, Brasil e Kingston, Jamaica, a partir do congestionamento, emissões de fontes móveis, possíveis efeitos negativos na saúde de usuários e residentes, e outros impactos na sociedade. Para esclarecer a questão central, quatro objetivos principais foram identificados, a saber:

1. Descrever e analisar o perfil urbano de Kingston e do Rio de Janeiro e de uma via principal de cada cidade;
2. Estimar custos sociais do congestionamento nas vias;
3. Propor metodologia, com base na literatura, para estimar e comparar emissões urbanas em vias de países semelhantes da América Latina e do Caribe;
4. Estudo de caso: identificar e descrever os problemas atuais do Túnel Zuzu Angel e a necessidade de estudos e atualização.

MEDOTOLOGIA

Entrevistas foram feitas com motoristas de veículos que atuam no segmento de transporte público em Kingston, Jamaica. As entrevistas foram conduzidas de 30 de maio ao dia 9 de junho de 2017 com motoristas aleatórios e, no dia 12 junho, em um dos pontos de reunião dos motoristas ao longo da Rua Molynes. Quinze perguntas foram feitas na pesquisa, com foco em congestionamento, uso de combustível, seguro e acidentes. A participação no estudo foi completamente voluntária e a identidade dos motoristas não foi revelada de nenhuma forma, somente foi feita a especificação da marca, modelo e ano do carro. Essa informação foi utilizada nos cálculos dos impactos socioeconômicos de congestionamento em Kingston.

Informações sobre modelos e metodologias para medir e modelar congestionamentos, emissões de fontes móveis, poluição atmosférica e riscos à saúde devido a poluentes emitidos, foram adquiridos com base na literatura técnica disponível. Dados sobre programas de monitoramento de poluição atmosférica e emissões de fontes móveis nas cidades de Rio de Janeiro, Brasil, e Kingston, Jamaica, foram coletados de ministérios e agências dos respectivos governos. Outras informações sobre transporte urbano de passageiros, suas frotas, e o perfil e o uso de combustível nas duas cidades, também foram obtidas de ministérios, agências, reportagens de jornais e observações pessoais da investigadora.

Durante o período de estudo nas duas cidades, a investigadora fez uso do transporte urbano formal e informal nas duas cidades. No Rio de Janeiro, os estudos e as observações foram conduzidas de fevereiro de 2014 a setembro de 2015, e em Kingston de fevereiro de 2016 a junho de 2017.

RESULTADOS E DISCUSSÃO

A pesquisa identificou e avaliou métodos para quantificar e modelar congestionamento, emissões de poluentes e exposição a poluentes através da análise da literatura, entrevistas e estimativas. O foco foi em estudos realizados por Toledo (2011) e Linton et al, (2015), modelos como COPERT e MOVES (USEPA) e metodologias, incluindo as diretrizes do IPCC, que podem ser modificadas e aplicadas aos países da América Latina e Caribe (ALC).

Molynes Road em Kingston, Jamaica e o túnel Zuzu Angel na Autoestrada Lagoa-Barra na cidade do Rio de Janeiro foram comparados para avaliar congestionamento e emissões. As emissões totais de CO2 e de CO2 por passageiro foram calculadas para a Jamaica sob três cenários assumidos, resultando em totais de emissão de 2,62 x 109 kg de CO2 (gasolina) e 3,09 x 109 kg de CO2 (diesel), com base em extrapolações de dados e em trabalhos de Abbas (2014). O tempo perdido como resultado do congestionamento, expresso em USD / h foi calculado para ambas as vias sob quatro cenários de velocidade e utilizando a forma de fluxo livre das vias a serem comparadas. Como esperado, os resultados indicaram maiores custos associados com velocidades reduzidas (-731,7 USD / h para Molynes Road e -1.131,2 USD / h na Autoestrada Lagoa-Barra, no Complexo do Túnel Zuzu Angel, a 10 km / h).

Foram realizadas entrevistas com operadores do setor de transporte, incluindo atores informais; as repercussões sociais das políticas de transporte urbano foram discutidas e os custos sociais foram estimados e descritos. Avaliações permitiram a identificação de pontos fracos no setor de transporte e forneceram a base para previsões e recomendações.

Tanto Kingston como Rio de Janeiro consideram questões relacionadas com o transporte urbano, monitoramento da qualidade do ar e abastecimento de combustível. Embora difiram em escalas de tamanho, ambas têm motivo de preocupação quando se trata de emissões de fontes móveis e estacionárias. Isso levou a considerações e manuais integrados sobre as emissões de transporte urbano e o monitoramento de alguns túneis críticos no Rio e o reconhecimento da necessidade de padrões de emissão móvel em Kingston. Além disso, ambas as cidades dividiram a responsabilidade da qualidade do ar e monitoramento de emissões com indústrias chave que contribuem significativamente para emissões estacionárias de poluentes. No que diz respeito ao combustível e ao seu abastecimento, não parece haver restrições à aquisição e produção de quantidades e produtos suficientes, para atender às demandas, tanto da companhia de petróleo jamaicana Petrojam ou da brasileira Petrobras.

Em Kingston, se a Autoridade de Transportes (Transport Authority) analisar adequadamente as principais questões relativas ao setor de transporte, como a legalização de motoristas informais e criação de novas linhas e rotas de ônibus, então um posicionamento mais forte contra táxis robôs (robot taxis) poderia ser esperada por parte dos usuários de transporte. Uma melhor compreensão de transporte urbano leva a um melhor fluxo de tráfego, sistemas e políticas.

No Rio, as mudanças de transporte urbano iniciadas em 2014 foram feitas para modernizar o transporte na cidade mas, na realidade, resultaram em ônibus BRT cheios, perda de rotas, transições de transporte incompletas (entre ônibus e outros modos de transporte) e aumentos de tarifas. O público, em essência, parece estar pagando mais para receber menos. Com menos áreas cobertas por ônibus, frota de ônibus diminuída, menos continuidade de viagens e muitos ônibus ainda sem ar condicionado, existem sérias questões que devem ser examinadas e resolvidas pela Secretaria de Transportes do Rio.

As pessoas desfavorecidas em ambas cidades são as que vivem mais longe. Menos rotas significam vários modos de transporte para chegar ao mesmo destino. Como resultado, os menos afortunados precisam fazer maiores sacrifícios do seu tempo e de seus salários para continuarem trabalhando ou estudando em certas áreas. É necessário um melhor planejamento que considere passageiros que têm uma maior dependência dos sistemas de transporte público e, geralmente, sofrem o peso de políticas e regulamentos ineficazes.

O monitoramento da poluição do ar deve continuar a ser de interesse para agências locais, com melhorias nos regulamentos e técnicas de monitoramento para responder aos aumentos no número de veículos, de emissões e as possíveis repercussões negativas para a saúde. A Prefeitura do Rio deve fazer maiores esforços para incentivar estudos dos seus túneis e vias altamente congestionadas, bem como a eventual implementação de estações de monitoramento nessas áreas. As agências de transporte e saúde ambiental de Kingston devem criar padrões adequados que avaliem e monitorem fontes móveis de poluição. Uma vez que os padrões e os efeitos das emissões sejam bem compreendidos, devem ser tomadas medidas para abordar as preocupações existentes com as vias públicas, o tráfego e a saúde.

CONCLUSÕES

O transporte público deve oferecer alternativas de mobilidade confiáveis para aqueles que trabalham ou estudam em áreas distantes de suas casas e que não possuem seu próprio modo de transporte. É importante que os formuladores de políticas e as agências de transporte se concentrem na criação de regulamentos que ajudem a trazer maiores benefícios aos que mais necessitam de transporte público.

A Jamaica e o Brasil já possuem estações de captura de emissões e possuem sistemas para monitorar esses dados. Recomenda-se que sejam realizados estudos periódicos considerando as emissões e os efeitos na saúde. É importante que todos os países criem e atualizem bancos de dados de sua frota de veículos, uso de combustível, quilometragem percorrida por veículos, total de passageiros e emissões de poluição atmosférica e que disponibilizem esses dados para pesquisas futuras.

Este estudo mostrou que é possível comparar questões urbanas nos países da América Latina e do Caribe, especialmente quando se consideram complicações decorrentes de cidades em crescimento acelerado, uma vez que os paralelos estão claramente identificados e em contextos compartilhados. Questões urbanas não estão isoladas; elas permeiam a vida cotidiana das pessoas na forma de congestionamentos de trânsito, doenças, aumento da poluição do ar e do estresse.

A informalidade no setor de transporte provavelmente crescerá se as necessidades da população não forem adequadamente consideradas. Consultas das partes interessadas são importantes e todos os participantes devem ser igualmente considerados. Se às pessoas não são oferecidas alternativas aos serviços de transporte informais, muitas vezes precários e perigosos, esses atores informais continuarão a existir e prosperar às expensas de uma melhor qualidade de transporte público. Onde se manifesta uma necessidade, haverá sempre um caminho e pessoas dispostas a se beneficiar dessa necessidade. Medidas extremas como a remoção de rotas, que forçam pessoas a aumentar seu tempo de deslocamento para o trabalho e as obriga a buscar alternativas mais radicais, não produzem benefícios a longo prazo, bem ao contrário. Por essa razão, gestores urbanos e agências públicas de transporte devem adquirir amplo conhecimento a respeito dos desafios enfrentados pelo morador de grandes cidades.

Planejar questões urbanas, projetar e construir sistemas físicos e políticos adequados continuará sendo relevante à medida que cidades crescem em todo o mundo. Embora o congestionamento seja difícil de definir e medir, é entendido pela experiência de longos atrasos, dificuldades em deslocamento, emissões móveis e efeitos resultantes na saúde. Esses problemas devem ser identificados, monitorados e projetos para diminuir seus efeitos precisam ser desenvolvidos. Só é possível planejar adequadamente o que é entendido. Para entender, é necessário experimentar, avaliar, medir e ponderar soluções.

Palavras-chave

Congestionamento; Transporte Urbano; Poluição do ar; Emissões; Informalidade.

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List of Abbreviations and Acronyms

ACRONYM	FULL NAME
AQMS	Air Quality Monitoring Station
BI	Buffer Index
CCD	Calculated Cost of Delay
CLD	Causal Loop Diagrams
CO	Carbon Monoxide
CO2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
COPERT	Computer Program to Calculate Emissions from Road Transport
EF	Emission Factor
EMEP/EEA -	European Monitoring and Evaluation Programme / European Economic Area
EMISIA -	EMISIA SA is an environmental research company that also provides the COPERT range of products
GHG	Greenhouse Gases
GIS	Geographic Information System
GPG	Good Practice Guidance
HWT TC	Half Way Tree Transport Centre
I&M	Inspection and Maintenance
IAMs	Integrated Assessment Models
IPCC	Intergovernmental Panel on Climate Change
JUTC	Jamaica Urban Transit Company
KMR	Kingston Metropolitan Region
LAC	Latin America and the Caribbean
MME	Ministry of Mining and Energy, Brazilian
MOBILE	Mobile Source Emission Model
MOVES	Motor Vehicle Emission Simulator (MOVES)
MT	Maximum Throughput
MTM	Ministry of Transport and Mining, Jamaica
N2O2	Hypoxic Gas Mixture
NEPA	National Environment and Planning Agency
NMHC	Non-methane Hydrocarbons

NMVOC -	Non-methane Volatile Organic Compounds
NO	Nitrogen Oxide
NO2	Nitrogen Dioxide
NO3	Nitrate
NOx	Nitrogen Oxides
PM	Particulate Matter
PM10	Inhalable particles, with diameters that are generally 10 micrometers and smaller;
PM2.5	Fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller.
PNC	Particle Number Concentrations
PPV	Public Passenger Vehicles
PTI	Planning Time Index
RCHO	Aldehydes
SO2	Sulphur Dioxide
SO3	Sulphur Trioxide
SOx	Sulphur Oxides
TAG	Temporally Adjusted Geostatistical Model
TAJ	Tax Administration Jamaica
TD	Total Delay
TTI	Travel Time Index
TTR	Travel Time Reliability
TV	Traffic Volume
UNFCCC	United Nations Framework Convention on Climate Change
USDT	United States Department of Transportation
USEPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
VTM	Vehicle Miles Travelled

1. Introduction

Congestion, although hard to define and measure can present considerable drawbacks to those who work, commute and reside within influence areas of thoroughfares with repeated traffic build-up. While "dynamic, affordable, liveable and attractive urban regions will never be free of congestion"[1] there is a need to better understand its causes and effects, from planning adequate road infrastructure in urban areas to understanding why commuters choose certain routes over others. The social effects of congestion can be inferred as: the loss of productive time and quality of life; the increase in fuel consumption, vehicle operation and maintenance costs; incident risk, air pollution and GHG emissions which are harmful to health and the environment[2]. Mac Dowell (2013) in The Green Cities 2013 report supports this idea by stressing that

> traffic congestion is manifested in environmental aggression, impacts on vehicle occupants, an increase in operation and maintenance costs and an increase in travel time for its users

Thus, congestion is a systemic problem requiring solutions.

In many cities and urban centres worldwide there have been trends of population expansion and increase, increased average kilometres travelled by vehicles, and increased vehicular ownership rates. These trends have resulted in over-congestion of surface roads and other structures, such as tunnels, during peak hours. Kunzli et al. (2000) noted that, as a major source of both primary particulate matter (PM) emissions and precursors of secondary PM, traffic substantially contributes to the overall impact of outdoor air pollution. Further, this high contribution is due to the emission densities of traffic being, on average, highest in populated areas. The combination of densely populated areas and high outdoor air pollution is a cause for concern.

The USEPA noted, in A Study to Characterise PM2.5, that one of the most important problems faced by urban areas is air quality deterioration, with mobile sources being major contributors to gaseous emissions released into the atmosphere

[1] Internationaltransportforum.org

[2] adec-inc.ca/pdf/02-rapport/cong-canada-ang.pdf and The High Cost of Congestion in Canadian Cities

in urban centres. Further, pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx: NO and NO_3), volatile organic compounds (VOCs), sulphur oxides (SOx: SO_2 and SO_3) are of great interest because of their environmental and health impacts. Of the pollutants emitted by mobile sources fine particles (PM2.5, particulate matter with aerodynamic diameter under 2.5um) have major impacts on health, climate and visibility.

Wherever combustion occurs, there will be a need to protect the public against dangerous emissions. The danger lies in the risk of persons coming into contact with toxic quantities of exhaust gas and its derivatives. Negative health effects resulting from exposure to air pollutants have been a key subject for scientific and governmental research. With growing evidence indicating a correlation between exposure to air pollutants and adverse health effects, more studies and modelling of urban centres, traffic and emissions are necessary.

It is accepted that outdoor air pollution contributes to morbidity and mortality, the extent to which this occurs remains to be fully studied and understood, especially considering variations in scenarios and between urban centres (Kunzli et al., 2000; Shabbar Ali et al., 2013). Some negative effects are manifested with short-term exposure, such as: shortness of breath, burning eyes, sleepiness, coughing, among others; or with long-term exposure which presents greater complications and a variety of symptoms. Since the assessment of individual exposure to pollutants can pose a challenge to epidemiological studies, as exposure and effects may be overestimated, alternate approaches to illustrate relationships and to encourage further research are necessary.

Models are excellent in cases where it's unviable or impossible to estimate all necessary facets of an exposure to an event. Models which correlate pollutants and emissions to health effects can be placed into a few broad categories, these being: Proximity models; Interpolation models; Land-Use regression models; Dispersion models; Integrated Meteorological-Emission models; and Hybrid models (Jerrett et.al, 2005) in increasing complexity. Hybrid models ideally require the use of personal monitoring technologies along with the methods of one of the other techniques to model emissions, exposure and to identify possible adverse health issues. This model type allows one to investigate the exposure an individual may suffer along a trajectory. Once personal measurements are taken, it is possible to check the baseline emissions resulting from vehicles on a highway, estimate individual exposure to various pollutants along trajectories and subsequently, highlight any hotspots of adverse health effects.

Hybrid models allow for the investigation of pollution exposure to the individual and by extrapolation, to society at large. It allows for a representation of traffic congestion, traffic emissions and health related concerns within an urban centre and along main thoroughfares. The model also allows for analysis of other road-features, such as tunnels. Emissions and pollution in tunnels can be overlooked, the use of this data as baseline is essential to understanding what may result from congested roadways, allowing for better understanding of the effects of a congested tunnel.

Congestion can therefore be viewed as a systemic problem resulting from an inadequate understanding of road users, political disinterest and a failure of relevant urban transit and transportation agencies to update infrastructure and plans. It is essential to understand urban profiles of cities to better understand what recommendations should be made to improve systems overall.

1.1
Purpose and significance of study

The central aim of this study is to compare and contrast congestion and its effects, namely emissions, social costs and possible adverse health effects, in two cities in Latin America and the Caribbean (LAC). Emissions and congestion must be monitored given the growth the region has experienced and its increased spending and acquisition power. As a result of population and economic growth, there continues to be a steady influx of persons into urban centres of Jamaica and Brazil. With this influx there has been an increase in vehicles and vehicular emissions on main highways. These factors have resulted in a greater need for housing; longer distances being travelled; and increased congestion, especially during peak hours in urban cities. Peak travelling hours tend to be in the mornings as persons are leaving for work or school and afternoons as these return to their homes. To create a descriptive urban profile of the cities and analyse social and health effects, a thorough and in-depth literature review was required.

Given the numerous studies conducted which review the available literature on models, modelling and approaches, this study focuses on well-rounded and in-depth examples to present summaries on the models which can be utilized when understanding congestion and estimating its impacts. The paper also considers indicators, and approaches taken by European and North-American transportation and environmental agencies, given the large number of studies and data routinely scrutinized by these two regions. Although this paper does not seek to present new approaches to consider congestion, it does note that there are several overlaps between approaches and that these can be better considered through their indicators.

1.2
Sequence of Paper

This paper has been organized into four main sections: Essays on congestion, associated health effects and modelling; methodology and study area identification; analysis of results; and recommendations for future studies.

Firstly, the problematic behind understanding how and why congestion occurs is identified and indicators of congestion are assessed based on the literature. Health and emissions, a noted cause for concern when considering growing cities and accelerated vehicle ownership, is treated by examining results of previous studies which focussed on health effects resulting from pollutants of mobile emissions. Modelling is considered with respect to the classifications and types available and an overview of two major mobile pollution estimation models, COPERT and MOBILE/MOVES. Other models are also briefly considered. Secondly, the methodology of the research paper is considered in line with available data, and an urban profile of the study areas is made. Thirdly, the paper looks at meeting the objectives stated, to better understand how traffic behaves and how congestion occurs in the two study areas. Fourthly, final observations are made considering the results of the investigations and recommendations for future studies are given.

In attempt to shed light on emissions in Latin America and the Caribbean, two important cities in the region were chosen, Rio de Janeiro, Brazil and Kingston, Jamaica. The study is focussed on examining the main routes taken by numerous commuters daily to go to and from urban centres in these two locations. Both study areas are plagued by congestion, long travel hours, passengers and commuters who are constantly being exposed to vehicular air pollution, and communities along the observed routes that experience daily emissions.

There were several limitations to this study as a result of geographic distances and data availability. Also, constraints presented themselves in the acquisition of personal monitoring devices due to their high prices and heavy taxation in both Jamaica and Brazil. Much time was also required to observe, analyse and understand how the urban traffic systems of both study areas operated, who their key players were and how they compared and contrasted.

Currently, to the knowledge of the researcher, there is no study comparing congestion and emissions between a major South American and a major Caribbean city. Although an introductory paper into future comparison possibilities, the researcher expects to outline similarities and to alert future researchers as to possible roadblocks in acquiring data.

2
Considering Congestion, Exposure and Emissions

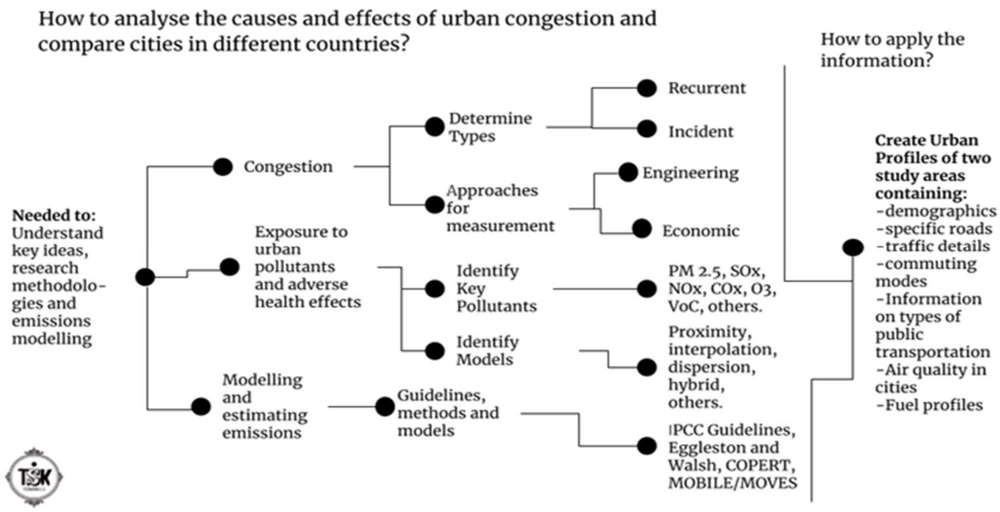

Figure 1: Rationale for study - How to address urban congestion and its effects

2.1
Exploring approaches to define and measure congestion

Congestion is difficult to define and quantify, impacting not only the individual, but also society at large. The ability to adequately quantify/measure, and value congestion is indispensable to being able to address it. Measuring congestion will therefore depend on clearly identifying its types and using the most appropriate method approach of valuation to account for the overall impacts which the phenomena causes. This paper will look at the types of observed congestion and several approaches and indicators that have been identified in the literature as ideal for understanding and measuring congestion as seen in Figure 1.

