A Novel Approach of Environment Impact Assessment and Emission Measurement on the Inter-city Transportation in the Greater Bay Area (GBA) of China using a Modified Gravity Model

Eugene Yin Cheung Wong[1], Danny Chi Kuen Ho[1], Stuart So[1],
Eve Man Hin Chan[2] and Chi-Wing Tsang[3]
[1]Department of Supply Chain and Information Management, The Hang Seng University of Hong Kong, Hong Kong
[2]Department of Design, Faculty of Design and Environment, Technological and Higher Education Institute of Hong Kong (THEi), Hong Kong
[3]Department of Construction Technology and Engineering, Technological and Higher Education Institute of Hong Kong (THEi), Hong Kong

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Abstract: The Guangdong-Hong Kong-Macau Greater Bay Area (GD-HK-MO) also referred as Greater Bay Area (GBA), is a megalopolis, consisting of nine cities and two special administrative regions, i.e., Hong Kong and Macao in South China. GBA has a total population of approximately 71.2 million people representing about 5% of China's total population with a combined regional GDP at USD 1642 billion in 2018, i.e. about 12% of GDP for the whole mainland China. Hong Kong acting as a window of China, plays a critical role in contributing to the growth of the GDP. Given the enormous scale of this regional economy and increasing collaboration among these GBA cities, it is utmost important to design a novel environmental impact assessment and emission measurements of the cross-border transportation among Hong Kong and various GBA cities with the aim of proposing countermeasures on carbon emissions of vehicles in the transport and logistics sector of the GBA. In the study, two modified gravity models are designed by considering social, economic, and other variables affecting the carbon emission of vehicles travelling within and across cities in the GBA. Further study will be pursued using decomposition analysis based on the modified gravity model to analyse the crucial contributors and determinants of carbon emission among the GBA cities.

1 INTRODUCTION

The need for sustainable low-carbon transport and logistics has become a top priority in many countries since emission targets were set at the Conference of Parties to the United Nation Framework Convention on Climate Change (COP21), and a number of countries have set policies to ban new petrol and diesel cars by 2030 or 2040 (Clover, 2017; McKinnon, 2018; Vaughan, 2018). Carbon mitigation in the transport and logistics sector was emphasised at the recent World Economic Forums because this sector is the world's second-largest carbon emitter, growing from 22% of global carbon emissions in 2011 to 23% in 2015 (IEA, 2012; IEA, 2017). The 2018 Policy Address of Hong Kong promoted the development of renewable energy as an integral part of mitigating climate change (Lam, 2018). Hong Kong has set a target of reducing carbon intensity by between 65% and 70% by 2030 compared with the 2005 level, which is equivalent to an absolute reduction of 26% to 36%, or a reduction in per-capita emissions from about 5.7 tonnes in 2015 to about 3.3 to 3.8 tonnes in 2030. Thus, exploring the use of renewable energy for major vehicles is critical for sustaining Hong Kong's long-term decarbonisation strategy as a smart city with low carbon transport and logistics (Alaswad, 2016; Environment Bureau, 2017). Currently, there are only 11,417 road-use electric vehicles (EV) in Hong Kong, including private cars and goods vehicles; as these account for less than 1.5% of all licensed vehicles, the challenges of achieving decarbonisation and renewable energy for sustainable transport and logistics are huge. There are studies that hydrogen-powered vehicles have lower carbon emissions, faster

