# ESTIMATING TRAFFIC IMPACTS OF AN OFF-HOUR DELIVERY PROGRAM USING A REGIONAL PLANNING MODEL

By

SHRISAN IYER

A thesis submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Master of Science

Graduate Program in Civil and Environmental Engineering

written under the direction of

Dr. Kaan Ozbay

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and approved by

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New Brunswick, New Jersey

*January 2010*

# ABSTRACT OF THE THESIS

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by SHRISAN IYER

Thesis Director: Dr. Kaan Ozbay



In this study a methodology is developed to employ a regional planning model to study the effects of an off-hour delivery program on the transportation network of New York City. The off-hour delivery program under study would shift deliveries to food and retail-related businesses within the borough of Manhattan to the overnight hours, by offering businesses a tax deduction incentive. Behavioral data describing the percentage of receivers participating by tax incentive offered is obtained and translated to commercial vehicle trips. The New York Best Practice Model, a regional travel demand model, is used to measure the impacts of shifting commercial vehicle trips on the rest of the traffic network. The results show that increasing tax incentive amounts reduces the amount of congestion throughout the regional highway network, and thus the proposed program would beneficial to transportation network. Further sensitivity analysis finds that running the highway assignment portion of the model alone does not produce expected results when changes are made to the highway network, and furthermore that the model is very sensitive to changes and its results unpredictable. In order to fully validate the results other models should be used in parallel with the regional planning model.

ACKNOWLEDGEMENT

The author would like to thank Dr. Kaan Ozbay for his guidance in producing this thesis dissertation, as well as the other members of the review committee. Additional thanks goes to the other members of the Rutgers Intelligent Transportation Systems program for their help in writing this dissertation. Sincere thanks also go to Professor Jose Holguin-Veras of Rensselear Polytechnic Institute, and his graduate students, who provided the data necessary to undertake and complete this study.

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## 1. Introduction

Congestion pricing and value pricing have become increasingly utilized by transportation planners as they seek to control demand and halt ever-increasing levels of congestion on urban highways. A major contributor to growing congestion is the sharp increase in freight transported by trucks. Goods must be delivered and current infrastructure necessitates a large proportion of them to be moved by truck only *(1)*. While transportation officials seek to limit the negative operational characteristics that trucks impose on highways, freight carriers are simultaneously searching for ways to improve their efficiency and productivity, currently being hampered by congestion and high travel times. A proposed solution entails providing tax incentives for city businesses to accept deliveries during off-peak hours, which would otherwise take place during the day. The benefits of such a program would be shorter travel times for carriers and fewer trucks traveling and parking on roads during the highly congested daytime hours, while the drawbacks are the financial burden of paying for overnight workers as well as persuading businesses and carriers to participate.

Such an off-hour delivery program is expected to provide benefits to the highway network, since fewer trucks during congested hours would improve highway speeds and decrease travel times. However the precise effects are unknown and their estimation is difficult. Freight planning models or highway networks can be developed and run in simulation software, but these processes are both time-consuming and require extensive data procurement. Instead, many city transportation agencies or metropolitan planning organizations already have developed traffic planning and simulation models. This study describes in detail the usage of the New York Best Practice Model (NYBPM), a regional planning model developed by New York Metropolitan Transportation Council (NYMTC), to model and observe the impact of an off-hour delivery program to the traffic network of the New York metropolitan area. A research methodology is developed for using NYBPM to manipulate and distribute freight trip tables based on the predicted percentage of freight vehicles that would participate in the off-peak delivery program, and calibration is conducted to make appropriate changes to the model.

Once the model's results are obtained analysis is conducted to determine the effectiveness and impacts of the scenarios modeled, as well as cost/benefit analysis of the scenarios. Strategies to neutralize the lost tax revenue of the off-hour delivery program by increasing tolls are tested to determine what level of toll increase is needed to make the program at least cost/revenue neutral. Finally the model's results are investigated for validity, with model runs made when small changes are introduced to the highway network in order to observe how the model reacts. The results are analyzed and recommendations made regarding the usage of these large-scale models in this context.