The two main types of observed congestion are recurrent and non-recurrent, or incident congestion. Recurrent congestion is typically a daily event with morning and afternoon peaks when most people are heading to work/school or returning home at about the same time. The duration of these peaks can vary between urban areas and between thoroughfare segments. Conversely, incident congestion is associated with random conditions and special occurrences such as: traffic incidents, accidents, construction work zones, adverse weather conditions, etc.

Incident congestion is more difficult to predict, this is problematic since the reliability and predictability of travel is of grave importance to businesses and social entities.

In The Cost of Urban Congestion in Canada[3], two approaches are highlighted to analyse congestion: the engineering approach; and the economic approach (Figure 2). The former, focuses on the direct and physical characteristics of congestion based on engineering principles which link vehicle flow, or traffic speed, to road capacity. The latter approach estimates the cost of congestion as the loss to society associated with excessive road use arising from the absence of proper pricing of the road infrastructure.

'Transport Canada Environmental Affairs' notes that in the engineering approach, congestion is defined in terms of the physical characteristics of the road. The definition consists of the theoretical engineering principles that link vehicle flow (actual throughput, measured as vehicles per hour) to road capacity (available capacity for throughput, measured as vehicles per hour). Traffic streams are generally described by three variables: density (vehicles per lane per kilometre), speed (km/hr) and flow (vehicles per lane per hour). Traffic flow is therefore the product of traffic density (vehicles/km) and speed (km/hr), these three variables are related: flow is equal to density times speed. All things being equal, as more vehicles enter the same road traffic density increases, travel speed falls, and travel time increases.

$$flow = density\ X\ speed$$

The economic approach interprets traffic congestion as the result of an increase in the cost of travel due to the presence of other vehicles. Congestion externalities arise as a result of the presence of additional road users, which increases travel times for other vehicles. Externalities here refer to the costs, or benefits, that are not market-priced, and that affect third parties as a result of actions taken by individuals. In contrast to environmental and noise externalities, congestion externality costs are, in part, internal to the transport-sector as a whole. The total cost of congestion is borne by the users themselves with each additional user inflicting costs on other users.

[3] www.adec-inc.ca/pdf/02-rapport/cong-canada-ang.pdf

The focus on traffic-related air pollution and economic valuation is based on the argument that traffic creates costs which are not covered by the polluters, motorists. These costs give rise to economic problems, not included in the market price, leading to a misuse of important resources, i.e. clean air, clean water and silence. These methods suggest that there is a need to adequately analyse the effects of congestion by looking at the externalities which are accrued by communities along thoroughfare and preferential transportation routes.

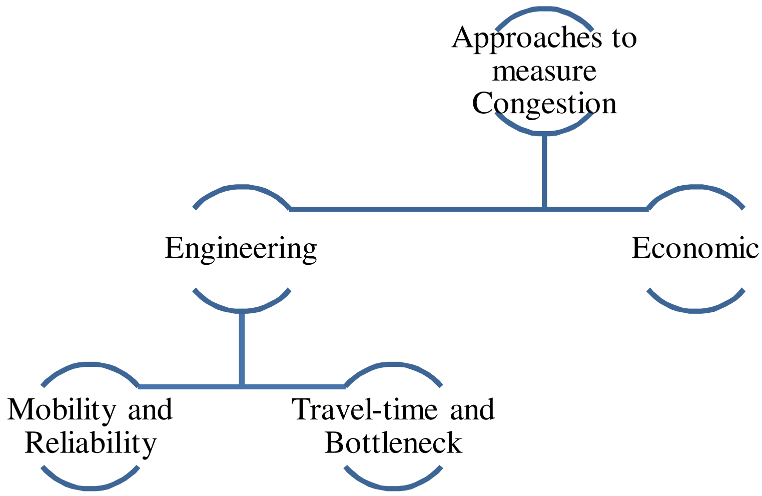

Figure 2: Categories of Approaches to Measure Congestion

Therefore, urban Form is crucial when analysing congestion. Routes chosen by commuters in favour of others, will guide the flow of transportation networks resulting in traffic build-ups or in free-flowing traffic. Urban patterns and densities, shape transport infrastructure and affect commuters and households. Urban form relates to the level of compactness or sprawl of an urban city, its causes and its impacts on congestion and pollution emission levels. Emission levels will affect concentrations and concentrations will have an impact on possible adverse health effects of human exposure to pollutants.

Apart from the overarching Engineering and Economic approaches to defining and measuring congestion, there are other approaches which can be placed under the engineering category. These other approaches can be seen in Figure 2. As shown, two other sets of approaches which will be treated here are: Travel-time and Bottleneck and Mobility and Reliability.

Toledo. 2011, through a review of the literature, and work done by Moran and Bang. 2006, 2008 and 2010, identifies and critiques two main approaches to defining congestion. He explains that given the negative impacts caused by road traffic congestion in urban city centres, and the need to assess these despite monitoring costs, congestion indicators can be used as proxies. These indicators are capable of detailing and describing congestion impacts through simulating patterns and behaviours with no continuous need for recurrent and periodical monitoring.

Naturally, there are several shortcomings to utilizing these indicators as opposed to continuous monitoring, two of these shortcomings are noticeable when considering: their lack of sensitivity to the dynamic and time-dependant nature of congestion and their limitations with respect to their use of data, originally collected for long-term planning tools; and their limitation in purpose, that of measuring impacts on travel time. Toledo. 2011, does not consider the more subjective or qualitative approaches to defining congestion, which have compound focus on social costs and costing.

A thorough analysis of the relevance of area-wide indicators and the respective approaches they belong to, can be found in Toledo. 2011. However, in essence, there are, according to his assessment, two ways to define congestion: The Travel Time Approach, which is treated in-depth by him and the literature and the Bottleneck Approach. One of the key outlined critiques regarding the travel time approach is that trips have to be completed in order to estimate the impact of congestion, this increases inactivity in estimations. Also, estimations of reference levels can be inconsistent when utilising non-congested data.

The Bottleneck Approach considers the increased demand over capacity at a punctual location. This implies that once there are more vehicles than the rate of throughput, there will be a bottleneck and as a result, queuing, delay and congestion. There are several constraints to collecting data with this approach; these stem from the differences in vehicle movement patterns between narrow streets, two-lane roads and highways. There also exists little consensus on the best data aggregation methodology.

Indicators treated under Toledo. 2011., can be seen in Table 1 and found in further discussion and with additional formulas and critiques in his work. This study considers the review he has made of the literature concerning congestion approaches and relevant indicators as an example to the many overlaps existing between approaches and their indicators.

Table 1: Indicators treated under Toledo. (2011)

NAME OF INDICATOR	DESCRIPTION OF INDICATOR
Excess Delay (ExD)	The average excess or lost travel time experienced by vehicle users on a road network. The difference between the Observed Travel Rate (TRobs) and the Reference Travel Rate (TRef).
Travel Time Indicator (TTI)	The ratio between the congested and non-congested or free-flow travel times.
Relative Speed Reduction	
Queue Indicator	Considers the time in queue or the “standing-still-seconds” a vehicle will experience.

(Source: Based on information from Toledo, 2011)

The Texas Transportation Institute assigns two main categories to approaches to measure congestion: Mobility and Reliability. Mobility indicators will focus on physical traffic parameters and actual time lost because of congestion, while reliability indicators focus on anticipating congestion and planning for it. The indicators for these approaches have been summarised in Table 2 and can be viewed more extensively on the Kentucky Transportation Cabinet website[4]:

Table 2: Two main approaches to congestion and their indicators by the Texas Transport Institute

MOBILITY MEASURES INDICATORS	RELIABILITY MEASURES INDICATORS
Volume-to-capacity ratio (V/C Ratio): The volume of vehicles divided by the capacity of the thoroughfare. **The Level of Service**: Which indicates, from A to F, how well a roadway is serving its intended traffic; with A = free-flow and F = very congested. This assessment is based on the V/C ratio. **Travel Time Index**: The ratio of average peak travel time to off-peak or free-flow standards.	**Buffer Index**: The buffer time, or extra time needed so as to ensure timely arrival for most trips.
Travel Delay: The amount of extra time spent travelling due to congestion. **Percent of Congested Travel**: The congested vehicle-miles of travel/total vehicle miles, or the amount/distance of travel affected by congestion.	**Planning Time Index**: The 95th percentile Travel Time Index, representing the extra time included by most travellers when planning trips during peak periods.

(Source: Kentucky Transportation Cabinet)

4 http://transportation.ky.gov/Congestion-Toolbox/Pages/Congestion-Measures.aspx

The Travel Time Approach, by the US Department of Transportation, Federal Highway Administration, is introduced as Travel Time Reliability (TTR), which considers how consistent travel times will be during the day and from day to day, allowing for a more effective use of time. This becomes necessary in cases of recurrent congestion, where commuters are required to consider worst-case scenarios when planning their trips so as to avoid greater delays as a result of extraneous circumstances. Therefore, commuters must factor in a buffer to their travel times to account for the unpredictability of travel.

TTR has implications for everyone, from employers to employees, distributors, suppliers, and air travellers. In measuring TRT, most measures compare days or times with high delays versus an average day or time. Measures to do so are:

90th /95th percentile travel times - indicates how bad delays will be on the heaviest days for the heaviest times. This measure, reported in minutes and seconds, is simple to understand but cannot be easily compared across routes.

Buffer Index (BI) - is the extra time needed to be added by most commuters to ensure on-time arrival, and accounts for any unexpected delays. Expressed as a percentage, its values will increase as reliability worsens. So that a buffer index of 50 percent means that for a 30-minute average time, a traveller should budget an additional 15 minutes (30 minutes x 50 percent = 15 minutes) to be on time most of the time. Here, the extra 15 minutes is referred to as the buffer time. The buffer index is therefore:

BI = ((95th percentile travel time – average travel time)/average travel time)

With the 95% representing the near-worst scenario and the extra time a traveller should allow for to arrive on-time for 95% of all trips. In other terms, by following this, the traveller/commuter would be late one weekday a month.

Planning Time Index (PTI) – refers to the total travel time that should be considered when an adequate buffer time is included. This index includes typical delay as well as unexpected delay, differing from the buffer time index. The PTI can be directly compared to the Travel Time Index (TTI), a measure of average congestion, on similar numeric scales. Where, a planning time index of 1.40 means that, for a 20-minute trip in light traffic, the total time that should be planned for the trip is 28 minutes (20minutes x 1.40 = 28 minutes). This index compares near-worst-case scenarios to a travel time in light or free-flow traffic. In other words:

PTI = (95th percentile travel time/ free-flow travel time)

It is important to note that other percentiles (85th, 90th, 99th) can also be used given the desired level of reliability and the routes chosen.

Planning Time will then be: the total travel time + the buffer time.

Some other important concepts treated in the literature are seen in Table 3 and based information by the US Department of Transportation (USDT).

Table 3: Other indicators and their descriptions, by the USDT

NAME OF INDICATOR	DESCRIPTION OF INDICATOR
Vehicle Miles Travelled (VTM)	Each location's traffic volume will be multiplied by the representative length of the route; all values are then summed to obtain the route's VTM. (Vehicle count x length of roadway)
Traffic Volume (TV)	Vehicle counts at a given roadway location, measured by a detector in each lane of location.
Maximum Throughput (MT)	Occurs when vehicles travel at speeds between 70-85% of posted speeds. Here, highways are operating at peak efficiency due to the higher number of vehicles passing an area. The MT, which does not have static speeds, will naturally vary between highway segments, influenced by roadway designs and traffic conditions.
Total Delay (TD)	Delay is calculated as: actual travel times – travel times at posted speeds/maximum throughput speeds.
Calculated Cost of Delay (CCD)	The cost of delay is calculated by applying monetary values to the estimated hours of delay, plus additional vehicle operating costs. The value of time for passenger trips is assumed to be half of the average wage rate.

(Source: United States Department of Transportation)

An important take-away from the assessment on indicators made by the Washington State Department of Transportation, is that congestion, or delay, imposes costs for the lost time of travellers. This includes higher vehicle operating costs from things like wasted fuel and other stop and go driving. Naturally, this will influence emissions from these mobile sources and can present health concerns to populations which reside in influence areas.

According to Schindler and Caruso. (2014) an assessment of the literature shows that, given an enclosed area and continued emissions, even low emissions, can lead to high concentrations of pollutants in locations. This is crucial when considering the impacts on population health in these dense centres. Local morphology of built-up areas will play a role in assessing effects on populations and health as open-spaces and street design and activities may further influence pollution dispersion and exposure. The authors note that Borego et.al. (2006) and Marshall et.al. (2005) both identify notable variations of exposure between the city centre and outskirts; and significant exposure differences for different pollutants: with the compact city resulting in less people exposed to higher levels of Ozone (O_3), but more people exposed to nitrogen oxides (NOx), in comparison to the sprawling city. The authors conclude that the importance of the peculiarities of an urban centre to emissions implies the need for sufficiently detailed representations of neighbourhoods for better modelling. Computing the pollutant emissions on the road will therefore depend on the number of cars passing, the distance travelled, and the urban form of the city. This reflects the formula; flow is equal density times speed.

2.2
Traffic emissions and health

The United States Environmental Protection Agency (US EPA) webpage on how mobile source pollution affects health offers a comprehensive outline on emissions and possible health effects. On the page, mobile sources of air pollution are divided into: On-road vehicles, which include motorcycles, passenger cars and trucks, commercial trucks and buses; and non-road vehicles and engines, which include aircrafts, heavy equipment, marine vessels, recreational vehicles and others. Ozone, particle pollution, air toxics and near roadway air pollution and health, are key issues that are briefly examined and can be seen below.

The US EPA explains that, one of the resultant pollutants of mobile emissions, ozone, a main component of “smog”, is created through chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds

(VOCs) in the presence of sunlight. Ground level ozone is potentially harmful if inhaled causing: difficulties in breathing deeply and vigorously; shortness of breath and pain; coughing and scratchy throat; inflamed and damaged airways; aggravation of lung diseases like, asthma, emphysema and chronic bronchitis; increased frequency of asthma attacks; increased lung susceptibility to infection; promoted sustained damage to lungs after disappearance of effects and can cause chronic obstructive pulmonary disease (COPD). Health complications caused by ozone are especially problematic for children, the elderly and all persons with lung disease such as asthma.

Particle pollution (or PM for particulate matter), refers to a mixture of solid particles and liquid droplets found in air where primary particles tend to be emitted directly from a source such as: construction sites, unpaved roads, fields, fires, etc. Secondary particles, which make up the majority of fine particle pollution, result due to complex reactions in the atmosphere with chemicals like sulphur dioxides and nitrogen oxides, emitted from automobiles, industries and the mixture of others. PM pollution is associated with: premature death in people with heart or lung disease; non-fatal heart attacks; irregular heartbeat; aggravated asthma; decreased lung function; and increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing.

As a result of large population densities and higher concentrations of emission sources found in urban areas, air toxics pose serious health risks. Once exposure to these occur at sufficient concentrations and durations, chances of getting cancer or experiencing serious health effects may occur, including: damage to the immune system; neurological disorders; reproductive disorders and reduced fertility; developmental disorders; respiratory complications and other health problems.

In relation to living, working or attending school within influence areas of roadway air pollution, the UN EPA notes that these people appear to have increased incidence and severity of health problems associated with air pollution exposure. Vulnerable segments of the population such as, children, older adults and people with pre-existing cardiopulmonary disease, and people of lower socio-economic income, are usually more at risk to possible health risks from air pollution near highly trafficked roadways. Health risks can include: higher rates of asthma onset and aggravation; cardiovascular disease; impaired lung development in children; preterm and low-birth weight infants; childhood leukaemia and premature death.

Urban residents spend considerable amounts of time in traffic environments daily; this influences commuters' exposure to different pollutants resulting from the choice of commuting (C. Yan et al., 2015). Transportation modes are important factors affecting the physical properties of the particles that commuters are exposed to. Where the longer the exposure time in environments where particulate numbers may build up, the greater the possibility of adverse health effects. C. Yan et al.,2015 discuss how sources with high emissions of very fine particles e.g. cooking and vehicle emissions, may greatly influence PM number concentrations (PNC). Since that ambient emitted ultrafine particles may penetrate into bus cabins, together with newly formed particles, leading to an increase of PNC in enclosed spaces.

C. Borrego et al. (2006) explain that road traffic usually provides one of the major sources of ambient particulate pollution, especially for finer particles. Peak concentrations of atmospheric particles tend to occur close to roads. As a result, road journeys, by car, foot, or cycle, tend to make up a large proportion of peak exposures. Once this is understood, it becomes clear that pedestrians on the roadsides are often under direct exposure to traffic plumes, especially during congestion, when there is a long continuous idling fleet and other ground source emission such as road dust. Bus commuters are under exposure because of re-suspended dust in closed vehicle cabins, leading to increased $PM_{2.5}$ inhalations (C. Yan et al., 2005). The previous observations provide good points for study when comparing exposure in non-Air Conditioned (AC) and AC vehicles, that otherwise, share the exact same characteristics.

It was highlighted by C. Yan et al. (2015) that walking pedestrians and bus commuters were exposed to a much broader range of PNC and $PM_{2.5}$ mass concentration (PMC). They also noted that on average PM_{10} and CO levels were 1.2 to 3.0 and 2.6 to 9.3 times higher in roadway transportation than in subways. According to M. Wang et al.,2014, recent studies of health effects of particulate matter (PM) show accumulating evidence of adverse effects on cardiovascular (CDV) mortality; studies of long-term exposure to $PM_{2.5}$ and PM_{10} have produced varying effect estimates, from elevated risks being shown in some cities in Europe and the US to little, or no, association in others.

M. Wang et al., 2014 speculated that the reasons for these differences resulted due to methodological differences, chance findings, variations of PM composition and population susceptibility. This assumption was tested by Y. Sellier et al., 2014., where four exposure models to nitrogen dioxide NO_2 and PM_{10} were studied in two metropolitan areas in France, specific health endpoints were investigated as a result of exposure. The investigated models were: the nearest air quality monitoring station (AQMS) model; a temporally-adjusted geostatistical (TAG) model; a land-use regression (LUR) model; and a dispersion model.

In their study, Y. Sellier et al. (2014) found that all exposure models showed higher exposure levels in urban and suburban areas and lower levels in rural areas. The influence of NO_2 exposure in these scenarios, specifically the higher concentrations of the pollutant, was a function of traffic, urban heating and industrial sources in urban areas. They noted that the dispersion model tended to generally underestimate the exposure levels to this pollutant. Y. Sellier et al. (2014) showed that different spatio-temporal approaches of air pollution exposure assessments, although with well correlated predictions, provide different rankings of the subjects regarding their exposure. This can lead to possible varying conclusions on associations with health endpoints.

Apart from methodological concerns M. Wang et al. (2014) postulate that population composition and age may increase susceptibility to air pollution exposure, while better medical treatment and medication in a population may also explain differences in results. Models which allow for the reproduction of studies and similar interpretations of results given different inputs are critical to further understanding the impacts of road and highway emissions of pollutants and the health effects on communities within the influence area. The literature appears to indicate a positive correlation between increased and sustained exposure to these pollutants and adverse pulmonary and cardiovascular effects. Further studies must be conducted and the dynamics existent within Latin America and the Caribbean must also be analysed to allow for a better study of the effects of increasing urbanization and urban sprawls, coupled with increased vehicle use within these urban areas and the health of nearing communities.

2.2.1
Linking emissions to health

Models to analyse urban emissions and assess adverse health effects can be classified as: Proximity models; Interpolation models; Land-Use regression models; Dispersion models; Integrated Meteorological-Emission models; and Hybrid models (Jerrett et.al, 2005).

Jerret et.al. (2005) provide a thorough and comprehensive look into mobile emission models and methodologies that allow for health impact assessments. Their study provides an overview of the application of the model, linkages to health effects and evaluations of the models discussed. Additionally, comparisons are made between models and with reference to studies conducted and results obtained. The authors also detail key recommendations for future studies considering the models examined and improving technologies. A brief summary of each model with their links to health effects follows:

Proximity Models (Buffers Models): As the most basic of models, these assume that the closer one is to emission sources, the more likely the possibility of exposure. Therefore, the models assume, if one is within the influence area of heavy air pollution sources, one is more likely to suffer from respiratory complaints, among others. According to Jerret et.al. (2005) the model provides a straightforward application for the analysis of long-term exposure classification.

Interpolation Models: Models of this nature rely on established monitoring and measurement stations which periodically estimate concentrations. Usually, emission estimates obtained from these stations are imposed over study areas thus allowing for the visualisation of a continuous surface of pollution. When using this model it has been noted that higher modelled concentrations of pollution appear to associate with increased respiratory health effects, mortality or modifiers of health effects.

Land Use Regression Models: This model type has, as its core aim, the prediction of pollutant concentrations at a given location or point as a factor of surrounding land use and traffic characteristics. One can say formally, that "...this method uses measured pollution concentrations Y at location S as the response variable and land use types X within areas around location (S) as predictions of the measured concentrations"[5].

