Modelling the Effect of Congestion Pricing on Traffic in New York City

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Master of Science

by
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ABSTRACT

With the increasing interest in the application of an urban road congestion pricing, a simulation of running a charging scheme in New York City could be useful for future transportation development. The scenario is charging on the inbound to the New York Center Business District (CBD). It is used to estimate the changes in traffic volume and traffic speed. By using the New York Best Practice Model (NYBPM) to set up the charging standards, a level of traffic congestion will be estimated, and it will be distributed in a certain pattern. The charging scheme is based on the concept of tolling "equity."

Keywords: Congestion price, Traffic volume, Traffic speed, CBD, NYBPM, Tolling equity

BIOGRAPHICAL SKETCH

The author, Zixu Zhou, was born on December 2nd, 1989 in Wuhan, China. Spending 18 years studying in Wuhan and Beijing, he finished the primary and secondary education. After graduating from the high school affiliated to Renmin University of China, he started his undergraduate study in Beijing University of Posts and Telecommunications (Beijing, China). When finishing his bachelor degree of Electronic Engineering, he applied for the Master of Science program in Transportation System Engineering. In fall 2013, he started studying in Cornell University.

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1. Introduction

For nearly a century [1], congestion pricing has been put forward as an efficient way of forcing road users to internalize the negative externalities incurred by the public when said road users drive on a congested road. Despite the overwhelming support of economists and transportation experts, fewer than half-a-dozen governments (Singapore, London, and Stockholm being the most well-known) have adopted the congestion charge in any form. While it would be inaccurate to suggest that there is not enough information available to the public and politicians to determine the advantages and disadvantages of congestion pricing in one specific area—namely, the effects of congestion pricing on overall vehicle emissions—little research has yet been conducted. Also, the public is well aware of the harmful effects of vehicle emissions on individuals' cardiovascular and respiratory health [2] as well as the direct relationship of vehicle emissions to global warming and climate change [3].

In New York City, the traffic situation has remained the same for many years. Moreover, during the rapid development of its economy, the necessity of improving the city's transportation system was much discussed. There is a coalition named “The Move NY” [4], which has had hundreds of conversations with people from various occupations. Its goal is to create an innovative plan to make the transportation system better for all New York’s citizens. The Move NY Fair Plan has been co-designed by the Move NY organization and the traffic engineer Sam "Gridlock" Schwartz. One of their plans is to make the City's tolling system fairer. One part of this is to reduce the high tolls in some places; another is to restore tolls in the regions where traffic congestion is heavy and public transport options are abundant.

The New York Metropolitan Transportation Council (NYMTC) [5] uses the New York Best Practice Model (NYBPM) to predict the variations in future traffic patterns in response to changes in the demographic profile and transportation system in the various regions of New York. The model integrates transportation behavior and interactions with an extensive database. The database includes a major travel survey of households from each area of the city, a land-use catalog, socioeconomic figures, traffic and transit counts, and travel times. Moreover, one major part of the model is a highway and road network simulation, which can be used to predict the traffic pattern in response to the tolls charged on different sections of the traffic network.

This paper will focus on examining the empirical data on the effects of congestion pricing on travel demand and traffic activity distributions by time and space. Based on the tolling proposal put forward in the NY Move plans, it attempts to provide a quantitative analysis of the charging scheme.

2. Background and Methodology

Research has not been conducted thoroughly enough on the effects of congestion pricing on overall vehicle emissions. There are fewer than ten published journal papers on the topic, and very few of those have been issued recently—i.e. within the past eight years. In these published papers, two different research methodologies have been used. The first is to directly measure ambient air quality before and after a congestion pricing scheme has been implemented. The second is to model an urban network before and after congestion pricing is implemented and then to create a simulation to determine the effects on overall vehicle emissions. In Section 2.1, there will be some analysis of the previous research that found out the effect of congestion pricing on vehicle emissions by simply measuring ambient air quality. In Section 2.2, there will be some discussion about the previous research that models the effects of congestion pricing on overall vehicle emissions through computer simulation models. Section 2.3 introduces the motivation for and details of the Move New York Plan. All three of these sections, as well as in the concluding Section 2.4, proposes a single scheme that combines the Move New York Plan with NYBPM in order to test the effect of congestion pricing in New York City.

2.1 Analyzing the Effect of Congestion Pricing by Using Ambient Air Quality Measurements

Chin [6] attempts to investigate the effects of congestion pricing on air quality in Singapore by analyzing ambient air quality values obtained from the city's Anti-Pollution Unit's Annual Reports. Chin's dataset and methods of data analysis are rudimentary. In Singapore, when the Area Licensing Scheme (ALS) is implemented, the air quality change only took the average on its levels for the two months (April and May) before and after the four months (June, July, August and September). Moreover, no control was used to compare these time periods. Also, it is not clear at which locations the ambient air quality readings were taken, and there is no control location to determine whether the improvements in air quality were simply the result of exogenous factors such as uncharacteristic meteorological conditions. Additionally, the analysis did not take into account seasonality factors: if NOx levels decrease every year after May, as occurred in 1975 when the ALS was implemented and the air quality was measured, it was not legitimate to conclude that the ALS had a positive effect on emission reduction.

Atkinson et al. [7] also attempt to use ambient air quality measurements by using the implementation of congestion pricing in London as a case study. The dataset and data analysis used by Atkinson et al. appear to be much more thorough than Chin's. However, they fail to conclude whether the air quality had improved as a result of the congestion scheme or other factors, such as the more economic use of fuel in personal vehicles or improved emission filtration technology on London's passenger buses. Presented with the same air quality data, Beevers and Carslaw [8] used a computer modeling technique to analyze London's congestion pricing scheme. One reason for doing this was that they believed the meteorological conditions in London in 2002 and 2003 were too erratic to use ambient air quality readings as a means of studying the congestion scheme's effect on air quality. They complained that Beevers and Carslaw repeated the two main shortcomings we saw in Chin's [6] analysis: 1. the very short analysis period, and 2. the lack of seasonality controls. Atkinson et al. avoided these issues by collecting and analyzing data from the two years before and after the implementation of the congestion charging scheme in London. By widening the time frame for analysis, they acknowledged that they could not fully attribute the measured changes in ambient air quality to London's implementation of congestion pricing. Hence, it appears that there is no optimal or even good timeframe for performing an ambient air quality assessment when the goal is to determine the effectiveness of congestion pricing on vehicle emissions. The Stockholm SLB, a unit of the City of Stockholm's Environmental and Health Administration, also agrees that measuring ambient air quality is not an effective means of determining the effects of congestion pricing on overall vehicle emissions.

Given that measuring the ambient air quality fails to provide conclusive results, the goal is to prove that computer modeling is the best means of measuring the effects of congestion pricing on overall transportation system. Another advantage of computer modeling is that it can used as a predictive tool as well as a photographic tool. Once the model is fully refined, and has been tested to determine its effectiveness on cities that have already implemented congestion pricing, like London and Stockholm. Moreover, it can be used to determine the effects congestion pricing would have on any new city contemplating implementing a congestion charging scheme.

2.2 Analyzing the Effect of Congestion Pricing by Using Computer Modeling

Previous work has been done to model the effects of congestion pricing schemes on vehicle emissions (Johansson et al., 2009; SLB, 2006). However, I believe that the previous models are overly simplistic. While this research is comprehensive to some extent, there are too many factors that have not been considered.