## 2. Literature Review

In order formulate a methodology to estimate traffic impacts of freight congestion control measures, literature in the field of freight planning was reviewed. The review focused on three specific subjects: policy measures to control freight travel such as value pricing or off-peak delivery programs, freight planning modeling, and using available traffic planning and simulation tools to estimate the impacts of a policy measure. The following section provides a brief summary of these subjects.

### *2.1 Freight Congestion Control*

Much work has been done regarding the quantification of the traffic impacts of congestion mitigation programs, but less has been done concerning programs targeted specifically at trucks or commercial vehicles. Programs addressing highway freight transportation problems are new and experimental, with only a handful of cities implementing congestion control measures *(2)*. The effects of truck and commercial vehicles on highway networks are known to be negative, specifically causing congestion due to their nature as large vehicles which generally travel at a slower speed than automobile traffic. Studies have shown that truck traffic negatively affects the flow rate of highways and local roads, thereby causing congestion on roadways with high traffic volumes *(3)*.

Holguin-Veras et al. determined that freight traffic generated by delivery vehicles to city businesses not only contributed to congestion, but caused added problems due to double-parking and blockages as a result of the lack of parking spaces during the day-time, peak-delivery hours *(4)*. These claims are supported by research into the effects of illegal parking on traffic congestion, which show that illegal parking (primary conducted by commercial delivery vehicles) causes significant capacity losses to roadways, which produce more severe effects during peak hours than during off-peak hours *(5)*. As a result, policy makers have sought to control truck and commercial vehicle traffic, particularly within cities' central business districts, with value pricing measures or by introducing off-peak delivery programs. Both ideas are gaining popularity in the United States, but the degree of their success is yet unknown.

#### 2.1.1 Value Pricing

Value pricing or congestion pricing has become a popular method to combat peak hour congestion. Congestion pricing is already utilized in many other cities, primarily in Europe, as well as Singapore. Value pricing is not new to the New York metropolitan area. Several area transportation agencies, such as the Port Authority of New York & New Jersey (PANYNJ), New Jersey Turnpike, and the New York State Thruway Authority currently employ some form of it.  A study conducted by the Regional Plan Association (New York) concluded that a proposed fee affecting both passenger car and commercial traffic entering Manhattan would limit the number of vehicles entering the central business district during the day-time, or most heavily congested hours *(6).* Adding variable toll pricing of up to $30 to enter Manhattan south of 60$^{th}$ street would result in anywhere from 500 to over 1,000 fewer trucks entering the charging zone during the peak period. Instead, the displaced trucks would shift to other times of day or reroute themselves if applicable.

In 2001, PANYNJ introduced variable time-of-day pricing on the highway crossings between the two states. Ozbay et al. using volume data found that as a result of higher tolls during the peak hours, a significant proportion of passenger car traffic shifted to travel times adjacent to the peak hours. Shifts in truck traffic were also found, however causality to the toll increase could not be established due to truck travel patterns being highly dependent on many things besides tolls, such as customer needs and logistical issues *(7)*. Carriers would require further incentives to shift travel patterns that include matching customer needs, such as off-peak delivery programs *(8)*. Another 2001 study by Vilain and Wolfrom found that at the same PANYNJ crossings, tolls made up approximately 10 to 29 percent of truckers' generalized cost of travel. Their interviews found that trucking companies were likely to pass on costs to producers, thus pricing alone could not change delivery patterns. Instead they required programs in conjunction with customers to shift travel times *(9)*.

### 2.1.2 Off-Peak Delivery Programs

Holguin-Veras also found that road pricing alone would not be sufficient to change delivery patterns. Rather than by just employing pricing, a more comprehensive solution to eliminating daytime freight trips would be to entice both carriers and businesses to participate in an off-peak delivery program *(10)*. Building upon previous research *(11)* he was able to conclude that off-peak deliveries (for example, 7pm – 6am) are a critical component to reducing congestion and other externalities brought on by freight traffic. Within the central business district of New York, deliveries to local businesses are the prime purpose of freight travel. Shifting deliveries to off-peak hours would not only improve traffic conditions during the daytime but would also save freight carriers time lost in congestion and parking fines when parking spaces would otherwise be occupied. Parking fines alone cost trucking companies between $10,000 – $23,000 per truck per year in Manhattan. Time lost in daytime traffic also severely affects productivity and contributes to costs.