[5] Jerret et.al. (2005)

Dispersion Models: These models are often based on Gaussian plume equations, combining data on emissions, meteorological conditions and topography, in an attempt to estimate spatial exposure by populations to background (pollutant) concentrations. These models have been coupled with GIS (Geographic Information System) allowing for the capturing of demographic and empirical monitoring data. When combined with GIS, there is a more realistic representation of the problem as a result of the above features, road networks and traffic information.

To make use of these models, background concentrations can be obtained from government stations for air quality monitoring in proximity of the study area. Other necessary data, meteorological, wind-speed, wind direction, ambient temperature, solar radiation and atmospheric stability class, can also be acquired from national meteorological and environmental monitoring agencies.

As emissions are usually from stationary sources, such as industries and residences; or mobile sources, such as vehicles and re-suspended particles, data capturing for emissions can expensive. In estimating emissions for stationary sources, mass emissions, stack height and diameter, etc, are required. Mobile source emissions are based off the estimation of emissions through the relationships between traffic counts, emission factors, and vehicle and fuel type.

Although the use of this model type may have practical applications for epidemiological studies, such as the identification of increased risk for the development of lung cancer, Nafstad et.al. (2003)., Bellander et.al. (2001)., stress that this may be limited to sites which already possess significant data on traffic and other emissions.

Integrated Meteorological-Emission Models: These expensive and complex models are generally composed of three modules: meteorological, chemistry transport and visualisation and analysis. They simulate the dynamics of atmospheric pollutants through the pairing of meteorological and chemical modules, where meteorological data is attributed to each step of the chemistry modules. There is no requirement for feedback loops between these two modules, since chemistry has only slight impacts on meteorological variables.

Models of this nature are ideal for regions that may not possess comprehensive observations, so that meteorological fields, required for air quality study and application, are not defined. Information produced by these models will depend on input data, model physics and the resolution and sophistication of land surface schemes (Jerret et.al., 2005)

Given its elevated financial, data and know-how costs, these models have not been used for studies seeking to link air quality to health. They do however, present great potential, especially for highly populated areas, where small pollution risks have the potential for severe secondary pollutant levels and high illness and mortality.

As previously mentioned, IME models require high data input, expertise and financial investment, this is detrimental to the possibility of their widespread use in linking pollutant emissions to health effects. Their potential benefits lie in their ability to simulate varying exposure scenarios, the inclusion of chemical transport and fate and assess the formation of secondary pollutants, like ozone. However, apart from their costly implementation needs, another drawback could relate to the grid results of these models, usually that of 1km. This may be too coarse for pollutants such as SO_2, NO_2, NOx, ultrafine PM and CO, which may vary at the local scale with concentration gradients over 50-100m distances.

Hybrid Models: These models are based on a combination of two or more model types, or the combination of one of the model types mentioned and the use of personal or regional air pollution concentrations monitoring. Personal monitors can be attached to clothing or be hand-held to monitor exposure to pollutants for a period of time. Regional monitoring data can supply background emission information to other models, such as buffers or distance models, to allow for better visualisation and more compelling evidence for adverse health effects linked to exposure.

Although personal monitoring may provide lower concentration measurements, they allow for more accurate exposure estimates. The quality of the data and study will depend on the model combination chosen and the study methodology. Personal monitoring is of interest since people spend most of their time indoors and as such, indoor air exposure will be of greater consequence.

This current study is focused on the combined effects of indoor, outdoor and background pollution in the cases of recurrent congestion for commuters who always travel a particular route. Such a situation occurs when persons are heading to work, school or scheduled leisure activities which occur during peak hours when congestion tends to result.

2.3
Methods for estimating urban emissions

The literature indicates numerous approaches, methods and techniques for estimating urban emissions. Although various models exist, there are key features which models attempt to consider and reproduce. Several methods will be treated in this chapter, with a focus on model reviews done by Linton et.al., 2011 and Eggeleston and Walsh. The first set of authors cover a wide variety of models, categories and their specified use, while the second set of authors review two leading models, COPERT and MOBILE/MOVES which are used by government agencies in Europe and the USA, respectively.

Linton et.al., 2015, identifies six main approaches and techniques for modelling vehicle emissions from transport (specifically CO_2 emissions), these are: Traffic network models; Micro-simulation models; Behavioural models; Agent-Based modelling; System-Dynamics Modelling; Techno-economic modelling; and Integrated Assessment models (IAMs). The authors mention a seventh alternative, which results from combining models to provide better assessment, account for data gaps, and allow for projections based off present circumstances. The models mentioned are discussed below:

I. **Traffic Network Models**:

These range in scale from micro to macro models and consider urban and road networks. In micros-simulations, origin-destination matrices are used to represent single trips within the network. As mentioned, the network in traffic models is based on real-world urban traffic networks and uses a combination of representative nodes, links and zones. Here, nodes are junctions and intersections; links are roads connecting nodes; zones are areas from or to where trips are made and the basis of the origin-destination matrix.

Micro-simulation provides a series of techniques which are of great interest since it allows small changes in networks to be analysed in terms of their impacts on transport and resulting emissions. This approach to modelling allows for the understanding of demand for mobility within the traffic system, and the establishment of emission levels.

II. **Behavioural Models**:

In the transportation sector, behavioural models seek to understand how transport infrastructure is used by travellers in an attempt to foresee needs and enhance decision-making which, in turn, provide a holistic view of activities. Models of this nature are based on social psychology and behavioural economics for their key principles and frameworks. In practice, these models can illustrate how and why travel motivation, scheduling and constraints impact traffic systems.

III. **Agent-Based Modelling**:

Consider the underlying motivations behind travelling and allow for a better understanding of travel patterns and a quantification of the demands on transportation sector. Through quantification of the amount of travel within a network, emission factors can be applied to estimate emissions from road transport. This type of modelling identifies key agents within a practice space, then observes how these key agents interact in an attempt to understand behavioural dynamics. Therefore, behaviours can be altered through multiple interactions between agents and their environment within the system being observed, lending to important insights into the system. Here, a bottom up approach to modelling is done considering "heterogeneous agents".

IV. **System Dynamics**:

Essentially, these models capture differences in the system over time by observing causal loop diagrams (CLD) through the simulation and analysis of relationships and mathematical modelling of stocks and flows. Highly versatile, these models incorporate qualitative and quantitative techniques and analysis, considering marketing developments and facilitating stakeholder interaction. These models are highly adept at capturing complex interactions at larger geographical and temporal scales than behaviour models.

CLDs are the main techniques used in system dynamics allowing for the exploration of the qualitative relationship between different portions of the system. They identify entities capable of affecting different aspects of the system and by turn are also affected. Feedback and linkages are important since changes are a key focus of the model type.

V. **Techno-Economic Models**:

Consider relationships between technology and economy, they can be combined with socio-economic data to analyse wider impacts. Given their scope, these models tend to be macro-scale models where transport may be a subcategory of wider economic considerations. Their macro-scale often leads to overlooking details which are normally captured in other, micro-scale, models; however, this information can be integrated into the model.

VI. **Integrated Assessment Models**:

Models of this type are macro-scale, able to capture transport data as a sub-sect of economic activity. They are able to analyse long-term environmental changes associated with the economy and output aggregated data on emissions. These models reflect how changes in technology can be reflected in results, impacting mobile-source emissions being analysed.

Combining approaches can lead to novel interpretations of transportation and congestion-related issues and aid in identifying innovative ways of tackling these problems. Combined approaches can allow for better understanding of behaviours, choices and allow for modifications in models if acquiring data is challenging.

2.3.1 IPCC Guidelines

The European Environmental Agency notes that the Intergovernmental Panel on Climate Change (IPCC) Guidelines, were initially accepted in 1994 and published in 1995, their use was reaffirmed at the 1997 Kyoto United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP3), with the review of the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. It was affirmed that these should be used as "…methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases".

The 2006 Guidelines were completed with request from the UNFCCC and included a completed update and revision of earlier guidance. Further, good practice guidance (GPG) and sectoral guidance were integrated to allow for more complete, consistent, comparable, transparent and accurate inventories which would account for all available resources. The updated 2006 IPCC Guidelines were separated into five volumes: Vol 1, General Guidelines and Reporting; Vol 2, Energy; Vol 3, Industrial Processes and Product Use; Vol 4, Agriculture, Forestry and Other Land

Use; and Vol 5, Waste. In 2013 a supplemental document was added to the guidelines: Wetlands.

Volume 2 of the Guidelines looks at energy: the emissions of electricity and heat production; industrial and residential combustion; oil production; and the impact road transportation has on NO_X, CO and NMVOC emissions. The Guidelines also indicate that emissions of NO_X resulting from fuel combustion are likely to be "fuel-NO", formed from the conversion of chemically bound nitrogen in the fuel; with nitrogen contents varying between fuel types. Combustion temperatures can form thermal NOx, which can also be formed from nitrogen in the combustion intake air. Various factors, including fuel type and combustion emissions will influence the generation of carbon monoxide (CO) and NMVOCs during under-stoichiometric combustion conditions. With respect to sulphuric emissions, the sulphur content of fuel will influence the emissions of sulphur oxides (SOx), with some sulphur being retained in ash. These factors are fully analysed by the IPCC Guidelines with best practices for data collection being clearly outlined.

Some developments in the updated 2006 IPCC Guidelines with respect to Volume II (Energy), as compared to the 1996 Guidelines, included the treatment of CO_2 capture and storage and methane (CH_4) from abandoned coal mines; better estimation methodologies are provided for these with emissions. There was no change; however, in the overarching methodology of 1996, emissions in the 2006 Revised IPCC Guidelines still follow the following formula:

$$Emission = [Activity\ Data] x\ [Emission\ Factor]$$

2.3.2
Eggleston and Walsh

Eggleston, S and Walsh, M[6], outline how gaseous emissions from mobile sources can be estimated by using the distance a vehicle has driven and emission factors. In essence, the authors review the models assessed under the IPCC Guidelines and illustrate how the calculation of total emissions from road transport

[6] Emissions: Energy, Road Transport (http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_3_Road_Transport.pdf)

can be estimated considering: emission factors; the activity rate (fuel consumed or distance travelled); extra emissions because of cold starts; extra emissions due to evaporation; in conjunction with a pondering of fuel type, vehicle type, emission controls fitted to vehicles in fleet, road type or vehicle speed. The equation for calculations is given as:

$$Emissions = \Sigma_{(abcd)} \left(\mathrm{EF}_{(abcd)} * \mathrm{Activity}_{(abcd)}\right) + \Sigma_{(b)}\mathrm{Cold}_{(b)} + \Sigma_{(b)}\mathrm{Evaporation}_{(b)}$$

Where:

- ➔ Emission = total emissions from road transport
- ➔ EF = Emission factor, as mass per unit of activity rate
- ➔ Activity = activity rate (fuel consumed or distance travelled)
- ➔ Cold = Extra emissions due to cold starts
- ➔ Evaporation: Extra emissions due to evaporation (NMVOCs)
- ➔ A) fuel type B) Vehicle type C) Emission control D) Road type/Vehicle speed

This model can be further explained observing that road transport is a major source of CO_2 as well as other gases such as NOx, CO, NMVOCs and smaller quantities of N_2O_2 (hypoxic gas), CH_4 & NH_3. Carbon emission is estimated from the carbon contained in the fuel. The emissions of other gases are best estimated from the distance the vehicles are driven and emission factors. In the absence of other information, factors related to fuel-based emission can also be used. Additionally, emissions can be classified as: Exhaust (tail pipe), resulting from the vehicle's engine as it is driven; cold start emissions, which are additional emissions resulting from when the vehicle starts from cold; and evaporation emissions, coming from the evaporation of petroleum from the vehicle's fuel system, engine and fuel tanks. By analysing and following the recommendations of the IPCC Guidelines the authors thoroughly delineate the requirements for the use of either the MOBILE or COPERT II models considering key data for calculation, these being: fuel consumption; activity data; vehicle types; emission controls; and vehicle kilometres.

A second important consideration in estimating emissions is the Emission Factor (EF). The second equation provided by the authors allows one to calculate the emission factor as a mass emission of CO_2; given as:

$$EF = 44.011 * \frac{1000}{12.011 + 1.008 * r_{H/C}}$$

Where:

- EF = mass emission of CO_2 factor (g/kg)
- $r_{H/C}$ = ratio of carbon to hydrogen atoms in the fuel (~1.8 for petrol and ~2.0 for diesel).

Methods for calculating EF for non-CO_2 emissions are also provided in the paper by Eggleston, S and Walsh, M (Emissions: Energy, Road Transport), utilising data from the USEPA through their software model MOBILE. This model, as well as its most current upgrade MOVES will also be treated in this study.

Eggleston, S., and Walsh, M., were keen in emphasising that several parameters are to be considered when estimating emissions from road transport. Apart from those previously mentioned, fleet age distribution, distance travelled and climate will also play an important role in estimations and in the accuracy of results. As a result, detailed information is provided by the authors on these key parameters with explanations on their use and how to acquire data for their use which falls under three main categories: Fuel consumption; Activity Data; and Emission Factors. Best practice methods are also noted within their paper.

I. Fuel Consumption

This factor tends to be better known than distances travelled by vehicles and allows for an estimation of CO_2 emissions (COPERT II, explained by Eggleston and Walsh, advocates the use of fuel consumption factors and distance travelled to estimate fuel use. Amounts are then compared with true figures of fuel used and vehicles kilometres are adjusted to match total fuel use).

> …the total fuel use gives the total CO_2 emission and the split between different vehicle types is determined by the vehicle kilometre data for each vehicle category.

The CO_2 emission factors proposed in the IPCC Guidelines can be seen I Table 4. In fact, emission factors can be estimated from the ratio of carbon to hydrogen in the fuel.

When looking into fuel consumption it is always important to consider how fuel is used nationwide. Additionally, it is necessary to consider any alternative sources for fuel supply vehicles may use; how much fuel is actually used for road transport and whether it is used for off-road use or small machinery; and how the statistics may account for things like no refuelling during cross-country trips.

Table 4: CO2 Emissions Factors for Road Transport in the IPCC Guidelines

<table>
<tr><th colspan="3">IPPC Guidelines: CO_2 Emissions Factors for Road Transport</th></tr>
<tr><th>(g CO_2/kg of fuel)</th><th>Petrol</th><th>Diesel</th></tr>
<tr><td>US</td><td colspan="2">3172.31</td></tr>
<tr><td>Europe</td><td>3180</td><td>3140</td></tr>
</table>

(Source: Eggleston and Walsh)

II. Activity Data

This factor considers vehicle types, emission controls and vehicle kilometres, since emission rates will depend on the type of vehicle being considered. The tables provided in the text are sourced from the IPCC Guidelines and indicate that vehicles can be divided into four main types for the MOBILE model, these being: light-duty passenger; light duty trucks; heavy-duty vehicles; and motorcycles (2 and 4 strokes). Comparatively, COPERT II classifies vehicles into five types: passenger cars; light-duty vehicles; heavy-duty vehicles; urban buses and coaches and motorcycles. The classifications offer key differences with respect to vehicle weight and use. It should be noted that vehicle fleet information of this nature is essential to estimate emissions other than CO_2 from road transport.

Several emission control technologies exist and are fitted to vehicles. The age of the vehicle is important when taking this into account. Given that these controls were introduced based on legislation, once vehicle years are known it is possible to know the emission control features found within the vehicles.

Catalysts act on gaseous emissions in several ways and may lead to significant changes in emissions of pollutants. Generally, these are aimed at COx, CO and NMVOCs but also have impact on direct greenhouse gases. Overall, catalysts will reduce hydrocarbon emissions, such as methane, although given the relative inertness of CH_4 to catalytic reduction this is less than for other gases. N_2O emissions increase with catalysts, so that road transport is the only significant source of the gas from fuel combustion. Largely, N_2O emission sources are from agriculture and other process emissions, this means that the number of petrol cars filled with catalysts is important for estimating N_2O emissions.

Leaded fuel will cause catalysts to fail so that cars with catalysts that have failed may emit more than vehicles made without catalysts. As a result of the paucity of information on the emission rates of vehicles with failed catalysts it is often assumed that these have similar emission rates as those built to the last pre-catalyst legislation.

Models will vary in what is accounted for with respect to emission controls. The MOBILE programme, considers inspection and maintenance (I&M) programmes where emission rates are dependent on standards of vehicle maintenance. In cases where a range exists for emission factors and no I&M programme is present, the high end of the emission range is used. Since emission factors are based on in-service vehicles in Europe, the standard maintenance is included in the measurements; this is adequate when estimating current emissions where measurement samples are representative of the national fleet. However, for projections, changes in I&M should be included by using the expected improvements in the emission rates.

Since catalyst performance may naturally degrade over time, the use of vehicle fleet age distribution can be utilised in identifying emission rates based on age (or mileage). In cases where emission control efficiency is related to vehicle age, older vehicles may do lower annual mileage and this feature must be considered when emissions are being estimated. Vehicle fleet emission control information is essential to estimating other emissions from road transport, beside CO_2. Fuel type is also important in estimating emissions, with noted differences existing between petrol and diesel cars. It is important to know the proportion of vehicle types (cars & vans) running on petrol and diesel, as well as other fuel (e.g. ethanol, bio-fuels, etc…)

Vehicle kilometres, distance travelled for vehicle types, is required by some approaches to estimate emissions. Often, data isn't readily available or of the best quality and ideally, annual driven distances by vehicle sub-type and emission control type should be estimated and taken into account in calculations. Further, different road types must be defined for certain models. In the case of COPERT II, average speeds on different road types guides the model with emission factors being given as functions of speed per vehicle type discriminated by emission control and engine size; once the data is available the approach can be used with estimates for road type. If the data is unavailable vehicle kilometres need to be estimated for the different road types, urban, rural and highway have often been used due to their different driving patterns and average speeds.

III. Emission Factors

IPCC Guidelines for emission factors for non-CO_2 emissions offer three tiers of increasing complexity. These go from the use of pondered fuel-based data in tables, to the use of MOBILE or COPERT II and other national models. Ideally, once a country possesses the relevant information, it is advised to utilise more detailed emission factors for more accurate estimates. The paper by Eggleston and Walsh considers four approaches in order of increasing quality. Here they also indicate how COPERT II or MOBILE could be slightly modified to work with specific data limitations.

Eggleston and Walsh, explain that the IPCC guidelines tier 1 approach gives fuel-based emission factors; since the simplest approach to estimate road transport emissions is based on how much of each fuel is consumed. Estimating CO_2 in this scenario is directly based on the carbon content of the fuel. For other gases, emission factors are averaged over driving patterns and speeds typical of the US or Europe. It is recommended that these not be used directly, unless users have no information regarding vehicle km driven on different road types, vehicle speeds and driving patterns. Both MOBILE and COPERT II give detailed models which take fleet types, road types and driving patterns into account. The intermediate approach can be used where the models are too complicated for the national data available but where the emission factors can be taken from the models to consider national fleets and driving patterns.

In estimating nitrous oxide (N_2O) several complications were outlined by the authors, mostly related to the lack of adequate vehicular data for emissions. Since N_2O is not a criteria pollutant and measurements of it in automobile exhaust is not routinely collected, studies have intensified attempting to understand why and under what conditions nitrous oxide can be created by three-way catalysts. In their paper the authors state that current IPCC Guidelines show significant increase in emission rates for vehicles with catalyst control. At the time, once they had reviewed the literary data and methods used to develop these emission factors, the USEPA found them to be limited in application. These limitations led the USEPA Office of Mobile Sources to conduct a careful study, in June and July 1998, which resulted in further recommendations for N_2O emission factors by vehicle type and control technology.

The three main points to take-away from the 1998 study were: Emissions were always higher with commercial (high sulphur) fuel than with indolene (low sulphur); emissions were usually higher with A/C on at 950F (550 ºC) than with A/C off at 750F (399 ºC); and nitrous oxide was unrelated to the mileage of the vehicles.

The last chapters of the paper focus of clarifying good practice methods by providing steps and recommendations which can be clearly followed to gather necessary data. Uncertainty is also considered, with explanations as to the types that can be found and what can be done to minimize them. Completeness, reporting, adequate documentation, quality assurance and quality control are also discussed so as to provide good practice guidance when developing inventories.

2.3.3
COPERT V and COPERT Street Level

The Computer Program to Calculate Emissions from Road Transport (COPERT), developed at the Aristotle University of Thessaloniki, was first released in 1989 (COPERT 85). The model was updated in 1993 (COPERT 90); 1997 (COPERT II); 1999 (COPERT III); and 2005 (COPERT 4) with several important updates in succeeding years with the latest being in May 2017, COPERT 5 is also currently available. Of particular interest is the development of 2015 COPERT Street Level, which too will be discussed.

> The program estimates transport emissions and projections from on- and off-road transport, compatible with European technologies. It was designed to aid European nations report vehicle emission levels to international institutions

In COPERT 4, vehicular emissions are calculated based on activity data provided by users on vehicles of specific categories and utilising vehicle-specific emission factors programmed for each vehicle type. Four emission sources are accounted for in estimating total emissions, these being: hot emissions; cold-start emissions; fuel evaporation emissions; and non-exhaust PM emissions (i.e. tire and brake emissions). Speed dependent emission factor formulae, developed through empirical multiple real-world tests, are also used by COPERT 4. Drive cycles considered involve the stop-go city traffic and suburban driving cycles with speed-dependent emission factor curves being derived from each distinct cycle.