Daniel and Bekka [9] model the effect that a congestion pricing scheme would have on vehicle emissions in an urban area in Delaware. The travel demand model they use is based on three of the four components of the traditional (and some would say outdated) four-step travel demand process. The four steps are: trip generation, trip distribution, modal split, and traffic assignment. Daniel and Bekka [9] only take into account trip generation, trip distribution, and traffic assignment. To model the effect of congestion pricing on trip generation, the authors simply set the demand elasticity to three different values (0.5, 1.0, and 1.5) and completed the analysis for all three. Using assignment software known as TRANSPLAN, the authors assigned users to links in the urban network based on the three demand elasticity values given above and each link's impedance function. The impedance function used was the marginal social cost function. One major shortcoming of the travel demand forecasting model is that it fails to consider the effects of congestion pricing on other modes of transportation. Wherever congestion pricing has been implemented, the use of public transportation has significantly increased. Daniel and Bekka’s [9] results show that the congestion pricing scheme will significantly reduce VMTs in the urban network, which will, in turn, reduce emissions. However, the model does not incorporate the increase in public transportation usage, which will result in an increase in emissions. Additionally, by 2013 standards, the EPA's Mobile 5a model is considerably out of date for modeling vehicle emissions.

Beevers and Carslaw [10] measured the effects of London's Congestion Charging Scheme (CCS) on vehicle emissions by extensively monitoring traffic before and after the CCS was implemented and then used that information to model changes in traffic patterns and predict emission changes due to the new travel patterns. The model they used to predict vehicle emissions was the road traffic emissions inventory from the London Atmospheric Emissions Inventory. Changes to the emissions of NOx, PM10, and CO2 were calculated by determining the total number of VMTs, the average speeds, and the vehicle fleet composition both pre-CCS (2002) and post-CCS (2003), and then entering those input parameters into the computer simulation model. The VMTs per vehicle type and the average link speeds were recorded for each hour of the day, and each day of the week on both the inner ring road (IRR) and inside the charging zone. The report shows that changes in average speeds have a greater effect on vehicle emissions than either changes in VMTs or changes in the vehicle fleet. One shortcoming of their model is that it does not take into account the distributions of speeds on each link; it is only concerned with average link speeds.

Beevers and Carslaw [10] almost immediately set out to rectify the shortcomings in their previous work by further examining changes in vehicle speeds and their effects on vehicle emissions. Using “Vehicle Transient Emissions Simulation Software” (VTESS), the authors attempted to determine the effects of driving characteristics (i.e. rates of acceleration/deceleration, top speeds, engine power, etc.) on vehicle emissions, as opposed to simply using average link speeds. The authors compared the results of the VTESS simulation, which took into account numerous driving characteristics besides average speed, with their previous work, which only took link speed into account. The results of the analysis are mixed. According to their report, using average vehicle speeds to model the emissions of NOx is comparable to modeling vehicle emissions taking into account the full range of driving characteristics. To a lesser extent, the same is true for modeling CO2 emissions. Conversely, using average vehicle speeds to estimate PM10 emissions does not effectively represent the actual vehicle emissions, according to the model, because PM10 emissions are highly dependent on the drive cycle. The effect of driving characteristics on PM10 emissions appears to be greater than the effect of average speeds. One major limitation of the VTESS model is that it only includes a very limited number of vehicle makes and models, which are then supposed to be representative of the entire vehicle fleet. According to Beevers and Carslaw, even using just the limited number of vehicles in the VTESS model, it is obvious that different vehicle models respond very differently to the same driving characteristics. They go on to state that "an improved understanding" of the effects of individual vehicles and driving characteristics on vehicle emissions is necessary to complete a comprehensive analysis of congestion pricing's effect on overall vehicle emissions using computer simulation modeling.

While Beevers and Carslaw [10] attempted to account for one shortcoming in their original model by examining the effects individual driving characteristics can have on overall vehicle emissions, they missed one important factor. Individual drivers drive completely differently to their fellow drivers, even on the same road; nevertheless, it is important to note that the various roads they use inevitably result in different driving characteristics, even if average speeds on those roads are equivalent.

2.3 The Requirements of the New York Best Practice Model

In 1994, the Transportation Research Board put together a special report on congestion pricing, *Curbing Gridlock: Peak-Period Fees to Relieve Traffic Congestion*. One of the papers in the book, Guensler and Sperling's “Congestion Pricing and Motor Vehicle Emissions” [11], argued that it is not possible to model congestion pricing's effects on air quality quantitatively. They claimed that there are various parameters associated with congestion pricing that are impossible to measure accurately. These include congestion pricing's effect on changes in trip generation, total VMTs, vehicle fleet composition, and vehicle operating environment. Additionally, they raised some major concerns about how vehicle emissions are modeled. They maintained that it is hard to use the primary vehicle operating environment characteristic to model vehicle speed. Also, it is too difficult to model the cause-effect relationship between the vehicle operating environment and vehicle emissions.

There are concerns about accurately modeling vehicle emissions; however, with advancements in data collection, data analysis, travel demand forecasting, and vehicle emissions modeling, it is not impossible to estimate the effects congestion pricing will have on vehicle emissions to a reasonable degree of certainty. Beside technological advancements, another huge benefit that researchers today have over researchers in 1994 is the availability of travel data from London, Stockholm, and Singapore, before and after congestion pricing was implemented.

Previous work has determined how one or two effects of congestion pricing reduces vehicle volume. However, some general methods need to be developed in order to take into account some major aspects of congestion price. One of these is to use a computer model. The computer software created to model vehicle emissions quantitatively, which is based on vehicles' operating environments and driving characteristics, has advanced immensely over the past decade. The New York Metropolitan Transportation Council (NYMTC) collects data from publications and reports with the aim of improving regional transportation arrangements and classifying the future needs of New York City. Moreover, it has been devoted to developing a comprehensive transportation system for years. Its goal is to use the transportation system needs to forecast travel demand through models that involve the compound measure of individuals and vehicles to meet the varying requirements of the traveling public. NYMTC presently uses a 2010 Base Year for the NYBPM. This Model forecasts variations in future travel patterns according to changes in demographic profiles and regional transportation circumstances. The model comprises 28 counties in New York, New Jersey, and Connecticut. It integrates transportation behavior and interactions with an extensive database that contains a major travel investigation of households, land-use, socioeconomic data, road traffic and transit design, and travel times. In the first part of the NYBPM model, it is about the highways simulation. The embedded highway network database contains all types of road, which is from minor arterials and upward. Moreover, it contains all traffic information details for each link grouped into four time periods: AM (6 am – 10 am), MD (10 am – 4 pm), PM (4 pm – 8 pm), and NT (8 pm – 6 am).

2.4 The Motivation of the Move New York Fair Plan

The Move New York Fair Plan is a developing coalition of various people and organizations who are concerned about the crisis enveloping the New York City's transportation system. The traffic expert Sam Schwartz and the Move NY Coalition have developed the proposal over several years. As now envisioned, the plan proposes a number of suggestions designed to maintain and modernize the New York regional transit system and road network. Although unanimity on any plan is rarely possible, this plan is believed to represent a wide consensus about the requirements of the New York transportation system and the best method of meeting them. According to the announced 2015 – 2019 MTA Capital Plan, the expansion and modernization of the traffic system have not been allocated sufficient funds. Meanwhile, severe congestion is still common. The congested traffic takes its toll on citizens' breathing, increases vehicle collisions, and increases the cost of living in New York City.