However a major hindrance to off-peak deliveries is the stakeholders' perceptions of the perceived benefits from the program. The research conducted indicates that receivers are insensitive to delivery time delays and problems encountered by trucking companies in city traffic. Likewise they would require a major financial incentive to operate and receive deliveries during the overnight hours. In addition, since city-bound carriers often make consecutive deliveries, a large number of receivers would be required to participate. 55% of receivers in the restaurant industry of New York stated that a tax-deduction equal to the salary of one individual would be required to participate in the off-peak program. The remaining 45% stated that even this would not be enough *(4)*. The Holguin-Veras-led research teams generally found that while implementation would be difficult, off-peak delivery programs alone or those with some combination of variable pricing were the best solution to reducing the negative impact of trucks on the highway network of New York.

### *2.2 Applicable Transportation Simulation Models*

The focus of interest for this study is to find the effects of the off-peak delivery shift program suggested by Holguin-Veras and others, by employing commonly used transportation modeling and simulation packages. While transportation planning and simulation software packages are widely used for modeling and evaluation of passenger travel by agencies, consultants, and researchers, not as much attention has been paid to utilizing these for truck and freight studies.

There are several traffic simulation tools available but selection of the right software is contingent upon the needs and budget of the study. The Federal Highway Administration has produced guidelines on the selection of the appropriate tools for traffic modeling purposes: the Traffic Analysis Toolbox, a series of reports begun in 2004, detailing the types of available tools and their applications *(12)*. Holguin-Veras et al. conducted a thorough investigation of freight modeling strategies and their applicability to the New York region *(13)*. Similarly Boile and Ozbay compiled a synopsis of several available transportation modeling tools and strategies used in practice in the New Jersey area *(14)*. A brief review of freight modeling techniques and their uses is presented.

### 2.2.1 Freight Planning Models

Some states and regions have developed statewide freight planning models, commonly in the form of discrete event simulation models for freight planning. Freight modeling is generally considered to be more complex than passenger modeling primarily because freight transport is influenced by a number of different agents, which are continuously changing *(15)*. Freight models can be produced in different forms, such as input-output models, trip-based, or commodity-based models. A trip-based model is more similar to a traditional transportation planning model, in that it models an individual vehicle's travel. Similar to passenger car models, they predict trip generation rates and their distribution. Meanwhile commodity-based models follow the exchange of goods in the market which better accounts for the complex interactions involved in freight transportation *(13)*.

Several agencies have developed different types of freight models, generally at the statewide level. The literature includes descriptions of models built for Florida, Kentucky, Iowa, Massachusetts, Oregon, Virginia, Indiana, Wisconsin, Minnesota, Oklahoma, Kansas, and Texas *(16,17)*. New Jersey, a major portion of New York City's metropolitan area, did not initially develop a statewide freight model; rather it included freight operations as a subsection of its statewide travel demand model. Later on, a multi-commodity model was developed for the state using GIS tools *(17)*. While having freight planning models would be useful for a freight demand management study, estimation of traffic impacts is not possible without a model that includes all classes of vehicles.

### 2.2.2 Travel Demand Models

Travel demand models are typically used by transportation planners to predict travel patterns within a given city, state, or region. They are generally based on large networks and perform modeling tasks on an aggregate basis. Travel demand models are often developed for metropolitan planning organizations to assess the impact of an improvement, forecast future travel, or air-quality analysis. The theoretical framework for most travel demand models is the four-step planning process; trip generation, trip distribution, mode choice, and traffic assignment. Commercial software tools have been developed to automate the process, which is particularly useful for large networks. Some tools that government agencies and transportation consultants use include TransCAD, CUBE/TP+/TRANPLAN, EMME/2, TRANSIMS, and VISUM *(12)*.

The modeled networks generally contain all major roads and highways, and in certain cases rail and bus lines. Travel demand is based on population and employment as well as other features of various sub-zones throughout the modeled area. Traffic assignments are run for different segments of the day, and are generally used to forecast future traffic conditions; however large-scale regional models generally perform static traffic assignment. That is, assigned volumes as link flows are not time dependent; they are aggregated over the full period, and thus, every vehicle simultaneously exists on every link that it uses in the *(14)*.