COPERT 5 is an updated version of COPERT 4 including both revised methodological elements and a reworked user interface aiming at a compilation of complicated annual national inventories that include multiple countries and years in a single file[7]. In a review and analysis of the model conducted by the Clean Air Institute, Factsheet 4, some weaknesses of COPERT 4 identified are: being limited in application to countries using Euro-type classification; the low percentage of use in regions outside of Europe; and its simplicity.

The COPERT Street Level (COPERT SL) model was first released in 2015, with significant upgrades in December, 2015 and July, 2016. It is identified by EMISIA, platform which makes all recent COPERT models available for download, as being an innovative approach to calculating emissions from road transport. Although based on the original COPERT software model, calculations are conducted differently in COPERT SL. In this innovative model calculations can be conducted on a single street or on a full city street network, and minimal input is required by the software. Additionally, emissions can be displayed on a GIS map to improve visualisation, and it is designed to complement traffic analysis tools facilitating a wide range of input datasets.

Contrary to the original COPERT model, COPERT SL is based on the hot emission factor calculation of the EMEP/EEA air pollutant emission inventory guidebook[8], with the following features: it has a minimal temporal level of 1 hour; a minimal spatial level of a small road; GIS visualisation is enabled; energy consumption estimates are not computed, however automated scenario executions and flexible advanced input data are possible. The model covers CO, CO_2, NO_X, PM and VOC emissions. All of these features make this model of key import to studies which focus on road-scales and for which acquiring excessive data may be problematic.

2.3.4
MOBILE and MOVES

[7] http://emisia.com/products/copert/copert-5

[8] http://emisia.com/files/workshop/2016/07%20Copert%20Street%20Level%20presentation.pdf

The US EPA advises that the MOBILE models series are inappropriate for current regulatory analysis, since they do not account for recent vehicle and fuel emissions standards. The models also do not consider a very large amount of new emissions and activity data now incorporated in the Motor Vehicle Emission Simulator model series. The MOBILE series have been superseded by the MOtor Vehicle Emission Simulator (MOVES) series.

The MOBILE model, developed by the US EPA, calculates emissions from passenger cars, motorcycles, light and heavy duty trucks is based on compiled data of numerous vehicles. The pollutants calculated by the model are hydrocarbons (HC), oxides of nitrogen (NOx), and carbon monoxide (CO). MOBILE also accounts for the influence of emission standards, changes in vehicle activity, population and any other variations in temperature, humidity and fuel quality. With the results from these tests, current and future projected inventories at the national and local level were calculated.

After the development of MOBILE 1 model in the 1970's, understanding and data of emissions, changes in vehicles, engines and emission control system technologies, regulations, emission standards and test procedures all led to updates in the model. Between 1978 and 2004, ten versions of MOBILE models were developed based on the factors mentioned above and improved computing capacity. The ten models were: MOBILE1 (1978), MOBILE2 (1981), MOBILE3 (1984), MOBILE4 (1989), MOBILE4.1 (1991), MOBILE5 & MOBILE5a (1993), MOBILE5b (1996), MOBILE6.0 (2002), and MOBILE6.2 (2004) the last of the mobile models.

MOVES2010 was released in December of 2009 and updated in August 2010 as MOVESa. At the time, the model was lauded as the state-of-the-art tool for estimating emissions from highway vehicles by the USEPA. The model was developed off numerous test emissions results and a better understanding by the USEPA of vehicle emissions.

MOVES2014a (2014), is the latest model which is acclaimed by the USEPA as an advanced tool for estimating vehicular highway emissions. It is able to make calculations on the national, county and project level for criteria pollutants, greenhouse gases and air toxics. The US EPA notes that the MOVES 2014a upgrade incorporates important improvements in on-road and non-road equipment emissions calculations.

These two models were discussed to provide a background to previous examined research and to serve as a parallel to the COPERT models developed in Europe. Given the complexities of the MOVES model, its data requirements and its significant data output, the model is not as interesting as COPERT SL for the specific road calculations of this study. Unfortunately, the current version of COPERT SL cannot be applied to LAC vehicle fleets; otherwise it would be the recommendation of the proposed methodology for estimations.

3
Urban profiles of study areas

Figure 3: Study areas compared, Kingston and Rio de Janeiro

(Source: Google Map base images, modified by author)

3.1
Molynes Road, St. Andrew, Jamaica

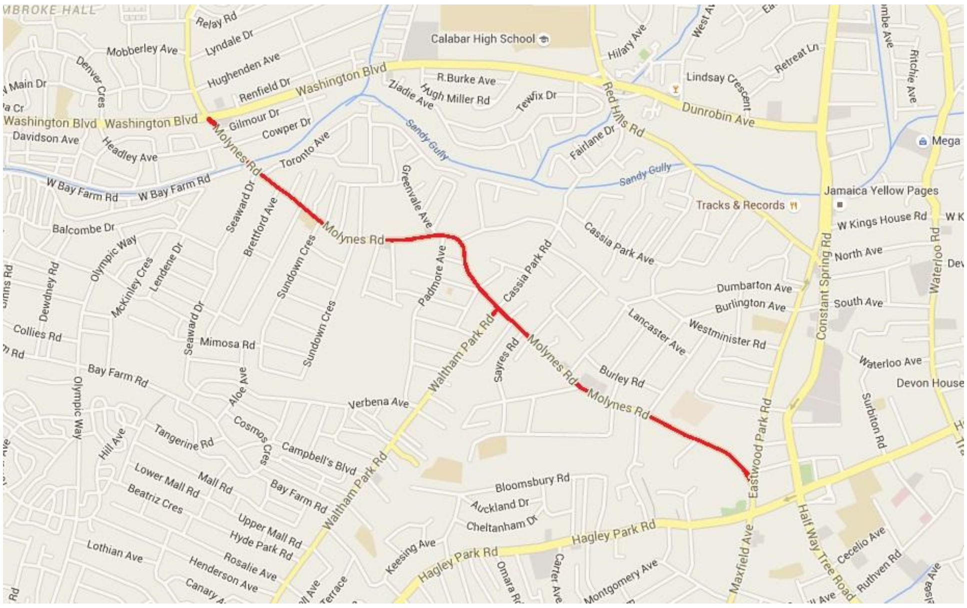

Figure 4: Molynes Road, St.Andrew - Study Area

(Base map: maps.google.com)

In Jamaica, the parish of Kingston and St. Andrew is considered the main business hub of the country. Kingston is restricted to the core of "Downtown" or Kingston 1 through 4, the rest of what is known as Kingston falls into St. Andrew. There is an estimated population of 666,041 (2012)[9] people in the Parish with low to high-income homes and a visibly evident class structure, similar to Rio de Janeiro.

Although Molynes Road extends from Perkins Boulevard to Eastwood Park Road for about 4.51 km, the study is restricted to the right half off Washington Boulevard, extending about 2.71km to Eastwood Park Road, ending near the transport centre (Figure 3). This stretch has a greater concentration of businesses and households and receives a greater variety of traffic. The area is densely populated along the road and less dense in the residential areas off the main road. The area is mostly composed of lower-middle income and middle-income families. There are many houses that have been subdivided into apartments and serve as rentals for university students, rural to urban migrants, and young professional couples.

Given the profile of its adjacent residential areas, schools, churches, auto-garages, wholesalers, restaurants, beauty salons and even small markets can be found along the road. The road is highly traversed and traffic is very heavy during peak hours on weekdays, with lighter traffic on weekends. This heavy traffic influences commuting time and increases travelling times. It should be noted that there are two thoroughfares that lead to other main roads; these are Waltham Park Road and Cassia Park Road (Figure 3). On weekdays these alternate thoroughfares are also highly congested.

As mentioned, this stretch of Molynes Road (Figure 3.) is densely populated (residential schemes, businesses, pedestrians, street vendors, auto-mechanics and others) and is associated with a heavy flow of vehicles on the busy streets and heavy traffic build-up and congestion during peak hours. Peak traffic hours are in the morning from about 7:30 am to 9:30 am and in the evenings from about 5:30 pm to 8:30 pm. This coincides with the bulk of workers in the Kingston area travelling to and from work. Physically, the traffic occurs mainly as a result of the Halfway Tree

[9] http://statinja.gov.jm/demo_socialstats/populationbyparish.aspx

Transport Centre (HWT TC) at one end, which is an intersection with streets and roads that are heavily used leading to bottlenecks and on the other end, Washington Boulevard which also supports heavy traffic and provides the alternate route into HWT from Spanish Town, St. Catherine.

Three commonly used commuting modes (i.e. Walking, coasters and JUTC buses) have great possibilities for higher exposure to air pollutants. All of the modes essentially take the same route with variations in exposure time and concentrations based on average heights and relative time in traffic. Coasters and JUTC buses are passenger buses; JUTC buses are larger, in their majority air conditioned and cater for over 100 people. Coaster-buses are smaller and in their majority aren't air conditioned. They generally hold more than their recommended capacity because of overcrowding of buses. In coasters windows and the main door are usually open, and as they are closer to the ground persons are more exposed to dust and re-suspended particulate matter along the route.

3.1.1.
Kingston Public Transportation System: Overview

The Jamaican public transportation system is governed by the Transport Authority (TA) of Jamaica, under the Ministry of Transportation and Mining. There are six categories that define the operation of the public passenger vehicles across the country (Table 5), these being: Route taxis; rural stage carriage; JUTC sub-franchise; Hackney carriage; Contract carriage; and Express carriage. With the exception of the JUTC sub-franchise, exclusively buses, and route taxis, exclusively cars, the other categories are a mixture of cars, mini-buses or coasters.

For this paper the number of public passenger vehicles (ppv) and private vehicles on the Jamaican roadways was of great importance (Table 6). Emphasis was placed on public passenger vehicles and commercial carriers since these operate in greater numbers within in the study area. Several routes are linked to the study area due to the concentration of residential schemes and businesses along the road. It must be noted that there is a large number of informal route taxis and rural stage carriages, locally referred to as 'robots' operating on this thoroughfare and within the study area. These 'robots' are not licensed to work as public passenger vehicles, most are silver plated and those that are red plated (public passenger vehicles), are not licensed to act as route taxis. There is currently an effort by the Transport Authority (TA) and the police, to decrease the number of these vehicles operating in Kingston and across the country; a similar effort has been ongoing in Rio de Janeiro for over three years. In Rio, the program has been highly successful in some areas and not as successful in others, with public passengers being affected when routes into densely populated communities cease to exist.

Table 5: Types of Public Passenger Vehicles, Jamaica

Type	Vehicle Type	Description	Num. of Passengers/ Seats	Observations
Route Taxis	car	May carry passengers paying separate fares along a designated route; stopping to pick up or let off passengers along route.	<10 seats	Route cannot exceed 18 miles / 30km
Rural Stage Carriage	bus	Carries passengers for hire or reward, at separate fares, stage by stage, along a designated route; stopping to pick up or let off passengers at designated stops.	>11 passengers	-
JUTC Sub-franchise	bus	Stage carriage licensed to operate within the Kingston Metropolitan Transport Region (KMTR).	-	Operate solely within KMTR
Hackney Carriage	car	Carries passengers for hire or reward by standing or plying for hire on thoroughfares or places frequented by the public.	-	-
Contract Carriage	car & bus	Carries passengers for hire or reward under expressed or implied contract, for use of whole vehicle, at agreed rate or sum.		Can only stand or ply for hire on roads or places designated for such activities
Express Carriage	bus	Carries passengers for hire or reward, at separate fares for each passenger and for a journey from one or more points specified in advance to one or more destinations.	>11 passengers	-

(Source: TAJ)

According to the Transport Authority as of September, 2016 there were 20,554 public passenger vehicles in Jamaica and 1,684 routes (Table 6).

Table 6: Number of licensed PPV by category and their routes in Jamaica

Licence Types	Number of Vehicles*	Number of Routes
Route Taxis (car)	11872	1014
Rural Stage Carriage (bus)	2473	632
JUTC Stage Carriage (bus)	367	29
Hackney Carriage (car)	1430	-
Contract Carriage (car & bus)	4385	-
Express Carriage (bus)	27	9
Total	20554	1684

*Number of licensed vehicles as of September 22, 2016 (Source: TAJ)

3.1.2
State of the Air in Kingston, Jamaica

In 1993, a road emissions study was conducted in Jamaica and reported by the University of the West Indies in 2001. According to the factsheet by the University, total estimates of emissions (tonnes) by vehicles were: 65,416 (CO); NOx (11,230); VOCs (9,867); and Pb (158.8).

The Kingston Metropolitan Region (KMR) has had its air under scrutiny for a number of years, more so after the Riverton Landfill fire of 2015. The local bodies in charge of monitoring air pollution have also been called to task given the quick rise in motor vehicle fleets and the presence of heavy manufacturing industries in the area; refinery, cement, electricity, and others.

The National Environment and Planning Agency (NEPA) is responsible for the implementation of programs (standards, regulations, air quality networks, air quality monitoring) to manage air quality across Jamaica. To fulfil its duty NEPA collaborates with the Environmental Health Unit (EHU) of the Ministry of Health, the Jamaica Bauxite Institute (JBI), the Jamaica Public Service Company (JPSCo), Petroleum Corporation of Jamaica, Meteorological Services and the Transport Authority.

Jamaican air-quality regulations and standards exist under the Natural Resources Conservation Authority Act (NRCA), which provides the necessary framework, under the 2006 Air Quality Regulations, for regulating emissions from major and significant point sources. These were developed pursuant to Section 38 of the NRCA Act of 1991.

In 1996, the NRCA Ambient Air Quality Standards Regulations were developed, emphasising the responsibility of the Government to ensure the integrity of ambient air quality to the protection of human and environmental health. These Regulations and Standards support the national air-quality monitoring programme by the NRCA-NEPA. Under these regulations ambient air-quality limits for critical air pollutants are outlined, namely: total suspended particulates, PM having diameters not less than 10 micrometres, lead (Pb), sulphur dioxide (SO_2), photochemical oxides (O_3), carbon monoxide (CO), nitrogen oxide (NO), and VOCs

The national air-quality monitoring program covers private and public facilities and measuring stations. In 2015, the NEPA operated four air-monitoring stations within the Kingston Corporate area and in St. Catherine, with two additional monitoring stations located in Montego Bay, St. James, and May Pen, Clarendon. At the time, the monitoring program was being expanded into two other large cities, Spanish Town and Mandeville. In conjunction with these, seven monitoring stations operated by air-pollutant discharge licenses were present in the Kingston Metropolitan Area (KMA); with two being operated by the Jamaica Public Service Company; one at Petrojam Limited; three at the Caribbean Cement Company Limited; and one at the Jamaica Private Power Company.

Thirty-nine (39) self-monitoring facilities are licensed under the regulations of the air-quality monitoring program, according to reports from 2015, and are mandated by licence conditions to undertake self-monitoring activities and reporting. The NEPA uses information from these entities and from their own monitoring stations to tabulate and assess air-pollution and air-quality levels across the country. Regulations of 2015 did not yet cover emissions from motor vehicles, an important gap the NEPA, the Ministry of Transport, Works and Housing, and other partners have been working to rectify in order to develop national motor vehicle standards.

MARSTON, J, (2015) affirms that the main strategies used to maintain air quality in Jamaica include: Ambient air quality monitoring; air dispersion modelling; emissions monitoring; and limiting of sulphur content in fuel. Sixty-two monitoring sites across Jamaica exist where criteria pollutants such as: PM, SOx, NOx, Pb, TVOC, CO, GHG (CO2, N2O, CH4).

3.1.3
Fuel Profile of Jamaica

The government of Jamaica indicated in 2013, that at the time, Jamaica had one of the highest road densities in the world with main and parochial road networks at a total of 15,248km traversing an area of 11,400 km^2. Further, the local economy at the time was heavily reliant on road transport for passenger and freight transportation (NWA, 2013).

In 2001, the University of the West Indies reported that Jamaica's vehicle fleet doubled from 171,000 in 1993 to 348,000 in 1999. Gasoline consumption increased parallel to this, from two to four million barrels between 1989 and 1996. The 2016 number of registered vehicles was of 20,554 and Jamaica currently imports an average 26 million barrels of petroleum a year.

Petrojam, currently supplies approximately 54% of Jamaica's annual 26-million-barrel petroleum requirements, while bauxite companies across the country import 35% for their operations. The remaining 11% is directly imported for the transportation sector by multinational companies. The company is in charge of most of the oil refinery processes for the country, the products they produce can be seen in Table 7. Regarding the 87 and 90 Octane gasoline produced by the company, these have been shown to be the two most acceptable levels for the Jamaican market and vehicle fleet.

Table 7: Products produced by Petrojam, Jamaica

	PRODUCT	DESCRIPTION AND USE
1	LPG/Cooking gas	Used for heating, cooking and making plastics
2	Naphthasol	Used as cleaning solvent
3	Gasoline	87 and 90 Octane grades of petrol for the transp. sector
4	Jet Fuel/ Kerosene	Fuel for jet engines, other aircraft and domestic equipment
5	Automobile Diesel/Gas Oil	Used in diesel engine vehicles and to operate generators
6	Heavy Fuel Oil	Used for industrial operations such as power generation and marine transportation
7	Asphalt	Used for road construction

(Source: Petrojam Website)

Vehicles in Jamaica are mainly imported from Europe, the USA, Japan and South Korea. There are no automobile factories in the country, and there are several luxury car concessionaires apart from standard models. Calculating emissions

estimates for such a fleet can be tricky given the different engine types and generally retrofitted and refurbished nature of most of the vehicles present in the country. As result of these imports into Jamaica, using the COPERT model, which focuses only on European vehicle models, is not advisable; MOVES models are better suited.

3.1.4
Further Observations: Emission Standards and Studies, Jamaica

Vehicles in Jamaica are mainly imported from Europe, the USA, Japan and South Korea. There are no automobile factories in the country, and there are several luxury car concessionaires apart from standard models. Calculating emissions estimates for such a fleet can be tricky given the different engine types and generally retrofitted and refurbished nature of most of the vehicles present in the country. As result of these imports into Jamaica, using the COPERT model, which focuses only on European vehicle models, is not advisable; MOVES models are better suited.

In 2003 the National Environment and Planning Agency (NEPA) of Jamaica, prepared the Update of Motor Vehicle Emission Standards for Jamaica. Although the document has not resulted in updated standards, it made recommendations as to the emissions of pollutants and I&M based on US, European and Japanese emission values and standards. These three were considered since, at the time, the Jamaican feet of vehicles, in its majority, came from these three locations. Currently, the Jamaican fleet also includes a significant number of vehicles from South Korea.

The NEPA document examines the types of mobile sources and their characteristics considering on-road vehicles, aircrafts, rail traffic, off-road vehicles and other devices with small engines. It considers the status of mobile air pollution sources in Jamaica and above mentioned sources for the year 2000. Of key interest, the paper outlines the necessary information required for MOBILE computations, making mention of a modified MOBILEJ (MOBILE Jamaica), as well as, making mention of the COPERT modelling program. The paper does not make any computations; instead, it highlights how these estimations could be made based on the mentioned considerations and the modelling program chosen.

The Jamaica Air Quality Management Programme, prepared by the NEPA in 2010, continued building on concerns related to emissions from industries, mobile sources and others. The paper focused on the development of an Air Quality Management Programme to monitor emissions through installations nation-wide that would capture and store data on key pollutants being emitted. Data gathered would allow for epidemiological studies, protection of public health and welfare, provide information to public on the state of the air and develop and guide relevant policies.

Of relevance to this current study, is the data provided on the total discharges and prevalence of respiratory disease in general and asthma in particular, among the cohort of 0-6 years (Table 8) where there is a noticeable decrease in cases. The NEPA concludes that this was likely as a result of the elimination of lead from gasoline and the ready availability of leaded gasoline, which currently only exists in pockets of the country. Although this data is from 2009, it gives an idea as to the cases of respiratory discharge, infectious and parasitic in nature.

Table 8: Respiratory system related disease and prevalence, Jamaica (2007)

ITEM	YEAR				
	2003	**2004**	**2005**	**2006**	**2007**
Total Asthma Discharge Among Children 0-6 Years	1042	830	1352	752	474
Asthma Prevalence per 10,000 Population (Children 0-6 Years)	4	3.1	5.1	2.8	1.8
Total Discharges For Respiratory Diseases in Jamaica	11,606	10,300	10,966	7,745	5,983
Respiratory Disease Prevalence per 10,000 Population	44.1	39	41.3	29	22.3
Total Discharges for Respiratory Diseases Children 0-6 Years	6,005	4,928	5,500	3,548	2,256
Respiratory Disease Prevalence per 10,000 Population Children 0-6 Years	22.8	18.6	20.7	13.3	8.4

(Source: Information from the Ministry of Health Jamaica, 2009: Jamaica Air Quality Management Programme)

The document goes on to consider the concentration of particulate matter, collected by a high volume sampler, and the results gathered. In 1989, an air monitoring exercise conducted by the Ministry of Health's Environmental Control Division found that the levels of particulate matter in areas such as the Spanish Town Road, Washington Gardens, Cooreville Gardens and Duhaney Park (areas near the Molynes Road), were up to thirteen times the recommended 150 micrograms per cubic metre[10]. Considering the increases in vehicles, construction,

[10] Recommendation by the National Ambient Air Quality Standards and the USEPA

industries and other activities which create PM, this issue remains a cause for concern.