Figure 1. New York Move Plan Tolling System [4]

As shown in figure 1, one of the proposals is to bring toll equity to the regional traffic network in order to moderate the grinding traffic congestion that inevitably produces increased vehicle emissions and damages the city's environment. Drivers who live outside New York City have to pay a high fee to drive over less-congested bridges, like the Verrazano, Bronx–Whitestone, Throgs Neck, and Triborough/RFK Bridges. However, more than one million vehicles in each direction are free to drive on the four East River bridges and across 60th Street into the Manhattan Central Business District (CBD). This unfair traffic tolling system is one of many important factors that undermines both the city's economic development and the quality of people's lives. Therefore, it is necessary to demonstrate the effect of charging on the four East

River Bridges and main streets into CBD in the simulation. Moreover, there also needs to be one reliable and authoritative piece of software to simulate the charging scheme.

The main purpose of this paper is to use the NYBPM as the computational simulation tool to monitor the traffic situation before and after adding a toll in a network setting to the four East River Bridges as well as to roads inbound to the CBD area. The toll will be added at the entrance of each bridge and street inbound to Manhattan CBD. It will be combined with the recent charging rate in New York area and the proposed toll in the Move NY Plan. Charging schemes are shown in the tables below.

Table 1.

Tolling fee $5.54

	AM	MD	PM	NT
Brooklyn Bridge	$5.54	$5.54	$5.54	$0
Manhattan Bridge	$5.54	$5.54	$5.54	$0
Williamsburg Bridge	$5.54	$5.54	$5.54	$0
Queensborough Bridge	$5.54	$5.54	$5.54	$0
CBD	$5.54	$5.54	$5.54	$0

Table 2.

Tolling fee $8.00

	AM	MD	PM	NT
Brooklyn Bridge	$8.00	$8.00	$8.00	$0
Manhattan Bridge	$8.00	$8.00	$8.00	$0
Williamsburg Bridge	$8.00	$8.00	$8.00	$0
Queensborough Bridge	$8.00	$8.00	$8.00	$0
CBD	$8.00	$8.00	$8.00	$0

In Table 1, each vehicle from the Brooklyn and Queens regions driving into Manhattan CBD is charged 5.54 dollars. In Table 2, each vehicle is charged $8.00. Also, drivers from the outer-bound of New York CBD (60th Street and above) are charged the same fee as those who want to drive into CBD from another region. These charging schemes are then used to predict the changes in traffic patterns in response to the changes in tolling fees on those major roads inbound to Manhattan CBD. Moreover, the charging period is from 6 am to 8 pm. Because traffic congestion is not severe between 8 pm and 6 am, there will be no charging in this period.

Since the traffic network database in NYBPM is based several years' worth of data collected by NYMTC, the simulation results will be convincing, and it will reflect the right traffic pattern in the charging area. By using this authoritative computational software to test the effect of the congestion price on NYC, the traffic situation will be compared by showing the changes in traffic volume and travel speed.

3. Results and Discussion

Figures 2 and 3 show the changes in the daily traffic situation for Brooklyn Bridge. The most notable changes are that a decrease in traffic volume and an increase in congested speed are associated with an increase in the price charged.

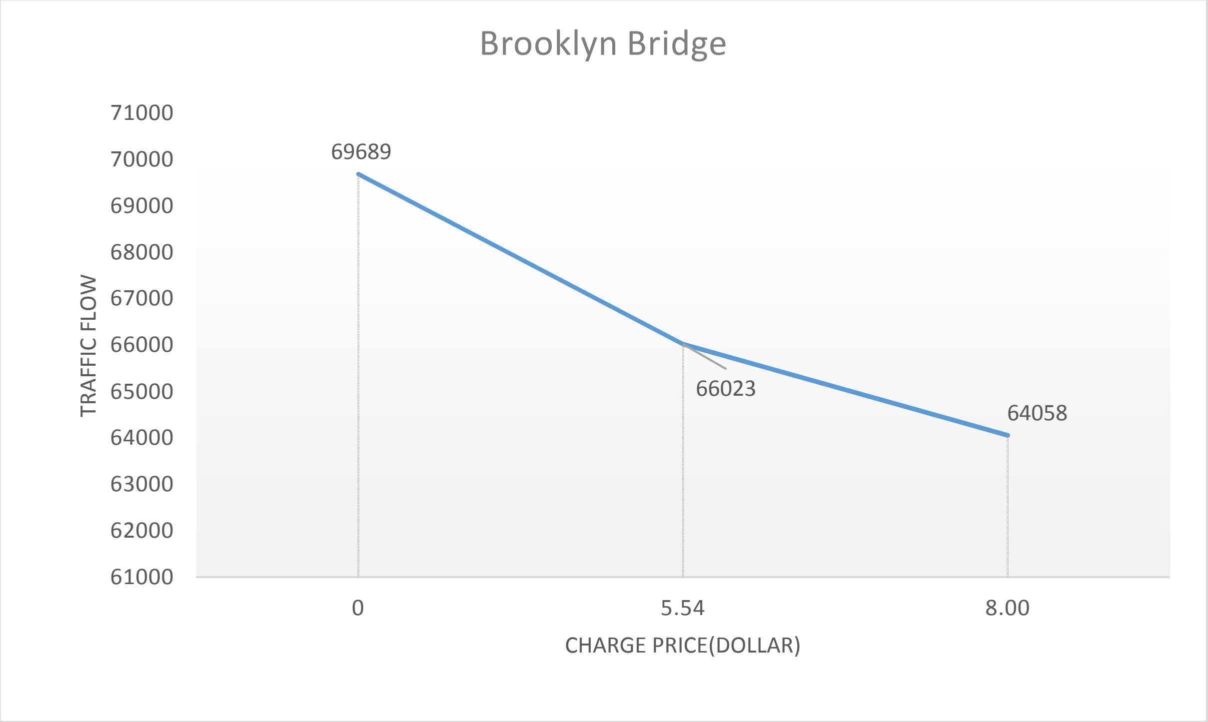

Figure 2. The change in traffic flows on Brooklyn Bridge.

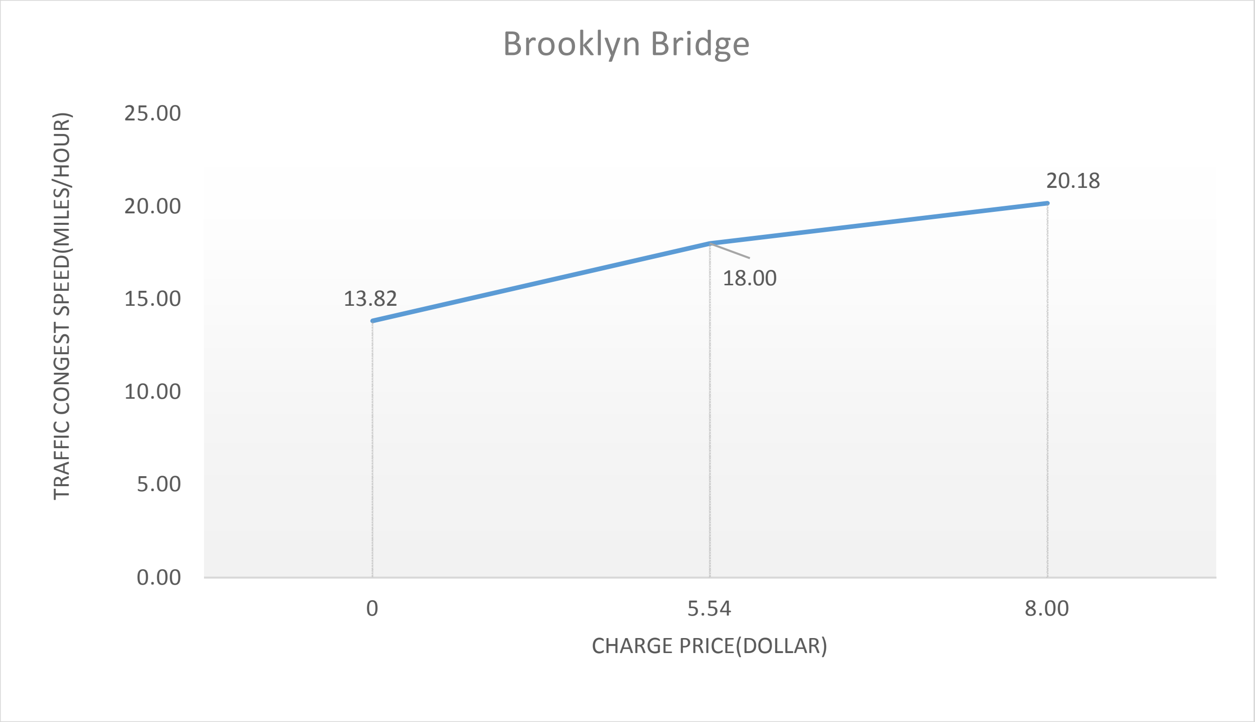

Figure 3. The change in the speed of congested traffic on Brooklyn Bridge.