Regional travel demand models seek to incorporate all travel throughout a region, or as deemed necessary by the developers. This can include models that only considering passenger cars, freight-only planning models, or a combination of both. Historically freight planning has garnered much less attention than passenger car models, and thus far fewer freight planning models have been developed. Boile and Ozbay report:

> *Currently, there are no transportation modeling approaches which account for both passenger and freight considerations. Some of the transportation planning packages that were reviewed ... [have] the flexibility to account for freight flows. Typically, however, for these types of applications, major modifications of the existing models are required and caution should be exercised to develop meaningful models (14).*

### 2.2.3 Passenger and Freight Planning Models

In order to assess the impact of a freight targeted-policy program, it is important to consider the effects to all classes of vehicles and the entire transportation system. While some domestic freight is moved by rail, a significant percentage of goods are transported by trucks, which use the same highway infrastructure as all other vehicles. This study focuses solely on trucks, and thus any changes to their travel patterns will affect the entire highway network and in turn passenger travel. To fully assess traffic impacts throughout the region, a model is required that considers both passenger and freight travel.

In recent years, while the New York Metropolitan Transportation Council (NYMTC), in collaboration with other neighboring Metropolitan Planning Organizations was investigating a regional freight planning model for the New York metropolitan region, it developed the New York Best Practice Model (NYBPM). NYBPM is a comprehensive regional travel demand model that incorporates all aspects of vehicular travel, including highway freight travel *(13,17)*. Regional travel analysis can be efficiently conducted with integrated passenger car and freight components. Simulations can be run to evaluate the effects of policies like toll increases, congestion pricing, or time-of-day shifts in freight activity.

Using travel demand models to estimate the impacts of similar OHD programs has been attempted before, in the city of Athens. Yannis, et al. presented a methodology to model modified commercial vehicle OD demands on a highway network when delivery operations within the city of Athens were restricted *(18)*. The researchers simulated the city's roadways under observed and modified commercial vehicle demands using a road network simulation model. They first observed existing traffic conditions to collect sufficient data to build a comprehensive roadway network, and then calibrated the collected data against actual conditions. Using the traffic simulation program SATURN, they were able to conduct traffic assignment based on actual (base) traffic demands and again with modified demands, which were caused by restricting delivery vehicles from entering the study area within certain times of day. It is important to note that SATURN is strictly a traffic assignment model, not a large scale travel demand model *(12)*.

Yannis et al. created a network that consisted of 285 production and attraction zones, with demand matrices for six separate time periods throughout the day.

Additionally, land uses and average stop times were also studied to represent the effect that actual delivery activities have on roadways, which manifest themselves in the forms of double parking or lane blockages. The researchers were able to code these activities into the network and thus modify the capacity of certain roads were deliveries were taking place. The simulations showed that by barring delivery vehicles from the study area from 7:00am – 10:30am, simulated average roadway speeds increased by 4.7%, and a similar restriction from 2:00pm – 4:30pm increased simulated average speeds by 1%. Conversely, the average speed for the 10:30am – 2:00pm period decreased by 5.8% as the displaced delivery vehicles were assumed to use this period to enter the study area. However the researchers noted that the increase in speeds during the morning and afternoon periods had a greater benefit than the loss in the midday periods, due to higher traffic volumes in the morning and afternoon.

For New York the availability of NYBPM eliminates the need to create a new network model for this study. However it should be emphasized that NYBPM was not designed specifically for or with an emphasis on freight modeling. NYMTC is currently studying alternative ways to study freight transportation and plan for future changes *(19).* Using NYBPM the same changes tested in the Athens study can be simulated and measured. Furthermore, a shift of commercial activity from daytime peak hours to off-peak night hours can be simulated by similarly modifying OD demands. Therefore a methodology will be developed to study the effects of an off-hour delivery (OHD) program suggested by Holguin-Veras and others in a similar manner to the study by Yannis et al., by employing the NYBPM as the primary modeling and analysis tool.