3.2
São Conrado to Gávea, Rio de Janeiro, RJ, Brazil

São Conrado (SC) and Gávea, are connected neighbourhoods located in Rio de Janeiro, city, Rio de Janeiro, state, Brazil. Both are considered as residential areas catering mostly to upper-middle-income and upper-class residents, with large pockets of low-income residents in informal settlements known as "favelas". Malls, golf courses, various medical offices, high schools and middle schools, a university, supermarkets and informal vendors operate along or just off the main thoroughfare within the area of influence of the study.

Although the main thoroughfare in question, "Auto-Estrada Lagoa-Barra" the Lagoa-Barra Highway, crosses several neighbourhoods, the study focusses on the segment of road after Fashion mall and through the Zuzu Angel tunnel, which leads into Gávea. The portion of the road which can be found in São Conrado, services mostly high-middle class and upper-class residents of the area, with noticeable pockets of "favelas", in the area, the most notable being "Rocinha", located above the highway and built into the mountain-side. "Rocinha" begins along the São Conrado portion of the highway and Zuzu Angel Tunnel, where several roads lead up into the hills where over 70,000 people are believed to reside.

Like Molynes, São Conrado's highway has several activities which occur along its length serving as the main route for persons coming from Barra and Recreio and are heading to São Conrado and Gávea; along with condominiums, apartments and houses in the area. As a result, the area suffers heavy traffic congestion during peak hours, when persons are heading to school and work, located either in the South Zone, or Barra, and when they are returning home. Additionally, although the Lagoa-Barra highway is wider than Molynes, it is essentially a two-laned highway, with lanes of traffic periodically branching off to turn offs. However, there is a centre lane as it nears the Zuzu Angel Tunnel entrance it bottlenecks into two two-lane roads which are the tunnel. Further, the built-up nature of the communities found within the influence areas and the presence of residential and commercial buildings along it, gives it a similar corridor feel as Molynes.

Study area A, RJ:

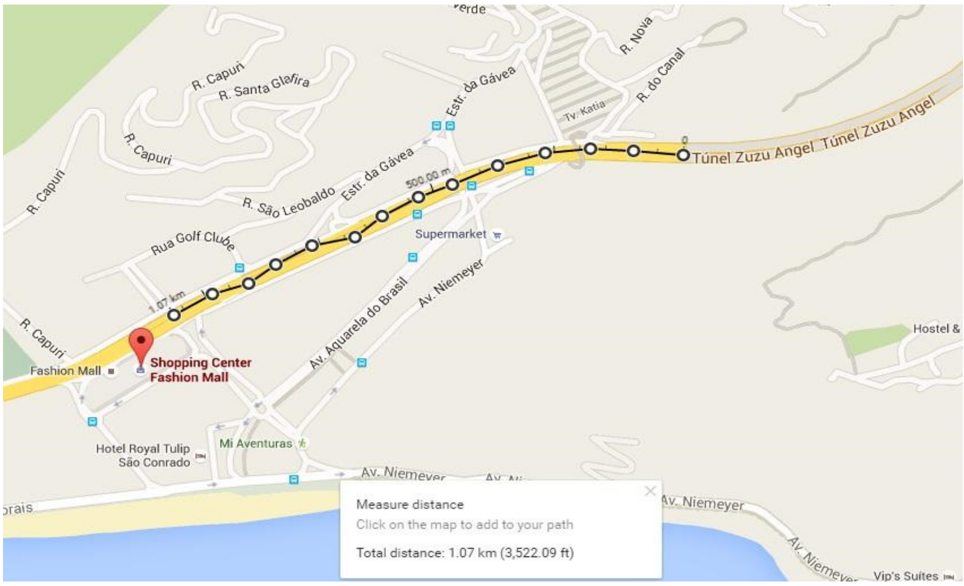

Figure 5: Map of Rio de Janeiro, RJ - Study Area A - Highway São Conrado to Rocinha

(Base map: maps.google.com)

Study area B, RJ:

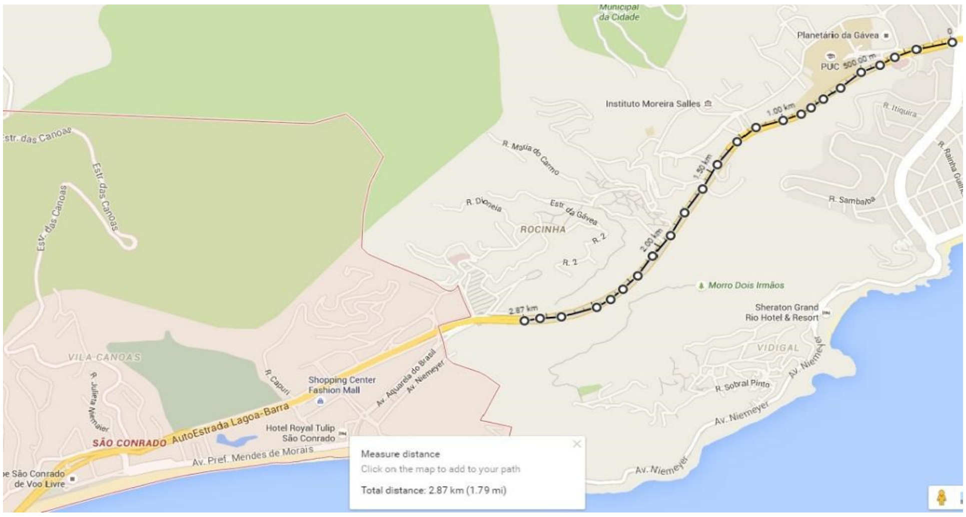

Figure 6: Map of Rio de Janeiro, RJ - Study Area B - Zuzu Angel Tunnel to Gavea

(Base map: maps.google.com)

The São Conrado portion of the highway extends for 2.3[11]km from Joá to the entrance of Zuzu Angel Tunnel; the portion this study focusses on begins at Fashion Mall and ends at Zuzu Tunnel Entrance roughly 1.07km of road (Fig. 5). Congestion along the thoroughfare occurs during peak hours, and results from the high number of residential areas and commercial establishments that encroach on the highway. It is also important to note that like Molynes, there is a main alternate route, this one hugs the coast over the Atlantic Ocean, and passes briefly along another “favela” by the name of “Vidigal”. These are the two main routes to head to the South Zone when coming from Barra, or to Barra from the South Zone. Given the high use mentioned, and the constraints imposed by the topography, residential areas, business establishments, encroaching and inadequate housing, the reasons for significant traffic build-up become clear.

Buses, similar to the JUTC buses in size and capacity, cars, motorcycles and bicycles traverse this thoroughfare. Unlike the majority of JUTC buses in Jamaica, at the time of investigations in 2015, not all buses running the Lagoa-Barra Highway route were air-conditioned; most notably the 200’s lines, 309 and the 316 numbered busses being mostly non-air-conditioned fleets. Most cars in the city are Brazilian made and air-conditioned. Motorcycle riders must wear helmets, and like Jamaica are allowed to travel through traffic. Pedestrians utilize sidewalks along the highway and the branching roads until meeting the Zuzu Angel Tunnel. Pedestrians are not allowed into the Zuzu Angel tunnel, given its length and the possibility of high exposure to dangerous pollutants like CO which can have disastrous acute health effects.

3.2.1. Rio de Janeiro’s Public Transportation System: Overview

The Brazilian institute of Geography and Statistics (IBGE) provides statistical information to the public, which is regularly updated, and at no cost on their website. This allows for transparency of the system and provides researchers a simple means of accessing baseline data.

[11] Roadway lengths were measured off Google source maps of the study areas.

The 2016 survey on vehicles by the National Traffic Department, of the Ministry of Cities of Brazil (DENATRAN), divides vehicles into eleven categories; Table 9 shows the names of the vehicle categories and the 2016 survey of registered vehicles in the Capital City of Rio de Janeiro. According to IBGE municipality and city information, there are a total of 2,699,949 vehicles, (with the total number on IBGE being 2,730,992 considering other vehicle categories not mentioned in tables) in Rio de Janeiro capital; 6,063,901 in the State of Rio de Janeiro; and 91,178,065 in Brazil.

Table 9: Vehicle categories and amounts in the city of Rio de Janeiro

CATEGORY OF VEHICLES	NUMBER OF RESPECTIVE VEHICLES IN Rio de Janeiro (City)
Automobiles	1,979,632
Trucks	43,154
Tractor-trucks	4,160
Pick-up trucks	123,929
Wagons	147,354
Minibuses	18,031
Motorcycles	287,883
Scooters	42,951
Buses	18,578
Tractors	298
Sport Utility Vehicles	33,979
TOTAL:	**2,699,949**

(Source: IBGE Website)

Rio de Janeiro has a very well developed and established urban transport system. Although there is room for improvement, there are many positive features which must be mentioned. Some of these include the wide range of buses and fares which allow for efficient premium and express services and which caters to persons who live in remote areas of the city. Attempts have been made to further integrate these areas by the combined use of bus rapid transit (BRT), trains, metros and buses.

The provisioning of buses and the like for the public transportation system in Rio is controlled by four main consortiums. The consortium responsible for the study area is Transcarioca, it is composed of 16 transportation companies that provide about 96 routes (see Table 10) to the public in the city alone[12]. These bus services ranged from about USD$1 to about USD$5 at the time of study mid-2015, until the price readjustments in 2016. The more expensive services are premium

[12] http://www.rioonibus.com/rio-onibus/consorcios-e-empresas/

and express services, and generally cover longer distances or specific routes, provide more comfort and cater to the wealthier segment of the population. Transportation vehicles with lower fares cater to the general population and can be jammed to capacity, something that is strictly regulated with premium and express buses. At the time of study, the metro-line from the south-zone into Barra da Tijuca was being completed for the 2016 Olympics. Therefore, all of the transportation between Barra and the South Zone was done through buses.

Table 10: Some services and routes provided by the Trans-carioca Consortium

SERVICE	DESCRIPTION	NUMBER OF ROUTES
LECD	Special Data Collection Lines	4
SV	Varying Services	11
SP	Partial Service	6
SE	Occasional Service	2
SN	Night Service	27
-	General lines and services	96

(Source: Modified from Rio Ônibus Consortium website)

There are minibuses which are operational in certain areas of the city, mainly in the suburbs and informal housing areas. These mini-buses were once prevalent forms of transportation around the city of Rio de Janeiro however, their use was aggressively targeted by the government and public transportation consortiums. Eventually the use of minibuses was curtailed and limited to specific areas, a highly unpopular government and agency decision especially for persons residing in informal communities and those living in suburban areas. Many persons who resided in areas where these mini-buses had no issues passing though, were forced to find alternate means of getting on to main roadways where they could access the public transportation provided by the consortiums.

At the time of study in 2015/2016, around 33 bus lines were being discontinued and others being re-assigned. This once again led to public dissatisfaction, specifically of persons who no longer had easy access to transportation, in the form of buses, with routes closer to their places of residence.

Unlike Kingston, there are little to no shared public transportation vehicles (PPV) which are automobiles. Only chartered taxis and Uber cars act as public transportation vehicles in the city. In informal settlements there are public motor-cycles which are available for hire, as a result of narrow, winding roads and hills, making motor-cycles more capable of accessing these areas and more affordable.

3.2.2
State of the Air in Rio de Janeiro, RJ

Air quality has been monitored in Rio de Janeiro since 1967 (Inea, 2014). The first study examining air quality by means of a monitoring network was done in 1996 and was supported by the Municipal Secretariat of Environment. The Federal University of Rio de Janeiro was in charge of developing the project. The study served as a guide for implementing air quality monitoring activities under the responsibility of the municipality in 2000. At the time, the installed network possessed four fixed, automatic stations and one mobile station (SMAC, 2014).

After the system was interrupted and was non-functional for two years, in 2008 the City Council and Petrobras established a partnership to implement the MonitorAr-Rio programme. The programme had the objective of re-establishing the operation of the municipal network of air quality measurement. Apart from returning to data collection, the partnership planned additions to the network by means of four new fixed stations, in addition to the older stations, and an investment in meteorological sensors and ozone analysers. This new network was complemented by an environmental education programme, which sought to inform children, adults and elders about air quality.

In 2012, a general report was prepared on air quality in Rio de Janeiro, resulting directly from MonitorAr-Rio. Beside the results on data taken from 2011 to 2012 on air quality, it also included basic concepts on atmospheric pollution and monitoring practices. A study on the areas around the stations was also presented.

With the granting of the title of Olympic City 2016, the State Institute of Environment (Inea) of Rio de Janeiro sought to amplify and modernize air quality monitoring and meteorological data tracking. To this end, sixteen new automatic air quality monitoring stations were installed between 2013 and 2014. Together with the five existing stations, the total number of stations in operation for air quality monitoring is twenty-one (SEA, 2014). Although the focus was on areas where Olympic competitions would occur, a legacy remains in areas where there is a lot of traffic and great population density accounting for higher levels of air pollution from transportation vehicles.

The above-mentioned stations continuously take samples of NOx, CO, SO_2, O_3, HC, and VOCs gases and particulate matter. The network is semi-automatic, with 63 samples capable of monitoring the concentration of particulate matter in the air and differentiating between inhalable or breathable, for 24 hours uninterrupted in six-day cycles (Inea, 2014). Beside these, the monitoring network of the state also relies on the support of stations operated and maintained by companies with a significant polluting potential. These stations are setup to send their data in real-time to INEA through an environmental license.

3.2.3
Fuel Profile of Rio de Janeiro, RJ

According to Petrobras, owner of Brazil's main Petroleum refineries, the refinery at Duque de Caxias (Reduc) was initially established to supply fuel to Rio de Janeiro and its nearby regions. Since then, the refinery has grown and now supplies eight states (Rio de Janeiro, São Paulo, Espírito Santo, Minas Gerais, Bahia, Ceará, Paraná and Rio Grande do Sul) and produces 55 products at 43 processing facilities; the main products produced by Reduc can be seen on Table 11, in no particular order.

Reduc is presently one of the largest refineries in Brazil with fully installed and operating refining capacities. It is responsible for the production of 80% of total lubricant production, is the largest natural gas processing plant in Brazil and has the most extensive portfolio of products.

There are two main categories of automotive gasoline commercialised in Brazil; Common (with a minimum of 87 Octane) and Premium (with a minimum of 91 Octane). From these two bases, distributors can offer gasoline which meet or exceed these categories. "Additive" gasoline in Brazil is Common gasoline with additives.

Table 11: Main products produced by Reduc refinery

	PRODUCT
1	LPG/Cooking gas
2	Petroleum Naphtha
3	Gasoline
4	Jet Fuel/ Kerosene
5	Automobile Diesel/Gas Oil
6	Petrochemical Gases
7	Asphalt
8	Paraffin
9	Lubricants
10	Coke
11	Sulphur

(Source: Modified from Petrobras website)

Petrobras has an exclusive blend of Premium gasoline which it commercialises as Podium (with a minimum 95 Octane) that also receives additives. By Brazilian Federal law, all gasoline must be mixed with anhydrous ethanol in the percentages demanded by the current legislation. In 2015, these percentages were of 27% in Common gasoline and 25% in Premium gasoline. Ethanol is also available at gas stations.

It is important to note that Brazil possess engines which are classified as Flex Engines, capable of receiving both gasoline and ethanol available at gas stations. Common gasoline can be used in vehicles with flex engines or gas engines. Commercialised Common gasoline by Petrobras, apart from being 87 Octane, have a maximum sulphur content of 50 ppm, no additives or colouring agents; Grid gasoline, developed for engines with electronic fuel injection, have additives and a green colouring agent; and Podium gasoline, distributed solely by Petrobras, is 95 Octane with a maximum sulphur content of 30 ppm, additives and no colouring agents.

Base gasoline, the primary product which then receives the anhydrous ethanol, is produced at several refineries, formulators and petrochemical centres across the country, or can be imported by companies authorised by the National Petroleum Agency (ANP) of Brazil.

3.3
Methods of assessment and quantification

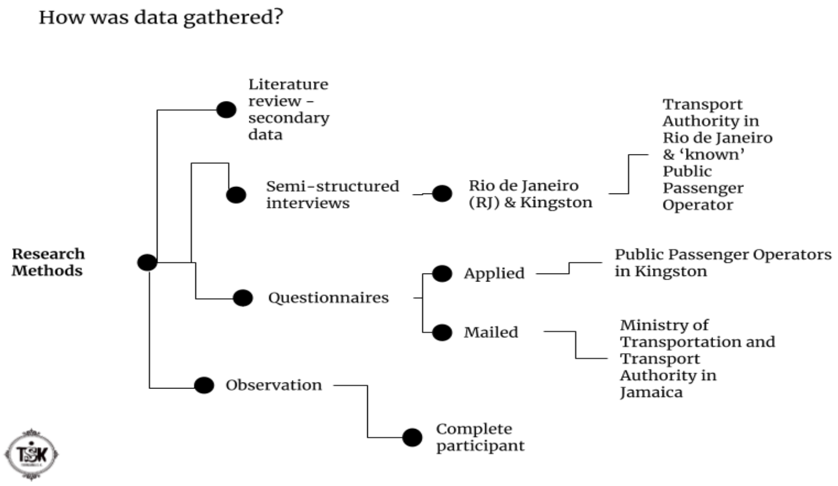

Figure 7: Research methodology - How data was gathered

Primary data was acquired through informal questionnaires (APPENDIX 1) conducted with licensed and "robot" public passenger operators during the course of three weeks. Secondary data on modelling types for exposure and emissions was gathered through a review of the literature. Data on the Jamaican public transportation sector was acquired from the Ministry of Transport and Mining of Jamaica and the Transport Authority of Jamaica. Information on Rio de Janeiro was acquired from government websites such as IBGE, MME, Rio ônibus, among others. Information regarding Jamaican air-pollution programs and Monitor-Ar program in Rio de Janeiro were gathered from online sources, which included official government websites, digital reports and articles (Figure 7). For direct comparison between study areas, the study conducted by Abbas (2014) on emissions of the transportation sector of Rio de Janeiro was used.

Emission quantities were calculated and extrapolated from received and investigated values for Jamaica (APPENDIX 2, 3 and 4). Additionally, a modified social cost assessment based on the model by Bilbao-Ubillos is considered and calculated. The study aims to give a snapshot of information currently available and to allow for future studies to prove or disprove information herein contained. Molynes road, the Lagoa-barra Highway and Zuzu Angel Tunnel are considered because of their repeated high volumes of traffic and congestion. Information gathered on the two thoroughfares and tunnel, is mostly from personal observations of the author and mentions in news reports and articles.

The collection and review of data allowed for the development of the study methodology being proposed for future studies in LAC cities where acquiring necessary data may be difficult. A Hybrid Study Model is proposed to analyse and quantify urban road emissions in the areas of study and to examine possible correlations between individual exposure and adverse health effects related to air pollution. The researcher is advised to make use of personal monitors to measure individual exposure and to complement this data by the use of dispersion models for both study areas. The dispersion model will rely on background baseline data from regional monitoring equipment, extrapolated individual exposure concentrations for road traffic emissions and acquired health data. GIS modelling software should be used to geo-reference the gathered data and to create relevant map overlays to illustrate relationships.

3.3.1
Linking vehicles, fuel and emissions

To contextualise the difference in scale between Rio de Janeiro, city and Kingston & St. Andrew, Jamaica Table 12 should be considered. The state of Rio de Janeiro is four times (4x) the size of Jamaica with about six times (6x) the population of the Caribbean Island. In comparison, the city of Rio de Janeiro is about three times (3x) the size of Kingston and St. Andrew Parish with about nine and a half times (9.5x) the population. Each city has its own culture, demographics and priorities, both however have been facing drawbacks and critiques because of their public transportation system and both have cause for concern with respect to pollutant emissions and air quality.

Table 12: Comparison between study areas - size and population

LOCATION	SIZE	POPULATION
Rio de Janeiro (State)	43,696 Km^2	16.46 million
Jamaica	10,991 Km^2	2.881 million
Rio de Janeiro (City)	1,255 Km^2	6.32 million
Kingston & St. Andrew	480 Km^2	666,041

(Source: Brazilian data - IBGE and Jamaican data - STATINJA (Statistical Institute of Jamaica)[13])

[13] statinja.gov.jm/Demo_SocialStats/populationbyparish.aspx

According to the Tax Administration Jamaica (TAJ), the agency responsible for keeping records on registered vehicles and licences in Jamaica, in 2016 there were 372,630 registered motor vehicles. TAJ estimated the unregistered fleet of motor vehicles nationwide at 15%, adding about 55,895 estimated motor vehicles to Jamaica's fleet. Motor vehicles registered by TAJ can be classified as seen in Figure 8. Vehicle categories and numbers for the city of Rio de Janeiro can be seen in Table 9 with 11 categories and 2,699,949 registered motor vehicles.