Figures 4 and 5 show the average changes in traffic flow and congestion speed during the charging period for Manhattan Bridge. The change in the amount of traffic flow for a 5 dollar charge is very obvious. But when the charge is increased to 8 dollars, the volume only decreases by 497, compared to a charge of 5.54 dollars. Also, the traffic in the high-occupancy vehicle (HOV) lane on Manhattan Bridge increases by 38% and 96% when the price charged is 5.54 and 8 dollars, respectively. Moreover, the delay and traffic congestion are not obvious in the HOV lane.

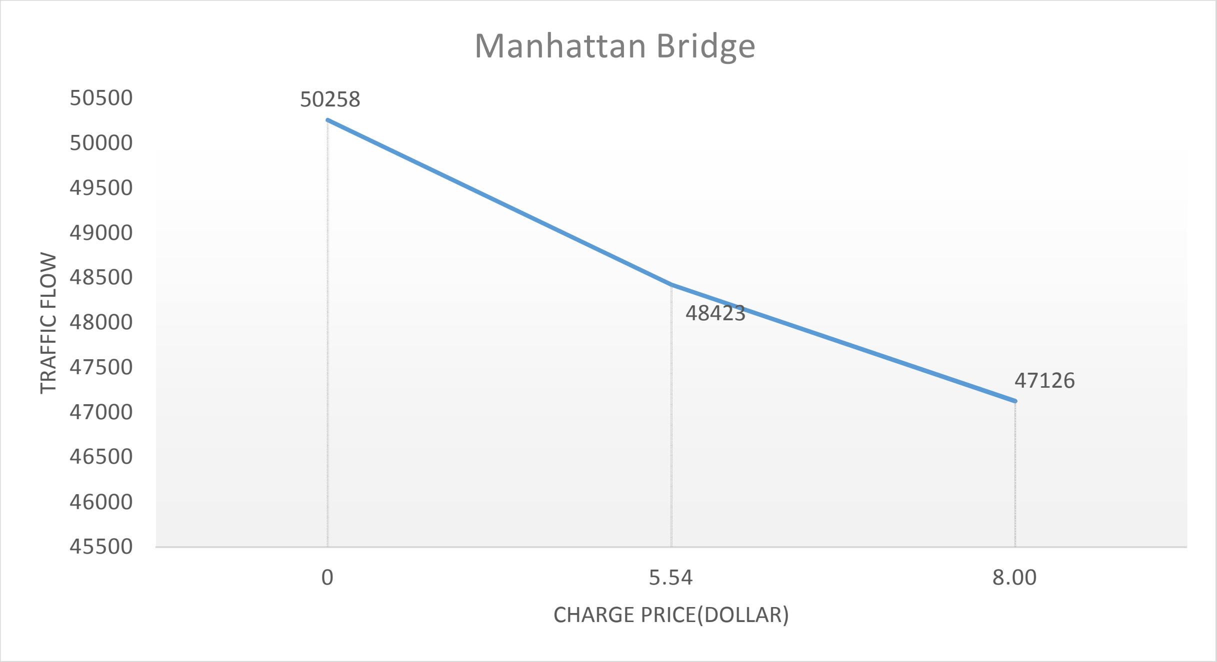

Figure 4. The change in traffic flows on Manhattan Bridge.

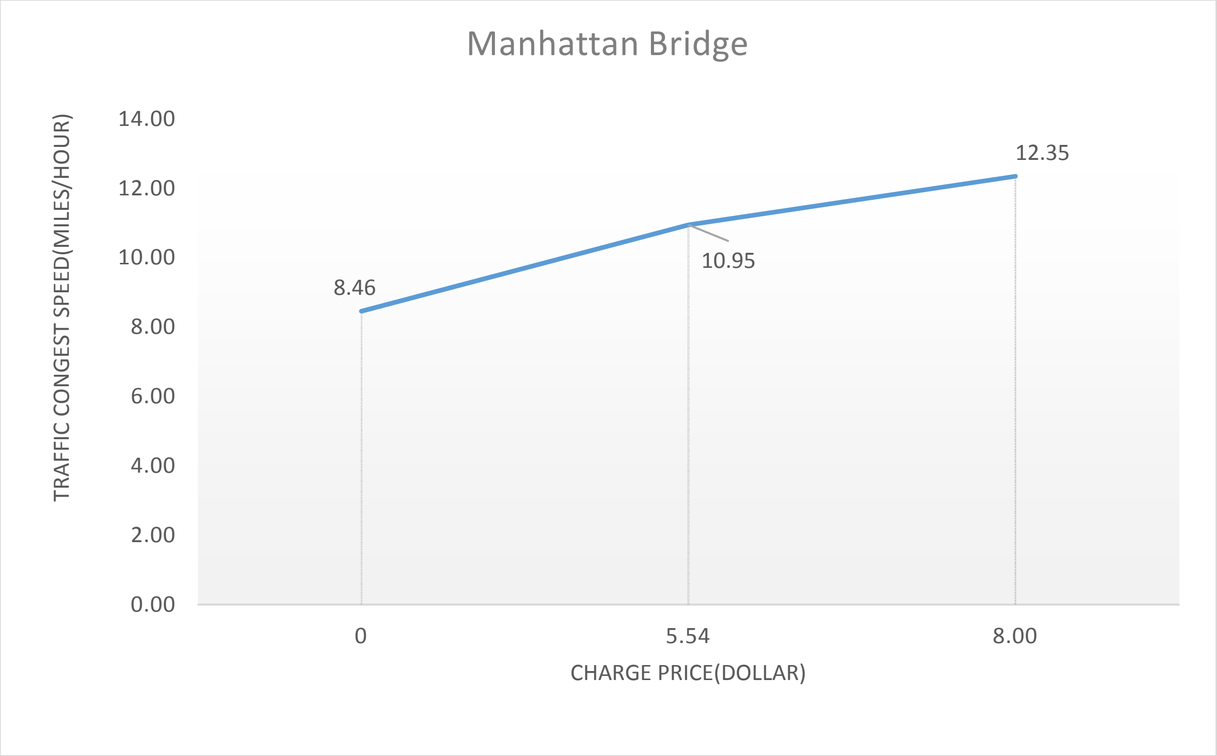

Figure 5. The change in traffic congested speed on Manhattan Bridge.

Figures 6 and 7 show the changes on Williamsburg Bridge. The decreasing pattern in traffic volume is not similar to that of congestion speed. The change is consistent when the charging price increases from 5.44 to 8 dollars. However, the congestion speed does not increase proportionally. One of the reasons is that the number of trucks and other big commercial vehicles does not decrease much when the price charged changes.