# 3. Methodology

### *3.1 Study Format*

To study the off-hour delivery program described a simple research methodology is proposed. Using behavioral data provided by an independent study, the percentage of business establishments in Manhattan – and by extension the number of commercial vehicles providing deliveries to them – willing to accept certain tax deductions to switch their delivery receipts to the off-hours is known. Using this data as input, a shift model is developed where commercial vehicle (CMV) trips in a transportation simulation model are shifted to the off-peak period. In the model, scenarios can be run and traffic assignment output data can be collected for a base-case, representing current conditions, as well as scenarios varying the tax incentive level and percentage of CMVs shifting to the off-hours. By calculating the differences between a scenario's assignment output and the base-case assignment output the effects of a certain scenario are measured. Additionally cost-benefit analysis can be conducted in terms of the cost of the OHD program and benefits to traffic congestion. A summary of this research methodology can be seen in Figure 3-1.

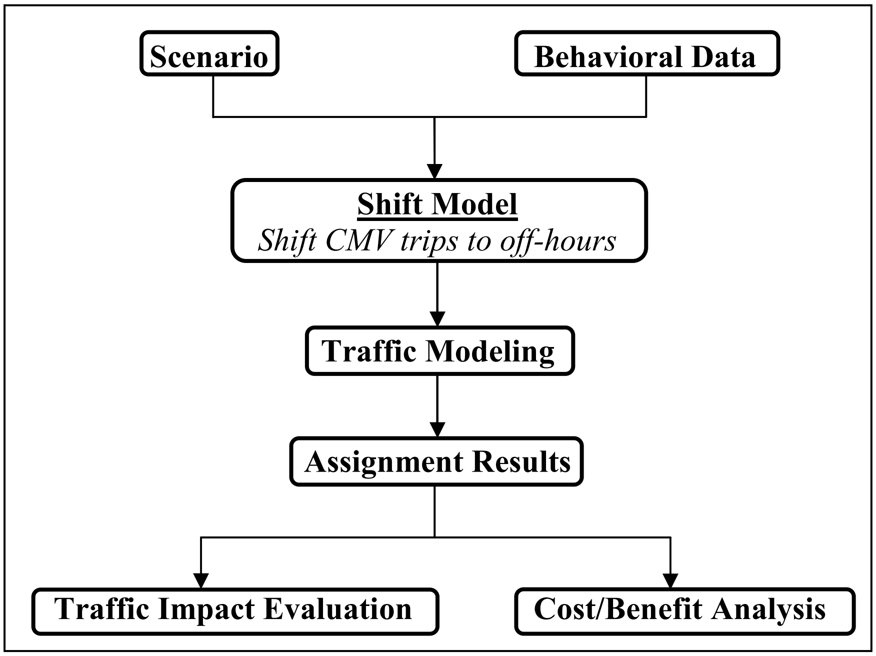


**Figure 3-1: Proposed Research Methodology**

### *3.2 Network Assignment Model*

In order to measure the effects of any type of shift in vehicular travel patterns, such as an off-peak delivery shift program, the changes in traffic conditions throughout the entire regional highway network are considered. If truck or commercial vehicle (CMV) traffic were to be shifted from one time period of day to another – from peak periods to off-peak periods – it is be beneficial to observe whether there is a measurable improvement to the remaining traffic conditions during the peak periods, and conversely whether off-peak conditions are significantly disrupted. NYBPM, a regional planning model will be used to estimate these impacts and the differences between current conditions and what would happen were the proposed program to be implemented will be compared.

There are several macroscopic planning models as well as microscopic simulation models of the study region that can be used to estimate changes in delays as a result of behavioral changes. Micro-simulation models cover relatively small portions of the overall study area (the New York metropolitan region), but the regional planning model, New York Best Practice Model (NYBPM), covers 28 counties in the New York area. NYBPM allows for studying the full effects of the program under study to the complete highway network of New York City and its surrounding areas.

### 3.2.1 New York Best Practice Model Overview

NYBPM is a well known and used model for forecasting travel patterns and behavior for all vehicle types in the New York region. It is a comprehensive macroscopic travel demand model developed for TransCAD software tool, containing nearly all major transportation facilities within the Lower New York/Western Connecticut/Northern New Jersey region. The full coverage of NYBPM is shown in Figure 3-2. The model contains networks for four time-periods, composed of about 4,000 transportation analysis zones, ten motorized modes of travel, and six trip purposes. The highway network itself contains over 50,000 links (classified into 21 link types) and is modeled for six vehicle class types: SOV, HOV2, HOV3+, tax, truck, and commercial vans. The full highway network can be seen in Figure 3-3. The advantages of the NYBPM are that it transcends a typical four-step highway modeling procedure, by utilizing specifically developed approaches to address the complexities of the New York metro-area transportation network. These include using micro-simulation-based travel behavior instead of average travel time, a new procedure for trip generation, a mode-destination stop choice model that is based on household characteristics and land use to predict the locations of intermediate stops, modeling entire journeys rather than trips, and a pre-assignment processor that generates time of day distributions for origins and destinations in the different time periods *(20)*.