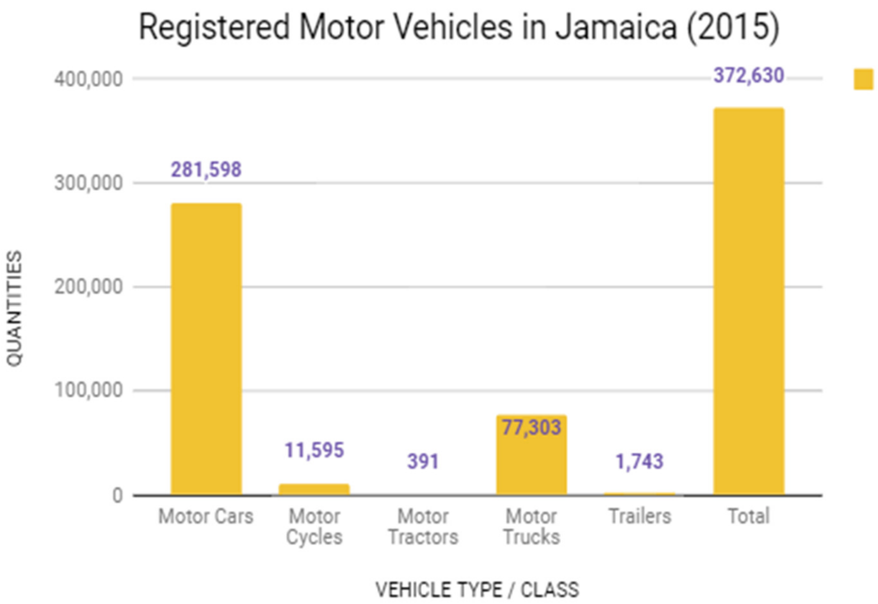

Figure 8: Registered motor vehicles in Jamaica by type

(Source: Tax Administration Jamaica, 2016)

In the last All Island Feasibility Study, conducted by the Transport Authority of Jamaica in 2012, Kingston and St. Andrew possessed 4,002 registered public passenger operators, about 18.1% of the registered PPV at the time. Of these, 947 were legal operators, 934 were illegal operators, 1,509 were contrary operators (operating outside their licences), 82 were informal operators and 449 operators did so with expired licences. In 2016, Kingston and St. Andrew registered 137,995 motor vehicles, representing about 37% of all registered vehicles in Jamaica (see Figure 9).

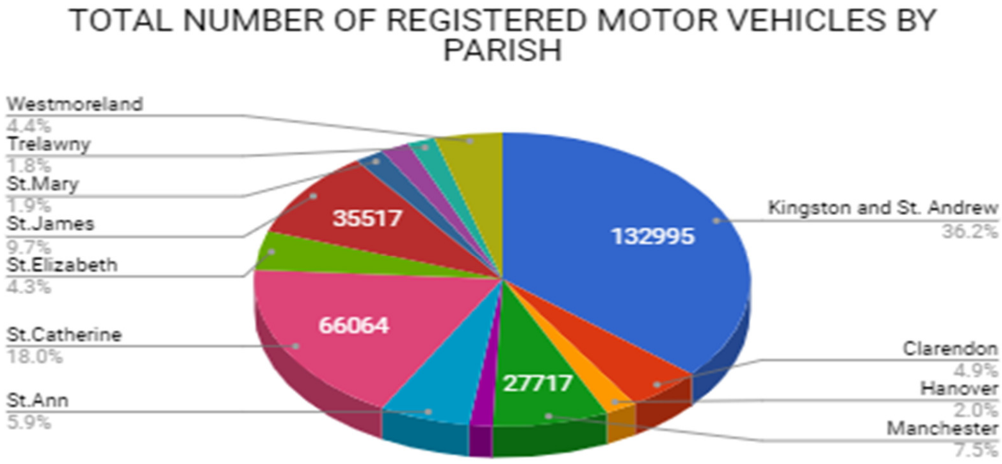

Figure 9: Vehicles registered by parish in Jamaica (2015)

(Source: Tax Administration Jamaica, 2016)

St. Catherine is one of the Parishes that feeds directly into the Kingston and St. Andrew Parish. Many of its residents in towns like Spanish Town, Portmore and Old Harbour, work and study in Kingston and St. Andrew. The parish had the second highest number of registered motor vehicles, at 66,064 and St. James, where one of Jamaica's tourism and business centres is located, Montego Bay, reported the third highest number at 35,517 motor vehicles (see Figure 9).

At the end of 2016 the Jamaica Urban Transit Company reported 367 operational buses covering 29 routes, of the 29 routes, six traverse the study area of Molynes Road as can be seen in Table 13. A key concern for the JUTC has been the maintenance of its buses as close to 100 of them were parked due to lack of parts, poor maintenance and decreased lifespan. Most buses are assumed to have a lifespan of over 20 years however, as a result of road conditions, vandalism and lack of adequate maintenance and repair, the lifespan of JUTC buses is reportedly halved. The JUTC believes that by 2018/2019 their fleet of buses will require new units to be able to serve their current 250,000 daily passengers.

Table 13: Average number of JUTC buses travelling on Molynes Road weekly

JUTC BUS ROUTES ON MOLYNES AND RELATIVE NUMBER OF BUSES PER ROUTE			
ROUTE	**WEEKDAYS**	**SATURDAY**	**SUNDAY**
21	14	8	7
21AX	4	0	0
21B	11	2	4
30	7	5	3
47	8	6	3
75	8	7	5
Total:	**52**	**28**	**22**

(Source: Modified by author Jamaica Urban Transit Company, 2016)

In Rio de Janeiro, about the same total of registered vehicles in the parish of Kingston and St. Andrew, reportedly 118,500 to 130,000 vehicles pass through the Zuzu Angel Tunnel (Case Study). Additionally, at Herbbert Moses Street, which intersects the Lagoa-Barra Highway in São Conrado, over 72,994 vehicles/daily were registered in 2013. This meant that between Herbbert Moses Street and Zuzu Angel Tunnel, there were between 45,500 and 57,000 additional vehicles which were concentrated in the study area and contributed to traffic and emissions of pollutants. Given the overall increase in vehicle ownership and new residential buildings in the area, the amount of people now living in the area has increased; and by extension congestion during peak hours is likely to also increase.

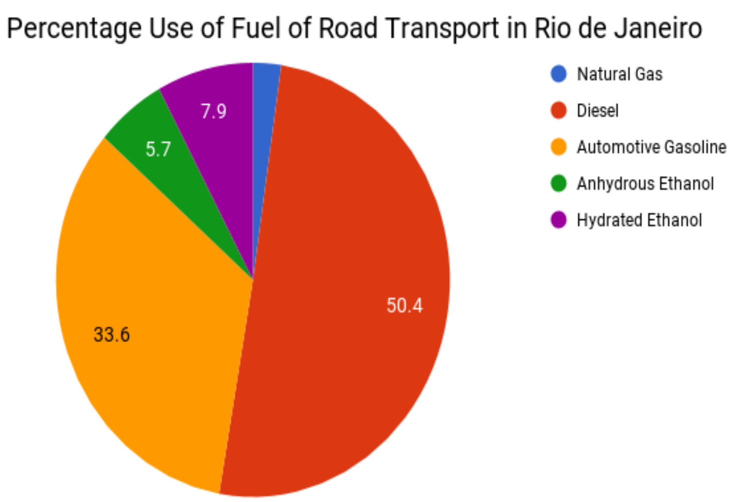

Figure 10: Discrimination of fuel use in Rio de Janeiro

Abbas (2014) states that road transport continues to be the main type of passenger and cargo transport in Rio de Janeiro, and the same can be said for Kingston. Given its importance, this mode of transportation naturally consumes most of the energy by fuel (Figure 10), derived in its majority from petroleum. However, although buses and heavy vehicles are among the highest emitters of CO_2 when compared to other modes of transportation (by passenger and by Km) they, together with metros, are the ones that least pollute as seen in Table 14.

Table 14: Relative emissions of CO2 of urban transport – modal matrix of CO2 emissions, Rio de Janeiro

MODE	KILOMETRIC EMISSIONS Kg of CO_2Km	AVERAGE OCCUPANCY RATES OF PPV	EMISSIONS/Kg per CO_2/PASS Km[1]
Metro	3.16	900	0.0035
Bus	1.28	80	0.0160
Automobile	0.19	1.5	0.1268
Motorcycle	0.07	1.0	0.0711
Heavy Vehicles	1.28	1.5	0.8533

(Source: Translated by author, modified table by Abbas, 2014)

If one further considers the above, in general terms and according to pondered factors relating to transportation mode, capacity, energy, and pollution by passenger, in Rio, every unit of bus is equivalent to 65 cars or 50 motorcycles for the same number of passengers (Abbas, 2014). As it relates to pollution, motorcycles pollute 32 times more than buses while automobiles pollute 17 times more.

Table 15: Comparative indicators of energy use and pollution emissions of buses, automobiles and motorcycles in Rio de Janeiro

MODE	OCCUPANCY PERSON/ MODE	EMISSIONS/Kg per CO_2/PASS Km[1]	
		ENERGY[1]	POLLUTION[1]
Bus	1.28	80	0.0160
Automobile	0.19	1.5	0.1268
Motorcycle	0.07	1.0	0.0711

Note: [1]Base was calculated in large equivalencies of petroleum (diesel and gasoline) | [2] Includes CO, HC, NOx and PM. (Source: Translated by author, table by Brazilian National Association of Transport Operators (NTU), 2009.)

Both motorcycles and automobiles waste more energy (fuel) per person transported than buses. The argument here is that in terms of energy efficiency, and environmental impacts, public transportation is the best choice for transporting passengers. Table 16 compares emission factors for automobiles, motorcycles and different fuel types, cross comparisons are shown with respect to vehicles and fuel and their respective emission factors; e.g. Flex-engines using hydrated ethanol, have an increased EF over common gasoline and flex-gasoline. It is important to note, when considering emissions by vehicles, that engines are becoming increasingly sophisticated so as to minimize the emission of pollutants. Abbas (2014) outlines this carefully through pondering the various stages of Proconve (Automotive Vehicles Air Pollution Control Programme) and concluding that fewer overall emissions existed for more recent vehicles; accounting for the difference seen in Tables 16 and 17 where there is a decrease in the EF for specific pollutants.

While public transportation can be a more effective and efficient way of transporting people, inefficient transportation and high individual automobile presence on roads, compounded with bottleneck roads, obstructions, tunnels and nearing communities generally lead to congestion, high localised emissions and resulting health issues. Congestion must be understood and managed to ensure that urban transit is a benefit and not a detriment to adjacent communities.

Table 16: Emission factors for CO, NMHC, RCHO, NOx, CH4, and PM for automobiles, motorcycles and LNG vehicles in g_pollutant/Km (older engines)

POLLUTANTS		Carbon Monoxide (CO)	Nitrogen Oxides (NOx)	Particulate Matter (PM)	(RCHO)	NMHC	Methane (CH4)
Light automobiles and commercial vehicles with Otto cycle engines	C. Gasoline	0.3	0.02	0.0011	0.0017	0.034	0.011
	Flex - Gasoline C	0.33	0.03	0.0011	0.0024	0.032	0.011
	Flex - Ethanol Hydrated	0.56	0.032	-	0.0104	0.03	0.011
Motorcycles	Gasoline C	1.02	0.1	0.0035	-	0.14	0.03
LNG Vehicles		0.56	0.29	-	0.0038	0.026	0.22

(Source: Translated by author, table by Abbas, 2014)

3.3.2
Understanding and calculating the social cost of congestion

For this study the modified social costing model considered is based on one designed by Bilbao-Ubillous (2008). It is used in his work as a method of identification, measurement and pricing of congestion costs on cross-town link roads. The original model considered cost and welfare loss resulting from congestion under two main headings: financial and environmental, with four sub-categories each. Given the difficulties in acquiring environmental data relevant to both study areas, the second component of the methodology was not included. This study considers the financial costs and welfare loss under the Bilbao-Ubillos model.

Table 17: Emission factors for CO, NMHC, RCHO, NOx, CH4, and PM for automobiles, motorcycles and LNG vehicles in g_pollutant/Km (Improved newer engines)

POLLUTANTS		Carbon Monoxide (CO)	Nitrogen Oxides (NOx)	Particulate Matter (PM)	(RCHO)	NMHC	Methane (CH4)
Light automobiles and commercial vehicles with Otto cycle engines	C. Gasoline	0.2	0.0133	0.0007	0.0011	0.0227	0.0073
	Flex - Gasoline C	0.22	0.02	0.0007	0.0016	0.0213	0.0073
	Flex - Ethanol Hydrated	0.3733	0.0213	-	0.0069	0.02	0.0073
Motorcycles	Gasoline C	1.02	0.1	0.0035	-	0.14	0.03
Urban Bus (Diesel)		0.0328	0.1669	0.0028	-	0.0067	-

(Source: Translated by author, table by Abbas, 2014)

It is explained by Bilbao-Ubillos (2008) that in seeking to estimate the costs and welfare losses in environmental terms, resulting from congestion on cross-town links, a distinction must be made between theoretical levels of exposure to emissions and noise and actual risks due to the proximity of the road segments most directly affected by the negative externalities resulting from heavy traffic. Accordingly, 'level one' exposure is found in the immediate surroundings of the streets in question and subsequent levels are found among people living in streets progressively further from the initial streets. Both study areas possess settlements and activities along the main thoroughfare, and subsequent tiers of residential areas as one moves out from the cross-links in question.

The four major financial costs or welfare losses associated with congestion on cross-links can be identified as the following:

I. Valuation of time loss as a result of congestion (Vehicle delay - C1)

This first item considers the difference in travel speed between the expected speed and the average/actual speed observed under congestion situations. The drop in speed, caused by congestion, accrues additional travel time, priced in terms of the average hourly wage of the region/country. Therefore, there is a differentiation between the current congested scenarios and a congestion free alternative, in the case of this study, the route at free-flow traffic. The monetary equivalent is the price of the time lost as a result of congestion on the road studied, or C1.

$$\text{Or: } C_1 = W\ (D^1 x\ V^1 - \ D^2 x\ V^2)$$

Where:

- ➔ C_1 = cost in monetary units of time lost
- ➔ D^1 = length of current road
- ➔ W = current average hourly wage in monetary terms
- ➔ D^2 = average length of proposed alternate route (km)
- ➔ V^1 = observed average speed over the road
- ➔ V^2 = Theoretical speed on alternate route km/h

II. Valuation of increased depreciation of vehicles and additional fuel consumption (C2)

The second item is used to refer to the additional costs incurred due to congestion in terms of additional fuel, oil consumption, vehicle maintenance and depreciation. Two assumptions of the model with respect to this are that: a. Any additional costs mentioned will be proportional to fuel consumption which is estimated directly; and b. Vehicles travelling along a congested road will consume fuel at in-town levels and when travelling along a non-congested road that they will consume fuel at out of town levels. The financial cost (C2) arising from additional fuel consumption, attributable to congestion, in vehicles travelling on a cross-town link can be expressed as:

$$C_{2=P(D^1\,x\,G^1 - D^2 x\,G^2)}$$

Where:

- ➔ C_2 = financial cost from additional fuel consumption
- ➔ D^2 = average length of proposed alternate route (km)
- ➔ P = average price of fuel measured in USD/L
- ➔ G^1 = average in town fuel consumption of vehicles in L/100 km
- ➔ D^1 = length of roadway
- ➔ G^2 = average out-of-town consumption of vehicles in L/10 km

III. Estimation of exposure hours of workers of economic activities along route

This item catalogues the types of businesses/economic activities to be found along the routes and the estimated work-hours of these; time cross-checks the operating hours of the economic activities to see if they occur during peak-hours when congestion is noticed. This section also identifies the residential areas that are influenced by the negative externalities of this congestion.

IV. Valuation of material damage arising from congestion-related accidents (C3)

The final item identifies specific accidents associated with traffic congestion on cross-town links, such as: Molynes and Lagoa-Barra. These can be attributed to decreases in speed because of multiple obstacles and to intersections with town/street networks respectively. Here, the monetary cost of accidents is taken as the result of a valuation of personal injuries and material damage caused. Overall it is important to note that these values can sometimes underestimate the social value of personal injuries in accidents. This valuation can be expressed as:

$$C_3 = P\ x\ V_p + D\ x\ V_d$$

Where:

- ➔ P = number of cases of personal injuries
- ➔ D = number of cases of material damages
- ➔ V_p = average unitary value of personal injuries
- ➔ V_d = unitary value of material damages

4
Critiques, Calculations and Recommendations for Future Studies

4.1 Urban Traffic Profile City Critiques

Both Kingston and Rio de Janeiro have considered the questions of urban transportation, air quality monitoring and fuel supply. Although differing in actual scales of size, both cities have cause for concern when it comes to emissions from mobile and stationary sources. This has led to integrated considerations and manuals on urban transport emissions, and the monitoring of some critical tunnels in Rio, and the acknowledgement of the need for mobile emission standards in Kingston. Additionally, both cities have divided the responsibility of air quality and emissions monitoring with key industries that themselves contribute significantly to stationary emissions and stack pollutants. When it comes to fuel and its supply, there doesn't appear to be any constraints to acquiring and producing sufficient quantities and products, to meet demands, by both Petrojam and Petrobras.

Notwithstanding, Kingston and Rio de Janeiro must assess and work towards understanding and meeting the respective transportation needs of their populations, especially those who have longer distances to travel. In the case of Kingston, these issues manifest with the lack of bus and taxi routes that target more affluent parts of the city this does not allow fluidity to and from these areas. The Transport Authority in 2016 and 2017 also placed more stringent requirements on registered route taxis, limiting pick-up locations and demanding greater modifications to be made to vehicles, while simultaneously employing zero-tolerance measures on "robot" taxis.

The above actions are problematic as they create uncertainty and chaos that commuters who work in hard to access areas must face daily but are also required to be on time. The need to go to these areas, regardless of if it's at an extra cost, and to get there on time, has created the high demand for the service route taxis, who are often off-route, and robot taxis provide. It also creates a problem of security which has manifested itself in several kidnapping and sexual assault cases in 2016 and 2017, in Kingston and Portmore, St. Catherine.

The issue is complex and balance has not yet been stuck. The increasing costs to register vehicles, register as a route taxi operator, and pay insurance for taxi vehicles, has led to potential “legal drivers” opting for illegality. This point was clearly brought out in the disparities between reported yearly insurance paid by registered route taxi operators, between J$ 200,000 (US$ 1562.89) to J$ 400,000 (US$ 3125.77) Jamaican dollars, and non-registered “robot” route taxi operators, between J$ 30,000 (USD$234.43) to J$ 40,000 (USD$312.58) Jamaican dollars. Interestingly vehicle groups share similar model types and model years, so it is not a matter of older versus newer vehicles.

These observations by no means seek to excuse the actions of “robot” and route taxis, but merely to illustrate the task before the governing transportation bodies of Jamaica. The TA must consider means of providing safe and reliable transportation to areas beyond the current boundaries of its transportation route, in order to provide alternatives to the public. Although small steps have been taken in this direction, with the establishment of some new routes such as, the Barbican to HWT route, line 74, and improved scheduling times of the Downtown to Barbican route, line 76, there remains a significant portion of the area which is by no means covered. These areas continue to appeal to registered and unregistered taxis, creating similar issues on Molynes Road, Eltham Road and taxis heading to Portmore and Spanish Town.

If the Transport Authority manages to address the issue properly, where more provisions are made for registering persons as legal drivers, and alternatives are provided in the forms of new bus lines and routes, then tougher stances against unregistered “robot” taxis can be taken and the public would be more willing to comply. Better understanding of urban transportation leads to improved flow of traffic and systems and better policies.

For Rio de Janeiro, the advent of modified and discontinued bus lines and routes and the recent partial incorporation of bus rapid transit and metro systems have resulted in inadequate steps being taken to meet the needs of the population. Prior to the introduction of the BRT system in the West Zone of Rio, steps had already been taken to crack-down on “illegal” mini-buses operating in the suburbs, informal settlements and formal residential neighbourhoods. Commuters came to rely heavily on government sanctioned public transportation systems provided by transportation consortiums in Rio de Janeiro. Changes were approved and implemented quickly, with little concern paid to the average commuter, given the hosting of international events: the 2014 World Cup and the 2016 Olympics. Many people were left to fend for themselves for part of their commute.

Although these urban transportation changes were to encourage a modern take on transportation in the city, in actuality there was greater chaos with over-packed BRT buses, loss of bus routes, incomplete transportation transitions (between buses and other transportation modes) and hikes in fares. The public has, in essence, been forced to pay more, for less. With less areas being covered by buses, fewer buses overall, less travel continuity and many buses still not being air-conditioned, there are clearly important gaps that must be looked into by the Transport Secretariat of Rio.

Disadvantaged persons in both cities are those who are poorer and those who live further away. Shorter routes mean several transport modes to arrive at the same destination as before without changes in salaries and working hours; as a result, the less fortunate are required to make bigger sacrifices of their time and their salaries to continue working or studying in certain areas. More planning is needed which considers all commuters who have a greater reliance on public transportation systems and generally bear the brunt of ineffective policies and regulations.

Air pollution monitoring must continue to be of interest to local agencies where improved regulations and monitoring techniques must be developed to account for increases in vehicles, emissions and possible negative health repercussions. Rio City Hall must make greater efforts to encourage studies of their tunnels and highly congested roadways as well as the eventual implementation of monitoring stations in these areas. Kingston transportation and environmental health agencies must create adequate standards that assess and monitor mobile sources of pollution. Once emission patterns and effects are well understood steps should be taken to address existing road, traffic and health concerns.

Urban cities require continuous monitoring and observation. Research and data development is essential to change urban form so that it reflects the needs of the population and allows for better standards of living.

4.2
Interviews: Conclusions and Observations

Interviews with Jamaican (Kingston and St. Andrew) PPV drivers were conducted during the last weeks in May, 2017 and first week in June, 2017. The interviews were semi-structured as seen in APPENDIX 1, and allowed for some observations to be made by drivers. The selection process was based on drivers taken by the researcher during the survey weeks and that were willing to answer the 15 questions. Some drivers were suspicious of the motives of the survey and had to be assured that their identities would not be divulged or recorded in any way.