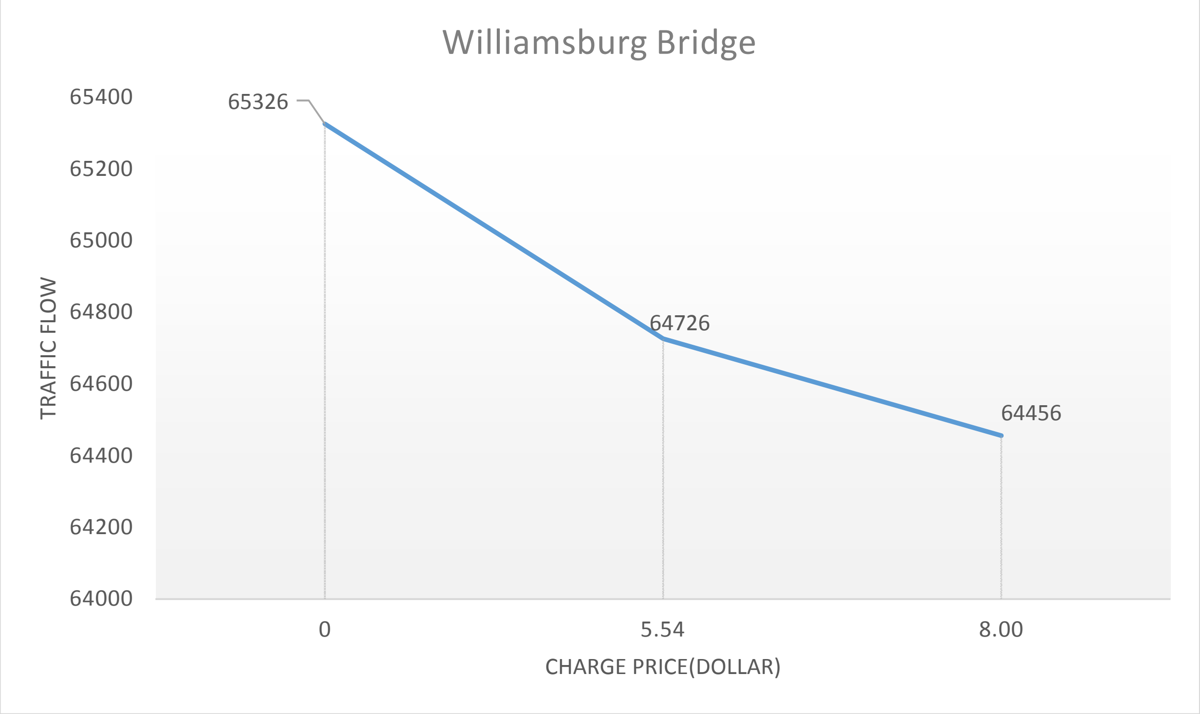

Figure 6. The change in traffic flows on Williamsburg Bridge.

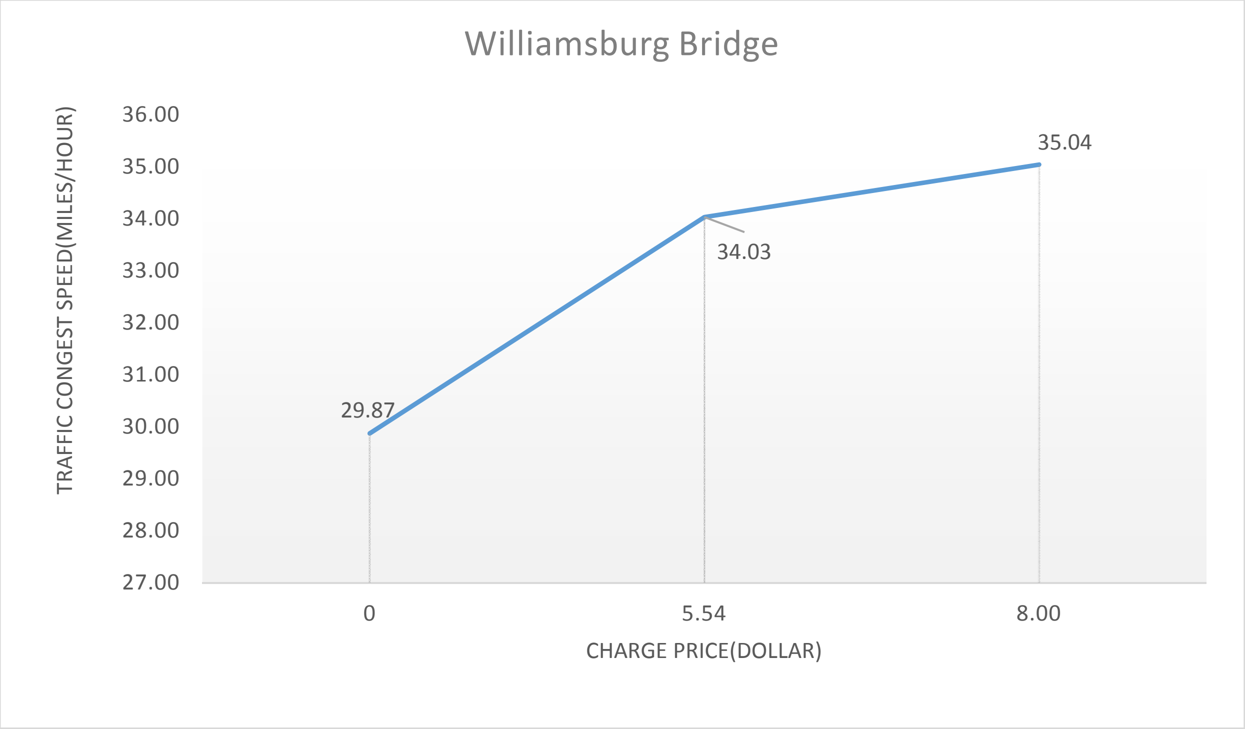

Figure 7. The change in traffic congestion speed on Williamsburg Bridge.

Figures 8 and 9 show the changes in the traffic pattern for Queens Midtown Tunnel. As a tunnel that is already charged a toll, Queens Midtown Tunnel is charged at 5.54 dollars when paying with an E-Z pass, and at 8.00 dollars when paying in cash. When simulating the congestion charge in the NYBPM, the charging rate remains the same. When the other four East River Bridges are charged at 5.54 dollars, the traffic volume increases by 15%. However, when the price charged increases to 8.00 dollars, the traffic volume decreases a little. One reason is that drivers will be willing to drive the longer distance across the Queens Brooklyn Expressway to go through the tunnel. And it is unlikely that they would be willing to pay the extra 3.54 dollars to enter Manhattan every day.