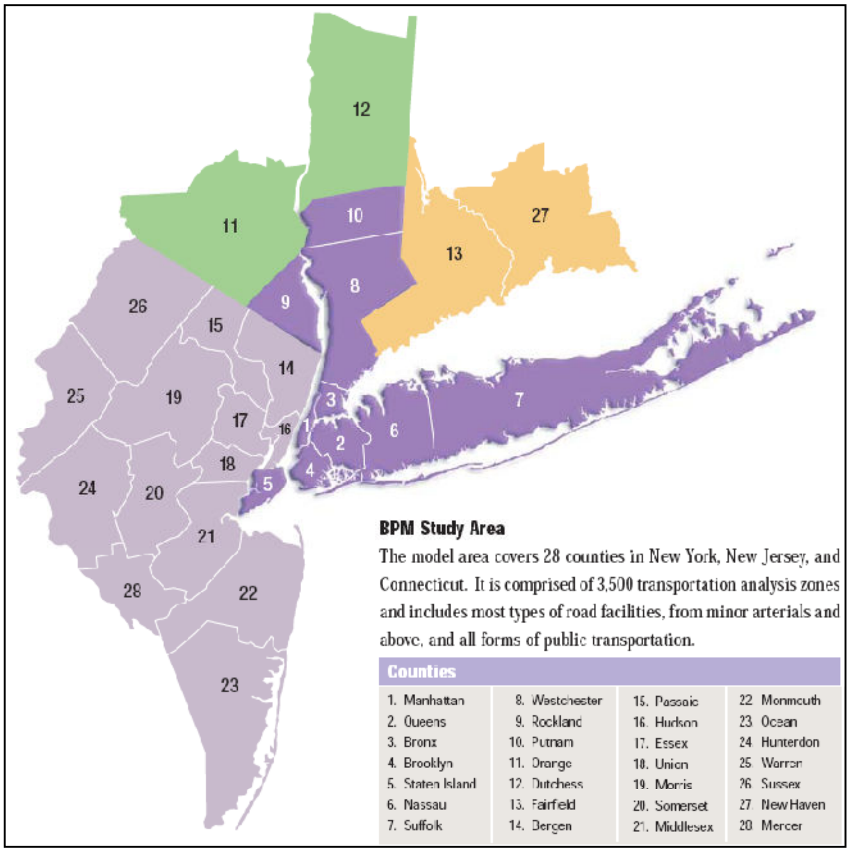


**Figure 3-2: NYBPM Coverage Area**[1]

NYBPM is particularly useful for analysis of the changes and redistributions of truck travel patterns, since it utilizes TransCAD's multi-modal, multi-class, assignment feature. The input origin-destination (OD) matrices for highway assignment are six-fold, one for SOV, HOV2, HOV3+, Trucks, and Commercial Vans. In the multi-class assignment, each trip class is treated separately and utilizes its own cost or volume-delay function, and classes prohibited on certain links are accounted for. Cars and trucks are assigned separately, but still allowed to find the best route to minimize their cost. The actual OD matrix for trucks was estimated from three separate components: gravity model, origin-destination surveys, and estimates from state models. Trip tables were then

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[1] Image taken from http://nymtc.org/project/BPM/background/BPMnewsltr.pdf

made for a specific truck network created containing 294 truck zones, and then this matrix was merged with the full NYBPM matrix *(21)*.