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refuelling speeds and lower maintenance costs over EVs, and a number of countries, including Germany, France, Japan and South Korea, have introduced hydrogen-powered fuel cells with government-supported pilot runs on the road (Cano et al., 2018; Ryall, 2018; Schoentgen, 2018; Topel, 2018; UNDP, 2017). Hydrogen-powered vehicles suit the emerging needs of long-range and high-utilisation transportation vehicles for logistics cars and trucks (Cano et al., 2018). With the large number of licensed vehicles in Hong Kong and cities in the Greater Bay Area (GBA; e.g., 3.18 million in Shenzhen, 2.34 million in Guangzhou, 62 thousands in Zhuhai, and 78 thousands in Hong Kong), achieving zero-carbon emissions in transport and logistics requires effective measurement of the carbon footprint of a vehicle and its usage in addition to the development of renewable energy for motor cars and trucks, especially given the increasing traffic flow between Hong Kong and Zhuhai across the Hong Kong–Zhuhai–Macau Bridge (HZMB) (National Bureau of Statistics of China, 2018). Thus, structured and systematic measurement of the carbon footprint of a vehicle is necessary, both from cradle-to-gate and cradle-to-grave, as is the exploration of renewable energy to mitigate carbon emission in transport and logistics in GBA cities. The car-manufacturing process is complex, involving component manufacturing and assembly, and there is a lack of research on the product carbon footprints of automotive, in particular cars and trucks (Berners-Lee & Clark, 2013; Zhao et al., 2012). In addition, because the hydrogen-oxygen combustion product is the cleanest substance (water and heat) and has a fast-refuelling speed, it has great potential for use in automobiles and automotive products. Replacing fossil fuels in the transport sector by renewable energy will help combat climate change through reducing the carbon footprint significantly within the vehicle operation cycle. The economic and environmental impact of the use of renewable energy vehicles travelling both within and amongst Hong Kong and GBA cities should thus be analysed.

The proposed project aims to develop an environmental impact assessment and product carbon footprint measurement for selected EV used in transport and logistics and to design a renewable energy hydrogen-powered fuel cell prototype for motor cars and trucks. A novel method for EV carbon footprint measurement and a renewable energy fuel cell will be developed. It is the objective to incoproate these carbon footprint measurements into the graviity model which is not covered by previous studies which usually emphasise on economic mass. A hybrid product carbon footprint will be adopted that integrates process-based and organisation-level approaches. Upon measuring the current emission level of vehicle automotive products in pilot companies, a solid-state hydrogen-powered fuel cell will be explored. A hydrogen fuel cell prototype will be developed and applied to vehicles' automotive system. The carbon emissions from conventional, hybrid, electric and hydrogen fuel cell vehicles will be evaluated and compared, and a sensitivity analysis and cost and benefit analysis will be conducted. A model analysing the economic and environmental impact on Hong Kong and cities in the Greater Bay Area (GBA) will be evaluated. A database platform with the carbon emissions of vehicles in the transport and logistics sector will be established that includes emission factors and carbon emitted by various types of energy-consumed vehicles. This database will facilitate measurement and research analysis activities to mitigate carbon emissions in transport and logistics in Hong Kong and GBA cities.

2 LITERATURE REVIEW

2.1 Gravity Model

The concept of a center of gravity of a material body is derived from physics and was first applied to analyze the spatial distribution of the population in the U.S. in 1872 (Hilgard, 1872). A center of gravity represents the point that can balance all of the gravity produced by the fulcrum that pushes back into the gravitational field, regardless of the location of the object (Kumler and Goodchild, 1992). In terms of the economic centers of gravity, the assumption is that economic forces, such as gross domestic product (GDP) and population, balance the regional economy (Kumler and Goodchild, 1992). Over the years, a large number of research studies in economics have widely applied the gravity model (Kandogan, 2014) to study the impact of geographic distribution on trade (Chan et al., 2018), immigration (Karemera et al., 2000, Lewer and Berg, 2008), population (Kumler and Goodchild, 1992, McKee et al., 2015; Yang and He, 2017), and land utilization (Chen and Zhou, 2011, Xiaolin and Fei, 2011). Existing studies have also used the gravity model to analyze the spatiotemporal distributions of carbon dioxide (CO_2) emissions and energy consumption (Zhang et al., 2012; Wang and Feng, 2017), urbanization (Fu et al., 2015), energy supply and demand (Zhang et al., 2012), and trajectory of CO_2 emissions of gravity centers as well as study their spatial and temporal differences (Song et al., 2015; Wang and Feng, 2017; Zhang et al., 2012). However, there have yet to be studies that use the model to investigate CO_2 emissions among the Guangdong-Hong Kong-Macau Greater Bay Area (GBA) cities.