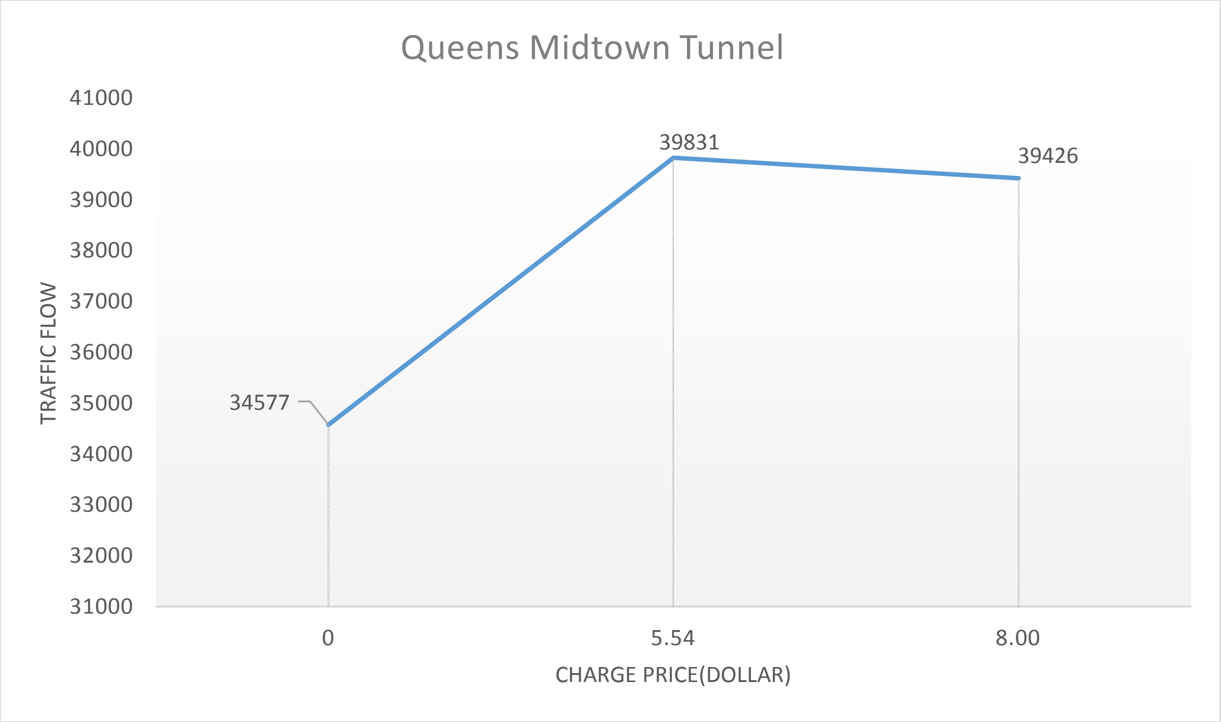

Figure 8. The change in traffic flows on Queens Midtown Tunnel.

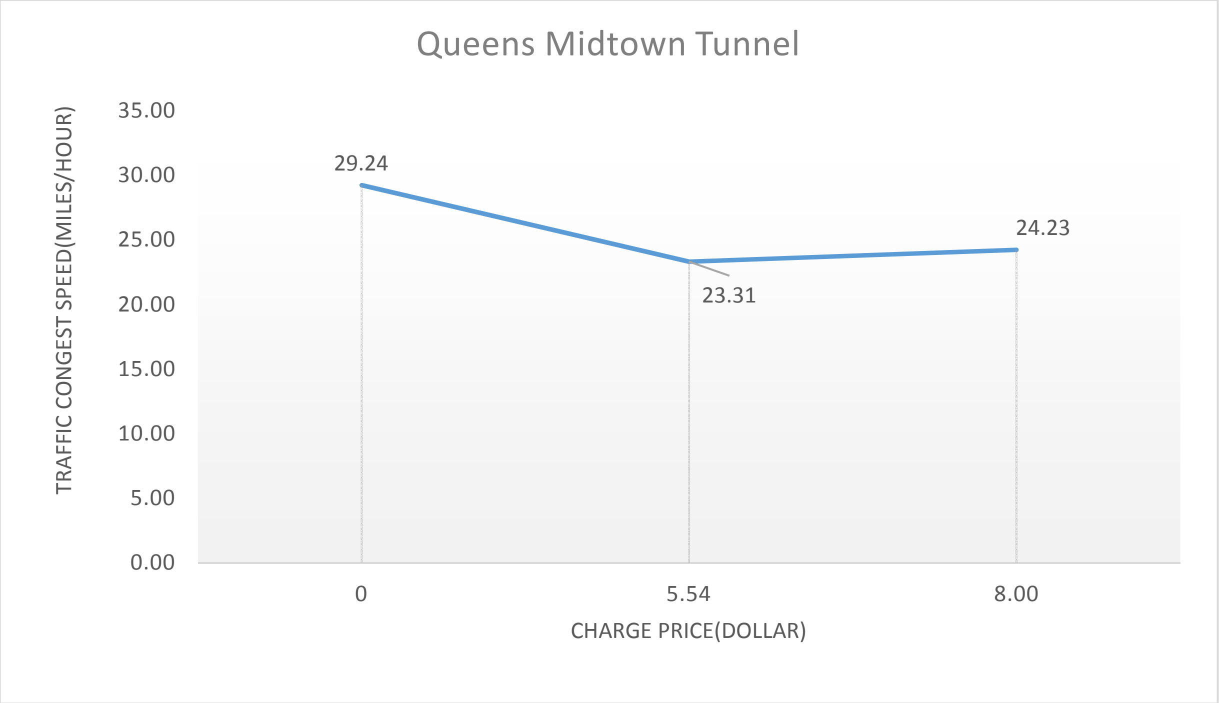

Figure 9. The change in traffic congestion speed on Queens Midtown Tunnel.

Figures 10 and 11 show the changes in the traffic pattern for Queensborough Bridge. The traffic volume decreases by 15% when the price charged is 5.54 dollars. However, the traffic volume increases again a little when the charging fee increases by 2.46 dollars. And the congestion speed changes according to a similar pattern. The reason is the same as in the Queens Midtown Tunnel scenario. When the fee charged increases to the same level as the other tolled routes, drivers will choose the shortest distance inbound to Manhattan.

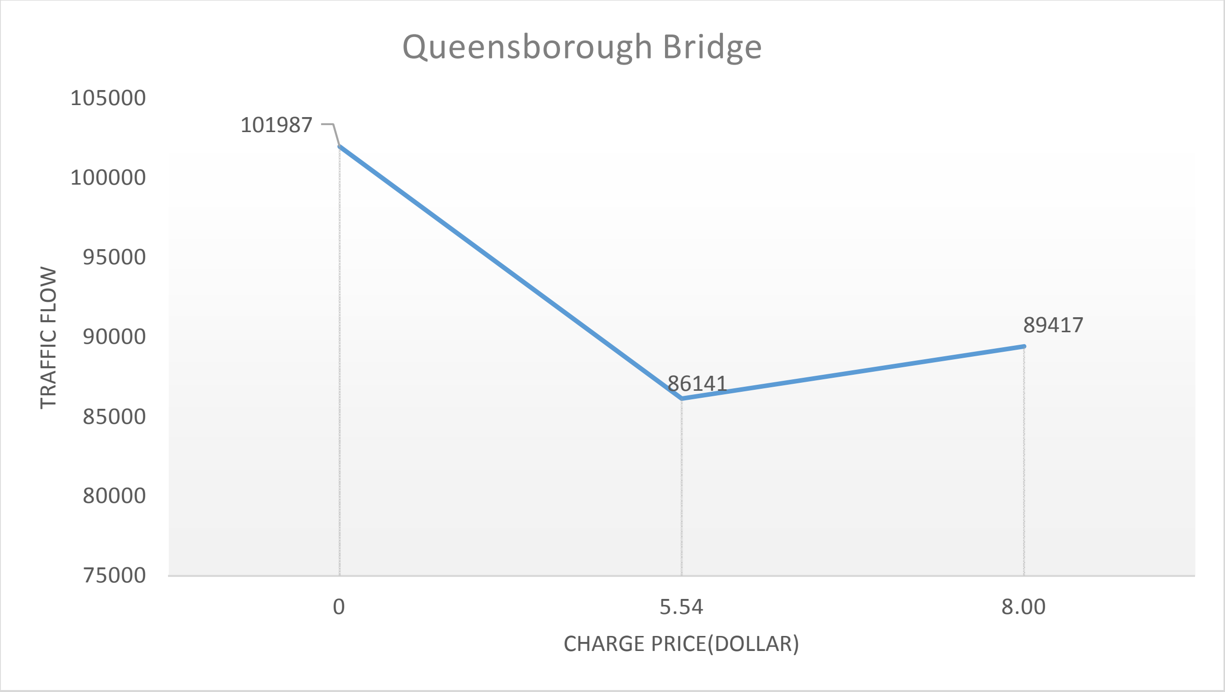

Figure 10. The change in traffic flows on Queensborough Bridge.