The drivers who were interviewed were not distinguished by name, license plate or license number. They included formally licensed drivers operating route taxis with red plates and specific notations on doors; licensed chartered red-plate operators and; informal actors operating red places and white plates. Many of these drivers do not possess their own vehicles and work for someone who requires a specific daily return (between J$ 5,000 and J$ 7,000 for automobiles, depending on the number of seats it can hold and higher for coasters). These observations are made by the researcher based on repeated interactions with PPV operators in Kingston.

It is important to note that although all interviewed drivers were male, there are a number of women who also operate both "legal" and licensed vehicles and informal or "robot" taxis. These women are included and often moderate Whatsapp groups and meet-ups which occur with formal and informal taxi operators.

Of the 21 interviewed drivers 43% kept within their route with 38% reporting driving various routes. Other routes ran were within the Kingston and St. Andrew parish and focused on HWT as a point of departure and return. Only one driver reported not running any other route. About 48% of drivers reported running routes between 11 to 16+ times a day. About 33% of drivers who reported running several routes reported that they completed over 11 trips a day. This infers that some drivers, in an attempt to avoid traffic or increase income based on passenger needs, may run shorter routes during the day.

Operators were drawn to locations either at the beginning or at the end of their one-way trip to fuel their vehicles. There was mention of then choosing the most reasonable gas station within the area to fill tank. Although most drivers (52%)

indicated filling up their tanks almost daily, a few indicated that their tanks were not necessarily empty and that this was to allow them freer movement once they had passengers. Once empty, operators generally spent between J$ 5,000 to J$ 7,000 to fill their tanks. Two drivers reported filling their tanks for J$ 4,000 and one driver paid about J$ 8,000 to fill his tank. Most vehicle models reported were post 2010 with a prevalence of Toyota vehicles; Honda and Nissan vehicles were the next highest models reported. Three drivers did not report their vehicle model and year.

Of note, filling the tank of a Toyota Probox 2010 was consistent at about J$ 6,000 and other Toyota models at around J$ 6,500. At about J$ 5,000 to fill a tank, Nissan vehicles were generally more economical than Toyotas.

Almost all operators reported doing everything possible to avoid traffic with the majority (66.7%) reporting spending under 40 minutes in traffic a day. One driver reported spending over 2 hours. It is likely that this driver is a chartered driver and as such must stay in traffic with his passenger. Drivers reported Constant Spring Road and Molynes Road as the two most congested roadways during peak hours.

As vehicular insurance is mandatory in Jamaica, all drivers reported having some form of insurance for their vehicles. Advantage General Insurance was the most reported insurance provider with policies ranging between J$ 40,000 to J$ 300,000 a year for vehicles. It is proposed by the researcher that vehicles with higher insurance policies are those licensed to act as PPV allowing multiple drivers. Most drivers reported seeing an average of one to three accidents a week along their routes; with 81% of them reporting not being in an accident in 2016 and 86% reporting not being in an accident between January and the end of May/June.

The researcher was able to candidly interview the majority of these drivers given the route taken daily and the use of their services. It is important to highlight the amazing contribution and fount of information that these operators are however, given their negative interactions with the Jamaican Transport Authority and the Traffic Police being able to conduct a wide-scale survey of them would prove difficult; however as difficult as it could be, it is necessary as it would allow authorities to gather information on total daily, monthly and yearly passengers as well as total kilometres travelled across their entire systems. This information is crucial for adequate calculating more sophisticated emissions and contributions to emissions of air pollutants in urban areas by mobile sources of the transportation sector.

4.3
Analysing and comparing emission estimates: Jamaica and Rio

As mentioned elsewhere in this paper, mobile emissions from urban transportation are a direct result of several factors, including route, temperature, fuel and vehicle age. This study sought to extrapolate results based on information provided by Jamaican government entities comparable to those gathered and presented by Abbas (2014). As such, a direct comparison between Jamaica and Rio de Janeiro could be made. Abbas (2014) utilizes 2012 data from the Brazilian Federation of Passenger Vehicles (Fetranspor) as seen in Table 18.

Table 18: Comparison of fleet and urban transportation data: Rio de Janeiro and Jamaica

LOCATION	YEAR	TOTAL NUMBER OF TRIPS	TRAVERSED Km	TOTAL NUMBER OF PASSENGERS	TOTAL FUEL CONSUMPTION	AVERAGE AGE OF FLEET
Rio de Janeiro	2012	16,514,136	755,123,683	1,200,401,168	273,669,061	3.35
Jamaica (1)	2016	92,452,018	2.04×10^{12}	921,800,784	7,579,054 (barrels)	13.79
Jamaica (2)[1]	2016	46,389,018	1.03×10^{12}	506,525,392	7,579,054 (barrels)	13.79
Jamaica (3)[2]	2016	29,115,393	6.44×10^{11}	350,797,120	7,579,054 (barrels)	13.79

Note: Scenario (1) based on reported averages by interviewed drivers (unrealistic considering overall trips made by various operators) | [1]Scenario 2 – at 8 trips a day (1/2 of reported average) considering longest trip 2x shortest | [2]Scenario 3 – at 5 trips a day, considering longest trip over 3x shortest

Data for Jamaica was provided by the Ministry of Transport and Mining and the Transport Authority. STATINJA, JUTC, NEPA publications, other government websites and informal interviews provided additional information and details for the information on the Jamaican vehicle fleet. Most calculations are extrapolations and estimates based on the available data and as such can present a high level of uncertainty. So as to understand how these numbers were estimated tables 19, 20 and 21 outline the items pondered and some of the calculations and assumptions made (additional information in APPENDIX 2). Information related to fleet age calculations can be found in APPENDIX 3.

Table 19: Scenario 1 – At 16 trips a day for all PPV vehicles – considering it will take all routes the same amount of time to complete trip, or passenger numbers will be the same

Licence Types	Number of Vehicles	Total Number of Trips / Day	Total Number of Trips / Year	Equations	Number of Passengers / Day	Number of Passengers / Year
Route Taxis (car)	11872	189,952	69,332,480	((5.3*16)*11872)	1,006,745.6 0	367,462,144
Rural Stage Carriage (bus)	2473	39,568	14,442,320	((29*16)*2473)	1,147,472	418,827,280
JUTC Stage Carriage (bus)	367	893.2	326,018	n/a	250,000	91,250,000
Hackney Carriage (car)	1430	22,880	8,351,200	((5.3*16)*1430)	121,264	44,261,360
Contract Carriage (car & bus)	4385	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
Express Carriage (bus)	27	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
Total	**20554**	**253,293**	**92,452,018**		**2,525,482**	**921,800,784**

Table 20: Scenario 2 – At 8 trips a day for all PPV vehicles – considering it will take the longest route 2x the amount of time needed by the shortest route to complete trip

Licence Types	Number of Vehicles*	Total Number of Trips / Day	Total Number of Trips / Year	Equations	Number of Passengers / Day	Number of Passengers / Year
Route Taxis (car)	11872	94,976	34,666,240	((5.3*8)*11872)	503,372.8	183,731,072
Rural Stage Carriage (bus)	2473	19,784	7,221,160	((29*8)*2473)	573,736	209,413,640
JUTC Stage Carriage (bus)	367	893.2	326,018	n/a	250,000	91,250,000
Hackney Carriage (car)	1430	11,440	4,175,600	((5.3*8)*1430)	60,632	22,130,680

Contract Carriage (car & bus)	4385	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
Express Carriage (bus)	27	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
Total	**20554**	**127,093.2**	**46,389,018**	-	**1,387,740.8**	**506,525,392**

Table 21: Scenario 3 – At 5 trips a day for all PPV vehicles – considering it will take the longest route 3x the amount of time needed by the shortest route to complete trip

Licence Types	Number of Vehicles*	Total Number of Trips / Day	Total Number of Trips / Year	Equations	Number of Passengers / Day	Number of Passengers / Year
Route Taxis (car)	11872	59,360	21,666,400	((5.3*5)*11872)	314,608	114,831,920
Rural Stage Carriage (bus)	2473	12,365	4,513,225	((29*5)*2473)	358,585	130,883,525
JUTC Stage Carriage (bus)	367	893.2	326,018	n/a	250,000	91,250,000
Hackney Carriage (car)	1430	7,150	2,609,750	((5.3*5)*1430)	37,895	13,831,675
Contract Carriage (car & bus)	4385	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
Express Carriage (bus)	27	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data
Total	**20554**	**79,768.2**	**29,115,393**	-	**961,088**	**350,797,120**

Emissions were calculated based on estimates inferred from acquired data and the three presented scenarios to account for some uncertainty of the collected data. Given the observed dependence of the Jamaican fleet on gasoline and the reported use of diesel, both fuel types were used to estimate total CO_2 emissions (Table 22) for the island.

Table 22: CO2 Emission Factors used for calculation

CO2 EMISSION FACTORS				
Gasoline A (kg/L)	Anhydrous Ethanol (kg/L)	Hydrated Ethanol (kg/L)	Diesel (kg/L)	GVN (kg/L)
2.269	1.233	1.178	2.671	1.999

As per Abbas (2014), to calculate the emission of CO_2 the following formulas were used:

For Diesel Estimates (EF = 2.671Kg/L):

$$E_{total} = EF \times QDiesel_{total}$$
$$E_{Km} = E_{total} / Km_{total}$$
$$O_{average} = (Total\ passengers)/(Trips \times 2)$$
$$E_{(Km/Passenger)} = E_{Km}/O_{average}$$

Where:

- ➔ E_{total} = Total CO_2 emission for the period
- ➔ EF = Emission factor (Kg of CO_2 per litre of diesel)
- ➔ $QDiesel_{total}$ = Total litres of diesel used by whole fleet
- ➔ E_{Km} = CO_2 emission per km
- ➔ Km_{total} = Total kilometres travelled by fleet
- ➔ $O_{average}$ = Average occupancy of buses
- ➔ Total Passengers = All paying and non-paying passengers and occupants
- ➔ Trips = Total number of trips by the full fleet
- ➔ $E_{Km/Passenger}$ = CO_2 emissions by Km and passenger

For Gasoline Estimates (EF = 2.269Kg/L):

$$E_{total} = EF \times QGasoline_{total}$$
$$E_{Km} = E_{total} / Km_{total}$$
$$O_{average} = (Total\ passengers)/(Trips \times 2)$$
$$E_{(Km/Passenger)} = E_{Km}/O_{average}$$

Where:

- ➔ E_{total} = Total CO_2 emission for the period
- ➔ EF = Emission factor (Kg of CO_2 per litre of gasoline)
- ➔ $QGasoline_{total}$ = Total litres of gasoline used by whole fleet
- ➔ E_{Km} = CO_2 emission per km
- ➔ Km_{total} = Total kilometres travelled by fleet
- ➔ $O_{average}$ = Average occupancy of buses

- ➔ Total Passengers = All paying and non-paying passengers and occupants
- ➔ Trips = Total number of trips by the full fleet
- ➔ $E_{Km/Passenger}$ = CO_2 emissions by Km and passenger

To calculate CO_2 emissions for Jamaica, several extrapolations were made considering passenger occupancy, Km travelled, total number of passengers and total number of trips. Additionally, assumptions were made regarding vehicle fleet composition and their respective use of fuel. This study assumed that under three scenarios (Tables 19, 20, 21) fuel being used by all registered PPV vehicles in Jamaica in 2015, was either gasoline or diesel. The values used were the known totals of E10-87 and E10-90 gasoline and auto diesel oil. It is likely that true value of consumed fuel, even under these assumptions, would have to be greater. However, as most registered vehicles in Jamaica in 2015 were cars, at 75.6% of total, this assumption was allowed.

As seen (Table 23), total emissions were the same in all three scenarios as they are a product of fuel consumed per fuel type and the standard given emission factors. If all fuel used was taken to be gasoline, regardless of E10-87 or E10-90, then total CO_2 emissions were approximately $2.62x10^9$ Kg, with fewer emissions per kilometre and emissions per kilometre per passenger than diesel. If all fuel used was diesel, approximately $3.09x10^9$ Kg of CO_2 was produced for 2015 in Jamaica.

Comparatively, in the city of Rio de Janeiro, there were fewer emissions at approximately $7.31x10^8$ Kg per 273,669,061L of consumed diesel to transport more passengers at higher occupancy. Estimated passenger values in Jamaica were at 76.8%, 42.2% and 2.42% of total passengers transported in Rio de Janeiro city, respectively for scenarios 1, 2 and 3. These values and comparisons are based off current estimates being done in this study with respect to previously mentioned assumptions.

Table 23: CO2 emissions for gasoline (with 10% ethanol) and diesel in three scenarios, Jamaica

FUEL TYPE	YEAR	TOTAL CO_2 EMISSION	EMISSION / Km CO_2	AVERAGE OCCUPANCY	EMISSION PER Km/ PASSENGER
E10-87 Gas (1)	2015	1,506,183,074.8	4.03E-04 3.33E-04	5.0	8.09E-05 6.68E-05
E10-90 Gas (1)	2015				
Diesel (1)	2015	1,315,478,731.8	6.43E-04		1.29E-04
All Gas	2015	2,623,675,116.2	1.28E-03		2.57E-04
All Diesel	2015	3,088,513,105.0	1.51E-03		3.03E-04
E10-87 Gas (2)	2015	1,506,183,074.8	1.47E-03	5.5	2.69E-04
E10-90 Gas (2)	2015				
Diesel (2)	2015	1,315,478,731.8	1.28E-03		2.35E-04
All Gas	2015	2,623,675,116.2	2.56E-03		4.68E-04
All Diesel	2015	3,088,513,105.0	3.01E-03		5.51E-04
E10-87 Gas (3)	2015	1,506,183,074.8	2.34E-03	6.0	3.88E-04
E10-90 Gas (3)	2015				
Diesel (3)	2015	1,315,478,731.8	2.04E-03		3.39E-04
All Gas	2015	2,623,675,116.2	4.07E-03		6.79E-04
All Diesel	2015	3,088,513,105.0	4.80E-03		7.99E-04
BRAZIL	2012	730,970,061.93	0,97	36.34	0.003

It is important to stress that given the nature of public transportation in Rio, managed by a consortium and integrated with almost all types of public transportation available; estimating passenger values in Jamaica is more complicated. The level of informality relating to passenger occupancy, public passenger drivers and vehicles used as PPV makes gathering accurate data complicated. Many PPV drivers will work several routes depending on the day and may full their vehicles beyond recommended capacity to increase earnings and to allow persons to get where they need to be.

To calculate CO, NMHC, NOx, RCHO, CH_4 and PM per Km and per passenger, the following formulas can be used:

For Diesel engines:

$$g_{pollutant}/Km = g_{pollutant}/g_{diesel} \times g_{diesel}/L_{diesel} \div Km/L_{diesel}$$

$$g_{(pollutant\ \llbracket Km \rrbracket\ _{(/Pass)})} = (g_{pollutant}/Km)/O_{average}$$

Where:

$g_{(pollutant\ \llbracket Km \rrbracket\ _{(/Pass)})}$ = grams of pollutant per Km and passenger

For Gasoline engines:

$$g_{pollutant}/Km = g_{pollutant}/g_{gasoline} \times g_{gasoline}/L_{gasoline} \div Km/L_{gasoline}$$

$$g_{(pollutant\ \llbracket Km \rrbracket\ _{(/Pass)})} = (g_{pollutant}/Km)/O_{average}$$

Where:

$g_{(pollutant\ \llbracket Km \rrbracket\ _{(/Pass)})}$ = grams of pollutant per Km and passenger

To further consider these calculations, fleet age must be analysed and categorised according so as to reflect the relative increase in emissions based on mileage as seen in Table 24. The Jamaican fleet is discriminated by year and overall percentages per total number of vehicles in APPENDIX 3.

Table 24: Increase in emissions attributed to pollutants based on mileage

Relative increase in emissions based on mileage, in g/80,000km				
FUEL	POLLUTANTS			
	CO	NOx	NMHC	RCHO
C GASOLINE	0.263	0.03	0.023	0.00065
HYDRATED ETHANOL	0.224	0.02	0.024	0.00276

(Source: Translated by author, table by MME)

Because of the increased level of uncertainty related to all the elements necessary to calculate CO, NOx, NMHC, RCHO, PM and CH4, the author chose not to calculate these figures believing results would not be realistic enough. For ideal calculations, the Jamaican fleet would have to be better discriminated by fuel type and by year and previous scenarios, including their relative uncertainties, would be used for calculations.

4.4
Social Costing, estimating the economics of congestion

Social costing can be an important tool to analyse congestion in ways different from the calculation and estimation of emissions or the distance travelled and fuel used. The method allows for attributing cost to being delayed along a congested thoroughfare, extra costs incurred by additional fuel consumption as well as more subjective measurements such as, dissatisfaction and irritation. Finally, once the data is available, the model is able to estimate and cost the impact of accidents as a result of congestion.

Given the difficulty in gathering the necessary data to calculate the other three items of the social costing method, only the first item C1 was calculated. C1 sets the foundation for where social costing can take urban problems like congestion when considering somewhat subjective issues.

Table 25 looks at the incurred costs of congestion along the two thoroughfares under study. As expected, the greatest costs arise from the lowest speed travelled on the roadway. This amounts to a loss of about 732 USD/hr on Molynes road and about 1131.2 USD/hr on the extent of the highway under study in Rio. These numbers bring an interesting perspective to congestion and indicate how costly the problem really is.

Table 25: Time lost as a result of congestion is USD/hr

a) The value of the time lost as a result of congestion (vehicle delay)					
C1=	**CONSIDERATIONS**	**Molynes**	**Lagoa-Barra**	**Zuzu Angel Tunnel**	**RJ - Total Study Road**
W	Average hourly wage	3.00USD/hr	3.19USD/hr	3.19USD/hr	3.19USD/hr
V1	Observed average speed over road	10km/hr	10km/hr	10km/hr	10km/hr
		20km/hr	20km/hr	20km/hr	20km/hr
		30km/hr	30km/hr	30km/hr	30km/hr
		40km/hr	40km/hr	40km/hr	40km/hr
D1	Length of current road	2.71km	1.07km	2.87km	3.94km
D2	Average length of proposed alternate road	2.71km	1.07km	2.87km	3.94km
V2	Speed on alternate road	100km/hr	100km/hr	100km/hr	100km/hr
c1=w(d1xv1-d2xv2)					
C1	**LOCATION**	**10km/hr**	**20km/hr**	**30km/hr**	**40km/hr**
	Molynes	**-731.7 USD**	**-650.4 USD**	**-569.1 USD**	**-487.8 USD**
	Lagoa-Barra	**-307.2 USD**	**-273.1 USD**	**-238.9 USD**	**-204.8 USD**
	Zuzu Angel	**-823.9 USD**	**-732.4 USD**	**-640.9 USD**	**-549.3 USD**
	RJ - Total Study Road	**-1,131.2 USD**	**-1,005.5 USD**	**-879.8 USD**	**-754.1 USD**

4.5
Proposed Guidelines for Estimating Exposure and Emissions in Caribbean Countries

The proposed methodology to estimate exposure and mobile emissions comes from an assessment of the literature, and from considering the possible data constraints for researchers wishing to conduct such a study in LAC countries where data may not be readily available. The methodology is structured into four parts and recommends, for best results, that the estimations be done two to three times a week, for two weeks, for three months. It is important to detail road and weather conditions at each outing, for recapping data and comparisons to meteorological data which may be acquired.

Part I – Understanding the baseline: This first part looks at the streets being studied. Thoroughfares to be considered should be buffered, through the use of GIS or other map software, at intervals of 50m from the road (50m / 100m / 150m / 200m). This is based on the literature that indicates studied pollutants may travel past 100m.

- At location, following the 50m meter marks, as much as possible, measuring emissions at each point;
- Follow the 50m point step above at 3 to 5 spots along the roadway being studied;
- Acquire data from national monitoring stations near the study area for the same day exposure is being tested by handheld device;
- Use dispersion model software to establish background baseline, note expected exposure at measured locations;
- Compare expected results to measured results.

Part II – Vehicle volume information: On the roadways being tested acquire vehicle count and vehicle volume information, from counters set up my local transport authorities, or manually through the use of a counter. Get this information for peak and nonpeak hours.

Part III – Individual exposure monitoring: Using a personal monitoring device, conduct exposure measurements through the three main forms of commuting mentioned previously in this paper:

- Walking for 1 hour during peak hours and 1 hour non-peak hours (optional to remain at one location exposed to the road for this step);
- Using indoor/handheld device, record exposure information in a bus while travelling at peak hour and non-peak hour (full hour not necessary for non-peak hours);
- Using indoor/handheld device, record exposure information in a mini-bus or car while travelling at peak hour and non-peak hour (full hour not necessary for non-peak hours);
- Ensure that weather and road conditions are observed.

Part IV – Vehicle emission estimations: Recommended model to be used for this step is MOVES (given the fact that many vehicle imports in the Caribbean are from the US, EU and Japan, this model allows for the computation of these variables easily once there is knowledge of gas emissions by engine type). This information can be gathered from local transportation agencies, car exporters and importers, or the websites of car fabricators.

- Using gathered fuel, vehicle type and engine types, apply any other gathered data to MOVES to estimate the road emissions of each day the exercise was completed;
- Compare personal exposure values to estimated emissions exposure values, use any difference to calibrate model;
- Extrapolate information for a work year or a school year, representing persons who are sitting in traffic and commuting along the roadway;
- Overlay any information using GIS or other mapping software;
- Overlay results gathered by measuring personal exposure, representing persons who reside or mostly work in the area;
- If any health data has been lifted or acquired for health complaints of residents in the area, overlay these results.