2.2 Transportation in Greater Bay Area

The Great Bay Area has a great potential for developing a comprehensive delivery network on the road as they are so near, the distance is not far away. There are roads to connect the Great Bay Area Cities. Each city has well infrastructure to fit The Great Bay Area development. As the city between cities is not far, using trucks to deliver is the most efficient, it is cheaper than barge and plane, so they will use trucks as their major transportation to deliver goods. However the carbon emissions of trucks are very high, it will cause serious pollution problems. Hence, it needs to replace traditional trucks by renewable energy vehicles. Also there are more truck EVs developing. It is a great opportunity to change the traditional trucks to renewable energy vehicles, thus, to improve the air pollution problem.

Huang, Guo and Xu (2020) issued a study that aims to develop a new method for examining the regional integration and the spatial connection that affect vehicle emission via crowdsourced traffic data and an emission model because GBA lacks an effective framework for accurately estimating the real-time transportation performance. The research selected the AutoNavimo and OpenStreetMap as sources to collect detailed traffic conditions of GBA including vehicle types, time periods, geographical areas, pollutants, vehicle operating characteristics, and road types. Next, creates a project-level database for the data input. Characteristic traffic data from the directions service and site-specific data (e.g. fuel information and meteorology conditions) are imported and stored in this database. The third step runs the developed model to calculate emission inventories. The final step is to establish different strategies to reduce the emission of GBA. The result found that vehicle energy consumption and emission have a difference between the expressway and other urban roads based on the speed . Based on the article, the project can consider using AutoNavimo and OpenStreeMap as sources to collect detailed traffic conditions of GBA cities.

2.3 Development of Hydrogen Fuel-cell Vehicles in the GBA

The development of the renewable-energy of hydrogen fuel cell vehicles in Hong Kong and South China is still in the starting phase; its impact, particularly on traffic flow and emissions, has yet to be evaluated. A growing number of studies have examined carbon emissions in this context, but a number of research gaps remain. First, previous studies examined this issue in various geographical settings at the national (Gambhir et al., 2015), provincial (Zheng et al., 2015) and city levels (Wang et al., 2017; Zeng et al., 2016) and in connected metropolitan areas (Du et al., 2017). However, research on cities in the GBA is inadequate. Second, studies at the city level have examined the carbon emissions of transport services within specific geographical boundaries, whilst carbon emissions from intercity road transport flow across city boundaries have received less research attention. Third, the potential of hydrogen fuel cells for carbon emission reduction in GBA cities remains underexplored, as the adoption of hydrogen-powered fuel cell vehicles remains in its infant stage. As such, road transport carbon emissions both within and between the 11 cities in the GBA and the carbon emission reduction potential of alternative fuel types, including a hydrogen fuel cell, will be analysed in this project. A modified gravity model will be designed and developed based on theoretical analysis, considering social, economic and other variables affecting the CO2 emission of vehicles travelling within and across cities in the GBA (Zhou et al., 2018; Anderson, 2011; Jung et al., 2008).

3 METHODOLOGY

3.1 Research Model

In response, the use of the gravity model will be extended in this study to analyze the crucial contributors of CO_2 emissions among the GBA cities. Until recently, this model has been mainly applied to aggregated data with cross-sectional or time-series estimation techniques to analyze traffic flow statistics. Here, the conventional gravity model is applied to determine the volume of CO_2 emissions in GBA cities and extended to cover other factors not considered in previous studies, such as number of domestic and cross border vehicles, type of energy source, traffic mix, etc. In addition, the determinants used are related to road transportation and policies including qualitative variables (as the dummy variables). The model will be subjected to a panel data analysis to investigate the fixed effects over time for each scenario, thus exploring the changes and increasing the manipulation of the data quality and quantity which would otherwise not be possible with the use of cross sectional or time series estimation alone. The model will be utilized to investigate the impacts of energy emissions, city-specific social and political determinants as well as economic indicators that affect the CO_2 emissions between Hong Kong and the GBA cities. In studies on traffic flow and population migration (Anderson, 2011), the gravity model is regarded as a common method to evaluate the strength of the flows. The conventional gravity model is based on Newton's Law of Gravitation and shown as follows:

$$T_{ij} = k\frac{P_i P_j}{D_{ij}^2}$$

where T_{ij} is the expected strength of the traffic flow; P_i is the quantity of generated traffic; P_j is the attracted quantity of traffic; D_{ij} is the distance between different traffic zones; and k is a gravity constant, which is usually set to 1 (Jung et al., 2008).