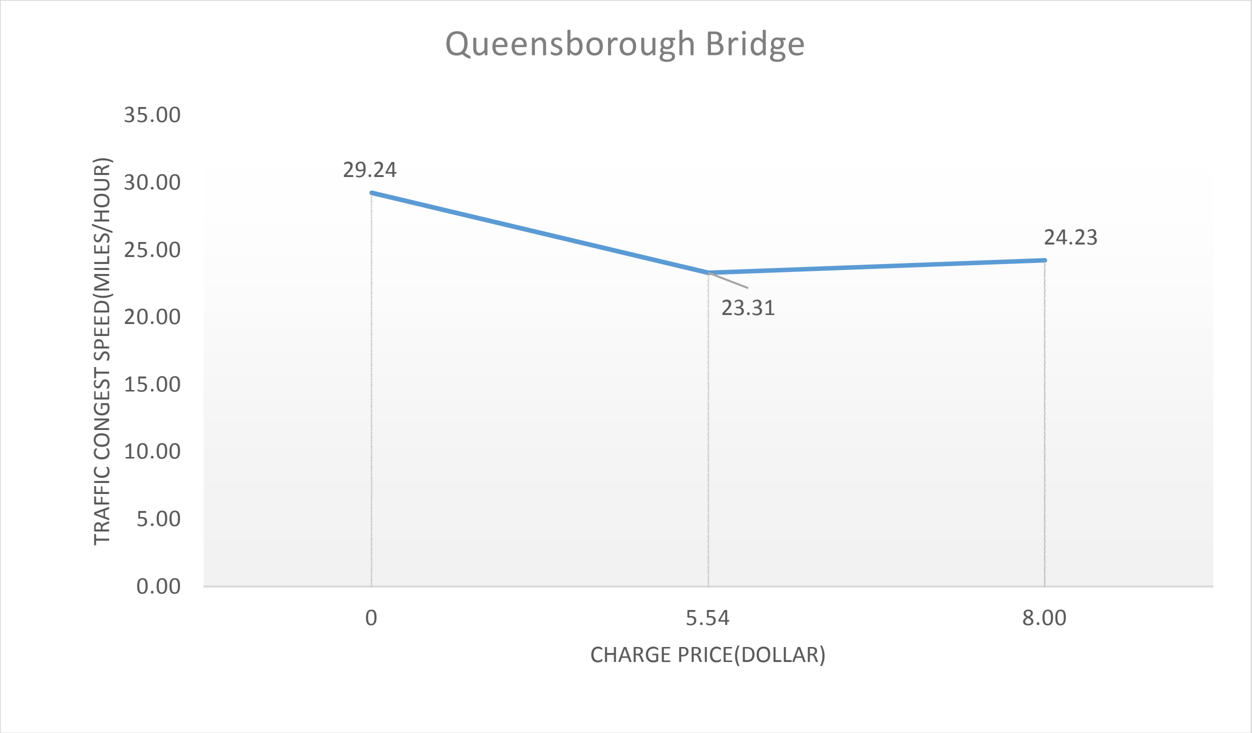

Figure 11. The change in traffic congested speed on Queensborough Bridge.

Figures 12 and 13 show the changing situation for Brooklyn Battery Tunnel. Like Queens Midtown Tunnel, this tunnel already charges drivers. However, the increase in traffic volume, as well as the congested speed, is associated with the new charge levied on Brooklyn Bridge and Manhattan Bridge. Without charging on these two bridges, the Brooklyn Battery Tunnel has a very good traffic situation. One of the reasons is that many drivers are willing to drive a long distance to go via Brooklyn Bridge or Manhattan Bridge to avoid the paying a fee for their entrance into lower Manhattan CBD. If these two bridges were also charged, especially at the 8 dollar rate, drivers would choose the shortest and quickest route into Manhattan.

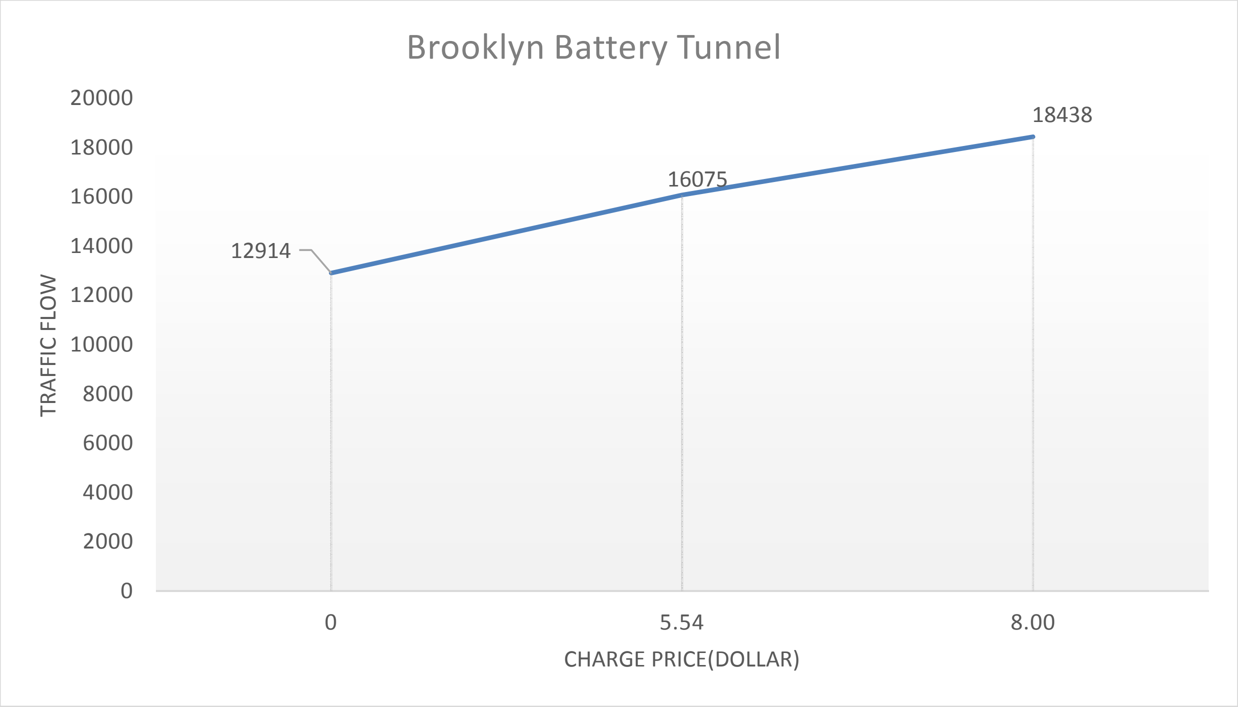

Figure 12. The change in traffic flow on Brooklyn Battery Tunnel.