These steps should be followed by data analysis; Discussion of results and observations.

Given the general lack of data on emissions and exposure in the region, any data that can be shared with institutions or health agencies is recommended.

4.6
Case Study: Zuzu Angel, a cry for study

Although Tunnels provide convenient travel, they simultaneously cause air pollution due to poor dispersion conditions as compared to open roads and may pose health risks. In tunnels, the concentration of PM_{10}, CO, NO, NO_2 and SO_2 increases as a result of the “piston effect” in these half-sealed spaces resulting in higher concentrations of pollutants (MA, C; et. al, 2011). Additionally, health studies have demonstrated that exposure to roadway PM can increase the risk of respiratory illnesses and be detrimental to human health (MA, C; et. al, 2011).

Air discharges through portals are complex and dispersion can be rapid depending on the configuration of the site. This type of discharge generates more risk of high concentrations of pollutants in urban areas. This in turn will likely affect adjacent human communities and nearby fauna and flora.

In 2012, 'O Globo', a Brazilian newspaper in Rio de Janeiro (ANTUNES, Laura. 2012), reported on the state of the tunnels in Rio by stating that these are not properly lit, they do not possess systems of exhauster fans, signalisations, and in some galleries the structure present signs of infiltration. According to the report, the tunnels that were the worst off were Reboucas, Noel Rosa, Joa and Zuzu Angel Tunnels. The faults presented by these went from a lack of adequate lettering on signs, to signs of infiltration, poor ventilation, exposed wiring and poor lighting.

Concerns about the state of some of these tunnels in Rio de Janeiro resulted in a study from 2009 to 2013/14, mentioned in two key reports and national journals, (MOTTA, Debora. 2008/2009; and MOUTINHO, Sofia. 2014) on the state of two tunneled areas (Rebouças Tunnel and Av. Brasil). The results indicated the severity of their relative situations, with one being precarious and the other possessing particulate matter exposure surpassing those advised by the World Health Organisation. Additionally, in the Reboucas Tunnel study, it was noted that some workers suffered mutations to their DNA (Tunnel Reboucas).

These results indicate that while air quality in Rio de Janeiro has been monitored since 1967 (Inea, 2014), boosted by automatic and semi-automatic stations and received an overhaul between 2014-2016 that expanded the monitoring network to twenty-one stations, there are still key localised issues. These locations require specialised targeted tests which are expensive to develop and time consuming to implement.

Located between the Atlantic and inland hills, Rio de Janeiro possess a topography that requires tunnels to allow movement between neighbourhoods. Given this need, maintenance of these tunnels should be a priority since they are essential to the socio-economic strength of the city. Further, studies and periodic checks should be conducted not only to ensure the physical integrity of the structures, but also the air quality within the structures. Especially since time spent in the tunnels can occasionally range from under a minute to several hours because of traffic jams, accidents or other incidents.

Previously known as Tunel Dois Irmaos (Two Brothers Tunnel), Tunel Zuzu Angel (Zuzu Angel Tunnel), is found in the city and state of Rio de Janeiro, Brazil.

It was inaugurated in June, 1971 extending 1522 meters and integrating the Zuzu Angel System, linking the neighbourhoods of Sao Conrado and Gavea, in the South Zone of the city. The system is further complemented by the Tunel Acustico (Acoustic Tunnel) extending 550m, the Tunel de Sao Conrado extending 250m and the Tunel do Joa extending 426m.

The system became a part of the constituency of the municipality of Rio de Janeiro in September of 1993. In 1993, the system catered to about 130 vehicles / day, currently over 118,000 vehicles pass through a day. It was monitored by a system of pollution control, closing for maintenance and cleaning from Mondays to Tuesdays, from 23hr00s to 5hr00s, except on weekends (Wikimapia).

Under ideal circumstances, ventilation systems will ensure that pollution levels are low inside the tunnel by diluting any pollutants emitted and outside the tunnel by contributing to a reduction in emissions. Zuzu Angel Tunnel relies on natural ventilation to circulate air within its passages. Here, two factors contribute to this system by creating a longitudinal air flow. The first is the piston effect caused by the directional traffic flow and an increase in levels of turbulence. The second is the difference in weather conditions between the two portals (atmospheric pressure, temperature or wind) which may be the cause of significant air glow in a tunnel. Natural ventilation is sufficient only to dilute pollutants in the case of short tunnels, with over 1km of tunnel, Zuzu Angel would ideally require added technology to properly dilute and remove pollution emitted within the space.

Longitudinal mechanical ventilation consists of pushing the air mass within tunnels outwards, with no additional fresh air aside from what is entering the portals. Waste air is almost always removed directly through the portals; this process can be supplemented by point extraction, or mass extraction, systems where thrust can be created by jet fans positioned on the undersides of a tunnel's roof. This added technology makes this ventilation system more effective. However, this feature it is not present in the Zuzu Angel Tunnel.

The natural longitudinal mechanical system of air ventilation found in the Zuzu Angel Tunnel is further aided by central dividing walls which are built as extensions from the ends of tunnels to prevent the recirculation of polluted air. Ideally, they can be used to prevent polluted air discharge at the end of one tube by penetrating the inside of the other tube under the vehicle induced piston effect; this can also be achieved by offsetting portals by 30 to 50 meters for two parallel one-way tubes. This configuration of portals between tunnels can be seen in the Zuzu Angel Tunnel.

When visited in 2012 (ANTUNES, Laura. 2012) by a local news team and a member of the Regional Council of Engineering and Agronomy of Rio de Janeiro (Crea-RJ), certain concerns were raised. Along with the other tunnels visited key concerns were presented on the Zuzu Angel tunnel, these being a lack of: exhaust systems, emergency telephones, signs with speed limits and radars. Additionally, signs of infiltration at some sections of the tunnel were noticed. While the physical aspects were noted, there was nothing mentioned about the air quality within the tunnel, especially in cases of traffic jams, accidents and other incidents.

When contacted about the above issues, the Municipal Secretariat pointed out that several entities are responsible for various maintenance activities within these tunnels. Comlurb, cleans; Rioluz, repairs lighting and other physical features; and CET-Rio, coordinates closures as well as identifies maintenance problems which need attending to in several tunnels. Based on this one could argue that MonitorAr-Rio should be responsible for air quality within tunnels, as they are responsible for air quality throughout the city. In reality, their focus is geared towards general air quality, seemingly ignoring these enclaves. As a result this increases the need for studies to be done on air quality in these tunnel systems.

5

Final Considerations

Urban public transportation is essential to the day-to-day activities of the majority of the population living in cities. Public transportation should provide reliable mobility alternatives to those who work or study in areas far from their homes and that do not possess their own mode of transportation. It is important that policy-makers and transportation agencies focus on creating policies that benefit those who rely on public transportation the most.

There is a need for Latin American and Caribbean States to conduct their own studies of the interactions between mobile emissions, air pollution and health effects. There are several available models and methodologies that can be used to allow national agencies and researchers to study air pollution, mobile emissions and to identify correlations between these and negative health effects in adjacent neighbourhoods. Given increases in population, urban areas and vehicles, it is necessary that LAC states understand the dangers posed by not adequately monitoring emissions from the get-go.

Since Jamaica and Brazil already possess emission capturing stations and have systems in place to monitor this data, it is recommended that periodic studies be done considering emissions and health effects. It is important that all countries create and update databases on their vehicle fleet, fuel use, kilometres travelled, passenger totals, air pollution emissions and make this data available for future studies.

This study has shown that it is possible to compare urban issues in LAC countries, especially related to complications arising from growing cities, once parallels are clearly identified and within shared contexts. Further, urban issues are not isolated; they trickle down to the day-to-day lives of people manifesting themselves as congestion, disease, increased air pollution and even stress.

Estimations of pollutants is possible within the LAC context however it requires that information be readily available for use and that government agencies be more transparent in making information available. Although results from studies can be damning, they allow for the identification of a problem and may offer new solutions not previously considered. Further, in allowing for comparative studies between LAC countries, the strengths of certain policies and practices can be seen and even adopted to fit the realities of another country.

With respect to transportation and the heavy involvement of the informal sector and informal actors, it is likely that the trend will grow if the needs of the population are not adequately considered and met. It is necessary to understand all sides of the issue therefore, it is necessary to speak directly to formal operators, informal operators and passengers. If persons are not given plausible alternatives to informal and sometimes dangerous transportation services, then these informal actors will persist. Where there is a need, there will be a way and there will be persons ready to benefit from this need. Heavy handed tactics that remove routes, force people to increase their commuting time and encourages them to take more radical alternatives are not beneficial in the long run. This is why urban planners and transportation agencies must fully understand the challenges faced by the urban dweller who wishes to commute.

Planning for urban issues, designing and building adequate physical and policy systems will continue being relevant as cities grow worldwide. Although congestion is hard to define and measure, it is experienced; as are long delays, difficulties in commuting, mobile emissions and resulting health effects. These issues must be identified, monitored and planned for. They require complete stakeholder involvement, especially between specialist and daily commuters. Surveys through questionnaires and focus groups could prove helpful in determining the best way forward on the issue. It is only possible to adequately plan for what is understood. To understand, there is a need to experience, assess, measure and ponder solutions. Given this need, more studies of urban systems, transportation and emissions are necessary. This paper presents ways it can be done in LAC countries.

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Glossary of Terms

TERM	DESCRIPTION
AQM Stations	Fixed devices that continuously measure gas and particulate pollution in real time.
Exposure	Being subjected to something which may have an effect. In the case of this study, being subjected to emissions of pollutants or particulate matter.
Fatalities	Death as a result of accident, violence or disease.
Gaussian Plume Model	Calculates air pollution concentrations by assuming that a pollutant plume will be carried downwind from its emission source by wind and that the concentrations in the plume occur horizontally and vertically on midlines of the plume.
Morbidity	Described as the deviation from being physically or psychologically well; it includes disease, injury and disability.
Mortality (rate)	Measures how often death occurs within a population during a specified period or interval.
Prevalence	The proportion of persons with a specific disease or attribute over a specified time or period.
Risk	Likelihood of "something" occurring; for example, becoming ill or dying within a specified time period.

Appendices

APPENDIX	DESCRIPTION
1	**Questionnaires**
	Questions
	Responses – Part A
	Responses – Part B
2	**Rational for CO2 emissions extrapolations and estimations**
3	**Jamaica Vehicle Fleet Profile (2016)**
4	**Co2 emissions based on Jamaica's motor vehicle petroleum consumption (2015)**

APPENDIX 1 – Questionnaires

QUESTIONS – With letters (A-F) at top representing the corresponding responses in the responses tables.

		A	B	C	D	E	F (ALL)
	QUESTIONS	**RESPONSES**					
1	What is your route?	01. BAR-HWT	02. BOU-HWT	03. BOU-CRS	04. OTHER		
2	Which other routes do you run?	01. BAR-HWT	02. BOU-HWT	03. BOU-CRS	04. OTHER	05. NONE	
3	How many times a day do you run your route?	01. 1-5	02. 6-10	03. 11-15	04. 16+		
4	Where do you normally fuel your car?	01. HWT	02. BOU	03. BAR	04. OTHER		
5	How many times do you fill your tank per week?	01. 1-2	02. 3-4	03. 4-6	04. 7+		
6	How much does it cost to fill your tank?						
7	What is the year and model of your car?	Y-		M-			
8	How long do you sit in traffic per day?	<20mins	<40mins	<1 hr	1-2hrs	2hrs+	
9	Which road do you think has the most traffic and why?						
10	At what times does Molyness have a lot of traffic?						
11	Which insurance company do you use?						

12	About how much do you pay in insurance a year/a month?					
13	How many accidents do you see on your route a week?	01. 1-3	02. 4-6	03. 7-9	04. 10+	
14	How many accidents did you have last year?	01. 1-3	02. 4-6	03. 7-9	04. 10+	05. NONE
15	How many accidents have you had this year?	01. 1-3	02. 4-6	03. 7-9	04. 10+	05. NONE

RESPONSES – PART 1 (Questions 1 – 9)

Responses	1	2	3	4	5	6	7	8	9
1	A	F (ALL)	D	E	C	$7,000	2011/Toyota Wish	A	Constant Spring/Waterloo
2	A	F	C	C	B	$5,000	2008/AD Wagon Nissan	A	Constant Spring/Molynes/Red Hills Road
3	A	F	C	A	D	$4,000	1992/Toyota	A	Papine/Molynes
4	A	F		A	D	$6,000	NO DATA	N/D	Papine/Molynes/oulevard
5	A	F	D	E	D	$5,000	2002/Toyota	A	HWT/Papine/Hayley Park/Molynes
6	A	E	D	C	F	$5,000	2001/Toyota Corola	A	Barbican/Waterloo/Molynes
7	A	F	D	E	D	$6,000	2010/Toyota Isis	A	Barbican/Papine/Molynes
9	F	F	C	E	D	$6,500	2008/Honda Civic	A	Waterloo/Molynes/Trafalgar
10	E	E	B	A	C	$6,000	2003/Honda Partner	B	New Kingston

11	A	E	A	E	B	$7,500	1994/Honda Civic	F	Constant Spring/Molynes
12	E	F	A	E	D	$6,000	2012/Toyota Axio	D	Boulevard/Waterloo
13	E	F	C	E	B	$5,800	2004/Nissan	E	Boulevard
14	C	E	E	B	D	$6,000	2011/Toyota	B	Molynes
33	A	F	D	E	B	$6,500	2010/Toyota Probox	A	HWT
37	E	A	C	B	B	$6,000	2011/Toyota Wagon	B	Molynes/Constant Spring
38	E	E	B	E	A	$6,000	2010/Toyota Probox	C	Trafalgar/Barbican/HWT Road/Oxford
41	E	E	B	E	B	$6,000	NO DATA	B	Hope Road/Old Hope Road/Molynes/Spanish Town Road
43	E	E	N/D	B	A	$5,000	Toyota Probox	B	Molynes/Bou/Waltham/Maxfield/Spanish Town Road
44	E	E	B	E	C	$8,000	NO DATA	C	Molynes/Waterloo/Constant Spring Road
45	B	C	A	B	C	$7,000	2010/Mazda	B	Molynes
46	C	B	C	E	C	$4,000	2011/Nissan Expert	D	Molynes/Waterloo

RESPONSES – PART 2 (Questions 9 – 15)

9	10	11	12	13	14	15
Constant Spring/Waterloo	F	Orion Insurance	2x year total 400+k	A	E	A
Constant Spring/Molynes/Red Hills Road	F	Advantage General	2x 150k	A	A	E
Papine/Molynes	7:30 - 9:30	Spectral	52k year	A	E	E
Papine/Molynes/oulevard		NO DATA	N/D	A	E	E
HWT/Papine/Hayley Park/Molynes	After 5pm	Jamaica Intl	40K	A	E	E
Barbican/Waterloo/Molynes	Peak hours	Advantage General/BCIC	45k	A	E	E
Barbican/Papine/Molynes	Peak hours	Advantage General	180k	A	E	E
Waterloo/Molynes/Trafalgar	Peak hours	Advantage General	300k	C	A	A
New Kingston	8:00-9:00am	Advantage General	40k	A	E	E
Constant Spring/Molynes	7:30 - 9:30am and after 8pm	Key Insurance Company Limited	44k	A	E	E
Boulevard/Waterloo	4:00-5:00pm	Advantage General	170k	B	E	E
Boulevard	7:30-8:00am & 5:00-8:00pm	General Accident	33k	D	E	E
Molynes	4:00-7:30pm	Advantage General	100k	B	E	E
HWT	7:30pm & peak hours	F	F	A	E	E
Molynes/Constant Spring	Before 8:00am & 4:30-5:00pm	NO DATA	30k	B	E	E
Trafalgar/Barbican/HWT Road/Oxford	Peak hours - 7:00-8:00am	Advantage General	300k	A	A	E

Hope Road/Old Hope Road/Molynes/Spanish Town Road	7:00-9:00am & 4:00-8:00pm	BCIC	29k	B	E	A
Molynes/Bou/Waltham/Maxfield/Spanish Town Road	Peak hours 8:00-10:00am & 3:00-7:30pm	NO DATA	N/D	A	E	E
Molynes/Waterloo/Constant Spring Road	Peak hours 7:00-9:30am & 4:30-7:30pm	Advantage General	50k	B	E	E
Molynes	7:00-9:30am & 4:00-8:00pm	NCB	100k	C	A	E
Molynes/Waterloo	8:00-9:00am & 4:00-5:00pm	UGI	70k	D	E	E

APPENDIX 2 – Rational for CO2 emissions extrapolations and estimations

A. The total km of roadways in Jamaica 22,121 km (includes 44 km of expressways) https://www.cia.gov/library/publications/the-world-factbook/geos/jm.html

B. JUTC buses work for about 18 hours (1080 minutes a day), with some of the earliest bus services beginning at 5 a.m. and closing off at 11 p.m. Buses usually circulate every 20,30,40,50 minutes, giving an average of 35 minutes. Rough calculations indicate about 30.9 trips a route, or (29x30.8) 893.2 trips.

C. Buses - JUTC reports serving about 250,000 passengers a day, therefore the pondered number of passengers a year would be: 250,000*365 = 91,250,000

D. In 2013, the legal coaster bus capacity was reported as 22 persons, although it has a seating capacity of 29. The amount of trips per vehicle will vary according to the route the vehicle takes, however for the sake of consistency, the reported 16 trips a day will also be used here. (http://www.jamaicaobserver.com/news/Legal-coaster-bus-capacity-is-22--Transport-Authority-says)

E. Cars - Motor cars are 75.57% of total fleet of vehicles; if one assumes the same for PPV vehicles, of the 22,074 registered PPV vehicles, motor cars will represent about 16,681.32 of total value. Considering allowed occupancy of PPV motor cars (4 passengers) and actual occupancy based on observation (5 to 7 with 7-seater vehicles), each car would carry about 5.3 passengers per trip. Operators informally reported running their routes over 16 times a day, this would equal ((16*5.3) *16,681.32) = 1,414,575.9 a day and 516,320,216.64 passengers a year.

APPENDIX 3- Jamaica Vehicle Fleet Profile (2016)

MODEL YEAR	VEHICLE AGE	# of MOTOR VEHICLES (JAMAICA)*	TOTAL VEHICLE YEARS
1994 and <	22	71,128	1,564,816
1995	21	15,387	323,127
1996	20	15,907	318,140
1997	19	14,508	275,652
1998	18	17,117	308,106
1999	17	14,354	244,018
2000	16	15,350	245,600
2001	15	16,138	242,070
2002	14	15,642	218,988
2003	13	16,280	211,640
2004	12	15,496	185,952

2005	11	14,473	159,203
2006	10	17,227	172,270
2007	9	21,466	193,194
2008	8	21,360	170,880
2009	7	13,824	96,768
2010	6	13,479	80,874
2011	5	7,687	38,435
2012	4	10,460	41,840
2013	3	7,919	23,757
2014	2	8,468	16,936
2015	1	6,697	6,697
2016	0	2,263	0
TOTALS		372,630	5,138,963
Average age of Fleet		**(5,138,963 / 372,630) = 13.8 years**	

APPENDIX 4

CO2 EMISSIONS BASED ON JAMAICA'S MOTOR VEHICLE PETROLEUM CONSUMPTION, 2015										
	PRODUCT	Fuel consumed (BARRELS)	Total Fuel Consumed (L)	EF	E_total	TOTAL KM TRAVELLED	E_km	O_average	E_km/passenger
SCENARIO 1	E10-87 Gas	2,286,611	663,809,200.0	2.269	1,506,183,074.8	2045131090178	7.36E-04	5.0	1.48E-04
	E10-90 Gas	1,888,631							
	Auto Diesel Oil	3,097,764	492,504,205.1	2.671	1,315,478,731.8		6.43E-04	5.0	1.29E-04
	ALL FUEL GAS		1,156,313,405.1	2.269	2,623,675,116.2		1.28E-03	5.0	2.57E-04
	ALL FUEL DIESEL		1,156,313,405.1	2.671	3,088,513,105.0		1.51E-03	5.0	3.03E-04
SCENARIO 2	E10-87 Gas	2,286,611	663,809,200.0	2.269	1,506,183,074.8	1026171467178	1.47E-03	5.5	2.69E-04
	E10-90 Gas	1,888,631							
	Auto Diesel Oil	3,097,764	492,504,205.1	2.671	1,315,478,731.8		1.28E-03	5.5	2.35E-04
	ALL FUEL GAS		1,156,313,405.1	2.269	2,623,675,116.2		2.56E-03	5.5	4.68E-04
	ALL FUEL DIESEL		1,156,313,405.1	2.671	3,088,513,105.0		3.01E-03	5.5	5.51E-04
SCENARIO 3	E10-87 Gas	2,286,611	663,809,200.0	2.269	1,506,183,074.8	644061608553	2.34E-03	6.0	3.88E-04
	E10-90 Gas	1,888,631							

	Auto Diesel Oil	3,097,764	492,504,205.1	2.671	1,315,478,731.8		2.04E-03	6.0	3.39E-04
	ALL FUEL GAS		1,156,313,405.1	2.269	2,623,675,116.2		4.07E-03	6.0	6.79E-04
	ALL FUEL DIESEL		1,156,313,405.1	2.671	3,088,513,105.0		4.80E-03	6.0	7.99E-04