The model in this study will include various factors of the conventional explanatory variables, such as the distances between the 11 cities, GDP, population, and factors related to road transport, such as the number of domestic vehicles, number of cross boarder vehicles that post the impact to the traffic flow. A modified gravity model using a hierarchical factor approach is derived based on the conventional model by taking the logarithm as follows:

$$\ln(T_j) = \alpha 0 + \alpha 1\ln(GDP_i) + \alpha 2\ln(GDP_j) + \alpha 3\ln(L_i) + \alpha 4\ln(L_j) + \alpha 5\ln(D_{ij}) + \alpha 6(TRK_{ij}) + \varepsilon_{ij} \quad (1)$$

where GDPi and GDPj are the gross domestic product for cities i and j, Li and Lj are the populations of cities i and j, TRK*ij* represents the number of registered vehicles of cities i and j. εij is a random error term, usually taken to be normally distributed. This formula is applied in the analysis.

In order to analyze the crucial contributors of CO_2 emissions, a second modified gravity model is constructed based on the conventional model as follows with the consideration of other factors on transportation and energy including the influence from the type of energy source and traffic mix, that contribute to CO2 emissions.:

$$\ln(CO_{2ij}) = \alpha 0 + \alpha 1\ln(Y_i) + \alpha 2\ln(Y_j) + \alpha 3\ln(L_i) + \alpha 4\ln(L_j) + \alpha 5\ln(D_{ij}) + \alpha 6(A_{ij}) + \varepsilon_{ij} \quad (2)$$

where CO_{2ij} are the CO_2 emissions from GBA city i to j, Y_i and Y_j are the income values for cities i and j, L_i and L_j are the populations of cities i and j, and D_{ij} is the distance between cities i and j. A_{ij} represents the factors that contribute to CO_2 emissions between the pairs of cities. Likewise, ε_{ij} is a random error term.

Model (2) in this study is targeted to include various factors of conventional explanatory variables, such as the distance between 5 cities, GDP, population as well as the factors that are related to road transport, for example, the number of domestic and cross border vehicles, type of energy used, traffic mix, etc., all of which contribute to CO_2 emissions. On the other hand, Model (1) is an alternative approach to quantifying the impact of environmental impact of the cross-border traffic in the GBA region. Owing to the research work is still in progress, only Model (1) is used to demonstrate the significance of our theoretical framework in this study.

3.2 Data Analysis Method

3.2.1 Panel Data Estimation Approach

The data were analyzed by using the panel data estimation approach with an econometric and statistical software – EViews, which is designed for econometric analysis. The findings will demonstrate the impacts of the crucial elements of CO_2 emissions on the GBA cities.

A pool cross sectional (PCS) or cross sectional (CS) ordinary-least-square (OLS) is often applied in the gravity model. Unfortunately, Cheng and Wall (2005) showed that these estimation approaches create biased results. Since there is no heterogeneity allowed in the error term for standard CS regression equations, the gravity model overestimates the results. In order to solve the problem of using OLS, the panel data estimation method will be utilized to determine the variables that affect the CO_2 emissions among the GBA cities over time. As Baltagi (2013) noted, the advantages of using this method will increase the volume of informative data in variability but with less collinearity among the variables. Moreover, the method will allow for more degrees of freedom and efficiency.

3.2.2 Data Collection

A panel dataset of 5 cities over the period of 2015 to 2020 is used in this study. Data of CO2 emissions in China are obtained from the China Emissions Accounts and Datasets (http://www.ceads.net/), which can be found and referenced in Shan et al. (2016). The other explanatory variables will be collected from the China Statistical Yearbook. The socioeconomic indexes of 5 cities including the annual population, GDP (at 2015 constant prices) as well as other socioeconomic data will be sourced from the statistical yearbooks, population and GDP (at 2015 constant prices) time series data of Hong Kong and Macao respectively, and obtained from the database of Census and Statistics Department of Hong Kong and Statistics and Census Service of Macao. The exchange rates of the Hong Kong dollar (HKD) and Macao pataca (MOP) to renminbi (RMB) will be collected from the China Statistics yearbook and China Foreign Exchange Trade System (CFETS, 2021). Emissions from Hong Kong and Macao will be collected from the Emissions Database for Global Atmospheric Research (EDGAR, 2021).