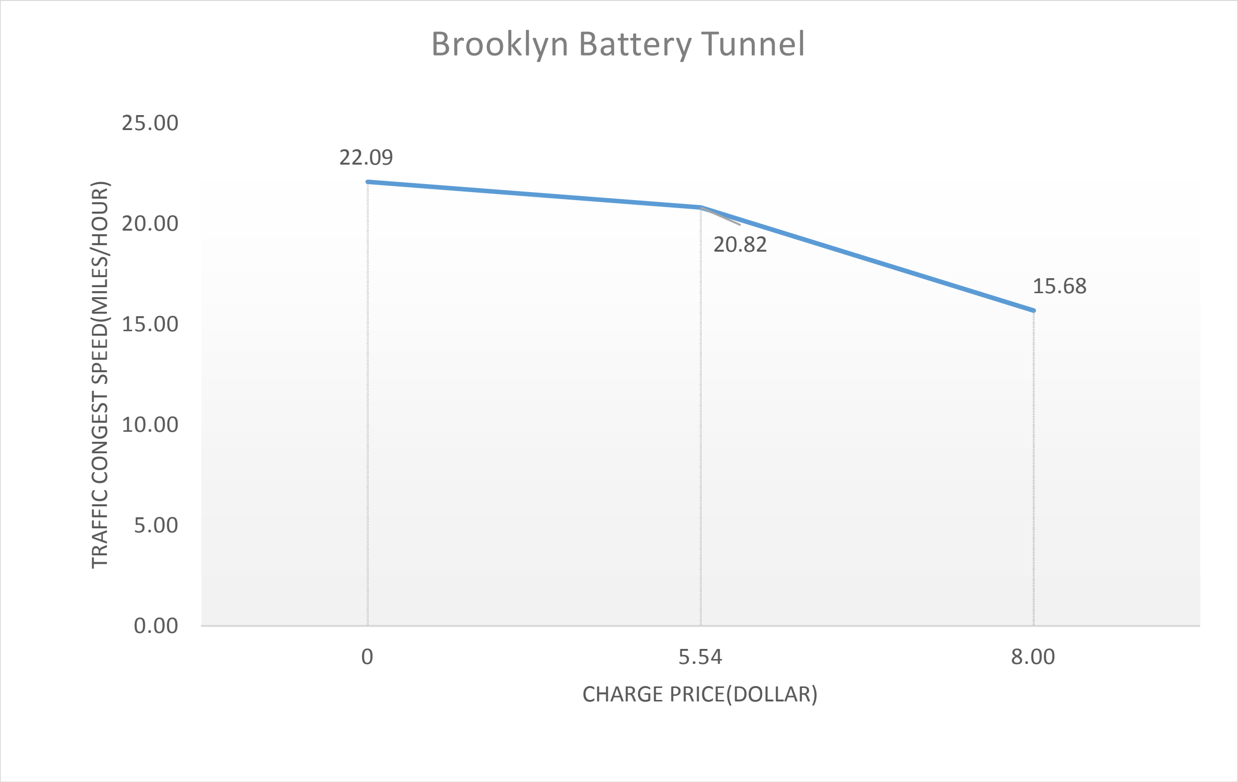

Figure 13. The change in traffic congested speed on Brooklyn Battery Tunnel.

Figure 14 shows the change in the traffic volume in Manhattan CBD. When the price charged increases from 0 to 5.54 dollars, the volume of traffic decreases by 2%. However, the change is not significant when the charge rises further to 8 dollars. One reason is that when the charging scheme is implemented, people would change to other modes of transportation, such as transit, to avoid the fee. For those who still choose to continue driving into CBD, the increase in the price charged will not convince many more of them to change to public transportation. Moreover, the mean daily speed increases by 3%.

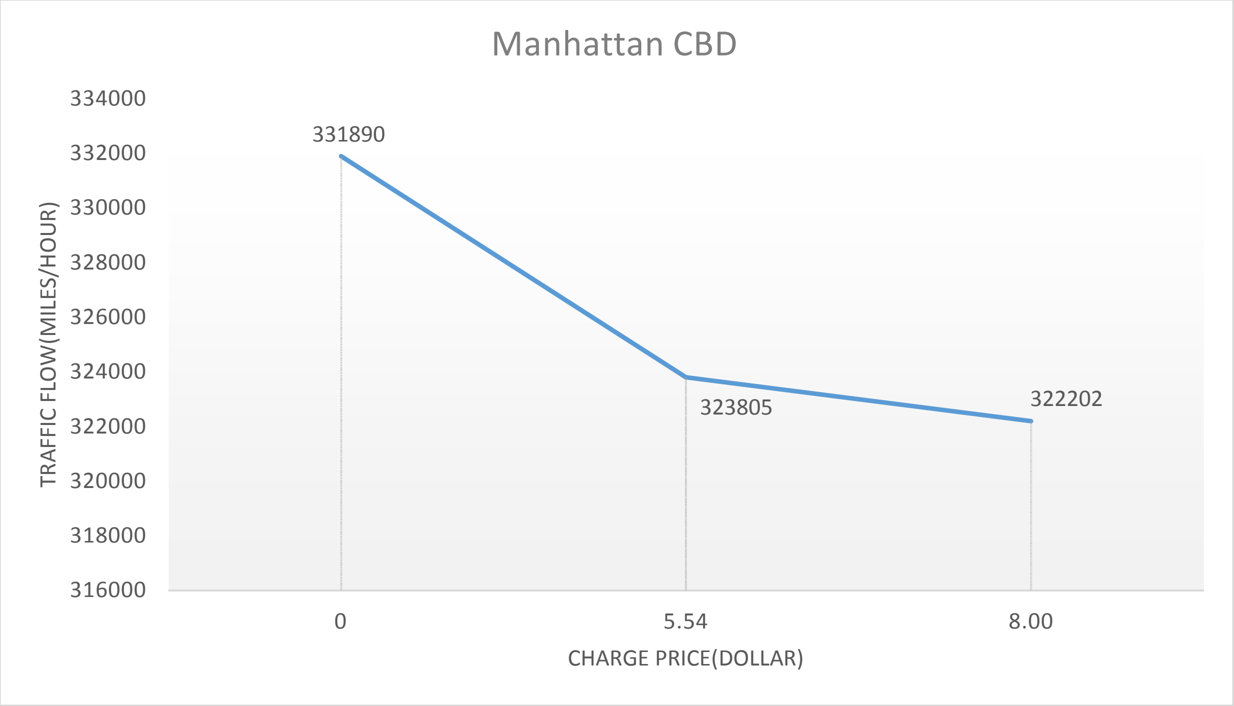

Figure 14. The change in traffic flows on Manhattan CBD.

5. Conclusion

The New York congestion price scheme has been shown and analyzed. There are some apparent results from the analysis of the effect of New York congestion charging scheme. First, there is a significant effect associated with increases in the price charged resulting in an increase in the speed of congested traffic and a decrease in traffic volume. Second, the traffic flow and traffic speed in each area do not change proportionally with the change in the price charged. Third, the change in one charging region can influence other nearby regions. Also, the effect of the price charged on traffic patterns will make many people reconsider their driving route. Finally, in the process of achieving tolling equity, the traffic pattern will have been finalized to an equally balanced traffic distribution.

It must be acknowledged that even though this computational software is equipped with an extensive database, the effect of the proposed congestion price scheme on New York City has not been fully calculated. First, the details of tolling equity is not exemplified or discussed in depth by the Move NY Plan. Second, the proposed charging scheme imposes one congestion price on all types of vehicle in one single simulation. Therefore, the simulation results are, to some extent, not comprehensive. Finally, the time-variant and VMT-based pricing schemes are more applicable, and they should be considered for future congestion price planning.

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