4 ANALYSIS AND DISCUSSION

In order to be able to use the Gravity model, we first collected the data of two major cities in the GBA in order to demonstrate the significance of the modified gravity model in terms of the preliminary assessment on environmental impact by the cross-border traffic. We collected data from the Census & Statistics Department of the Governments in Hong Kong and Shenzhen between 2003 and 2019, i.e., the period after China joined the World Trade Organization (WTO). Data includes traffic flow between the two places, GDP of the two cities, Population of two cities, number of registered vehicles of two cities and the distance between two HK and SHZ.

Model 1 was tested with multiple regression analysis in the SPSS 17.0 software, while the resulting regression statistics are shown in **Table 1**, the regression coefficients of various predictors ae shown in **Table 2**. The approach enables the study to obtain the explanatory power of each independent variable separately as well as the significance of the hypothesised relationships for determining the fitness of the proposed conceptual model through evaluating the significance of multiple correlation coefficients and the beta values.

Table 1: Regression statistics of gravity model 1 (first iteration).

Regression Statistics	
R^2	0.858
Adjusted R^2	0.794
p-value	0.000

Table 2: Regression coefficients of gravity model 1 (first iteration).

Regression Coefficients (Sig.)	
GDP SHZ	0.982
GDP HK	0.384
Population SHZ	0.074
Population HK	0.075
Total Vehicles	0.009

The results in **Table 1** shows how good the model explanability is, i.e., model prediction, while **Table 2** shows how good the coefficient estimates are, i.e., the predictability of independent variables (IVs). The results indicate that the regression model is significant, but the coefficient estimates of the model are insignificant except the IV, total vehicles. According to the results of correlation analysis, the correlation among the GDPs and other IVs exceeds 0.5 (the correlation between variables is becoming more significant where the range of values of correlation coefficient is between 0 and 1) which has a poor multicollinearity. Then, we exclude the GDP variables and re-run the test and summarized in the results in **Table 3** and **Table 4** below.

Table 3: Regression statistics of gravity model 1 (second iteration).

Regression Statistics	
R^2	0.848
Adjusted R^2	0.812
p-value	0.000

Table 4: Regression coefficients of gravity model 1 (second iteration).

Regression Coefficients (Sig.)	
Population SHZ	0.048
Population HK	0.016
Total Vehicles	0.001

The results in **Table 3** remains significant, while the coefficient estimates summarized in **Table 4** indicates that the results are significantly improved. Hence, we obtained the following regression model based on the results in the second iteration of the test.

$$In(T_{ij}) = (28.589) + (0.3995)\, In\,(L_i) + \\ (-2.486)\, In\,(L_j) + (0.102)\, In(TRKi_j) + \\ (0)\, In\,(D_{ij}) \qquad (3)$$

We can use the model to forecast traffic flow. With more time-series based CO_2 emission obtained later on, we will include the total life cycle emission of each vehicle in Model 2 with the aim to find the total emission in the further of different types of vehicle.

5 CONCLUSIONS

The modified gravity model is developed in this regard. The model will analyse the crucial contributors of CO2 emission among the GBA cities. Until recently, gravity model has been mainly applied to aggregated data with cross-sectional or time-series data estimation techniques to analyse traffic flow statistics. Here, the novel model is applied to CO2 emissions from GBA cities and extended to cover other factors not considered in previous studies. In addition, the determinants which are related to road transportation and policies including qualitative variables. The model will be subjected to a panel data analysis to investigate the fixed effects over time for each scenario, thus exploring the changes and increasing the manipulation of the data quality and quantity which would otherwise not be possible with the use of cross sectional or time series estimation alone. The model will be utilized to investigate the impacts of energy emission, city-specific social and political determinants as well as economic indicators that affect the CO_2 emission between Hong Kong and the GBA cities.

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