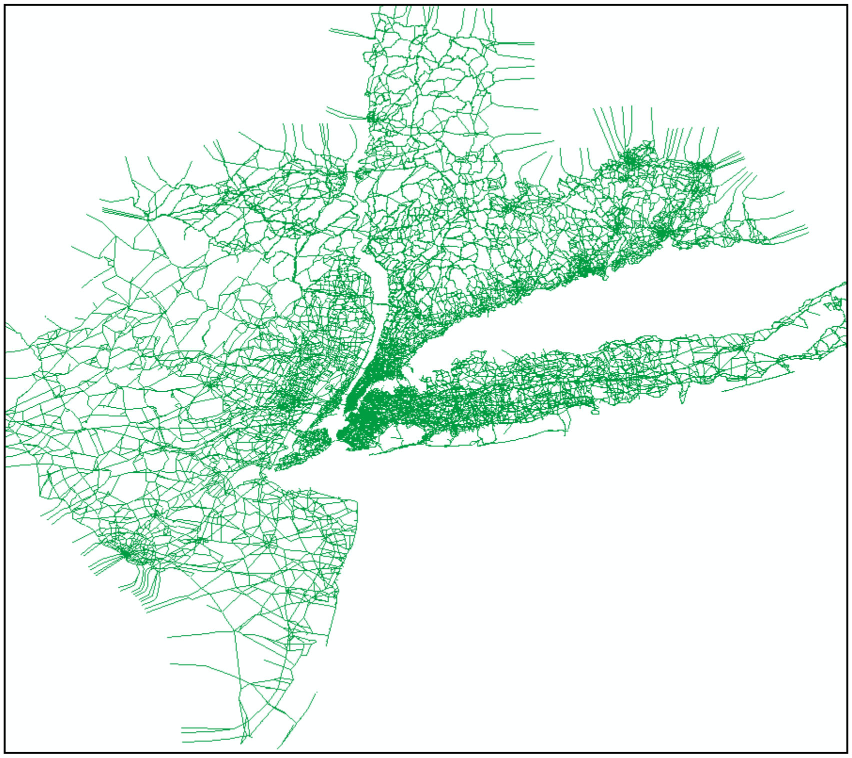

**Figure 3-3: NYBPM Highway Network**

The assignment portion of the model is really a collection of four models for four periods of the day. It is composed of four network periods, each with their own networks as well as different origin-destination matrices. The four period networks are AM Peak Period (6 – 10am), Midday Period (10am – 3pm), PM Peak Period (3 – 7pm), and Overnight Period (7pm – 6am).

### 3.2.2 Investigating the Reliability of NYBPM Results

Development and calibration of NYBPM by the New York Metropolitan Transportation Council (NYMTC) are still ongoing, including producing newer versions of the model. When the model was obtained, it was initially run under a base (year 2002) scenario; no changes were made to any demand levels and features of the transportation networks were left unmodified. The initial link flow results of a typical model run for the 2002 base year were then compared with real traffic volumes on bridges and tunnels in and around New York City reported by NYCDOT *(22)*. It was found that although NYBPM generally performs accurately when all vehicle types are aggregated, truck flows into and out of New York City was largely underestimated. Network-wide, NYBPM was found to perform accurately but individual discrepancies may also be due to variations in traffic assignment. NYBPM fully runs in TransCAD version 4.5; however this version does not account for fixed costs such as tolls in its assignment process. If only assignment is run, it can be run in TransCAD 4.8, accounting for these improvements. Being a CMV-focused study, calibration of the network and truck underestimation was deemed necessary and conducted, summarized in Chapter 4. Based on the methodology, all final scenarios are run in NYBPM for year 2007, with assignments conducted in TransCAD 4.8.

### *3.3 Behavioral Data*

The Behavioral Data was obtained from the project team at Rensselear Polytechnic Institute (RPI) led by Professor Jose Holguin-Veras. The summary of the data acquired is the percentage of receivers within Manhattan willing to accept a certain tax deduction to shift their delivery operations to the off-peak hours (7pm – 6am). The data is only based on businesses in the food and retail industries. Additionally the behavioral estimates are for every zip code in Manhattan, or for simplicity, community board groupings. There are four main community board groupings in Manhattan, shown in Figure 3-4

In order to represent the percentage of CMVs considered to be candidates for the OHD shift, a number of factors must be considered. The behavior modules are designed to predict the number of receivers to shift based on a tax incentive, including the impact of freight carriers servicing an industry. Various industries respond differently to the incentive, and their percentages of total truck traffic varies. Table 3-1 shows the breakdown of deliveries within Manhattan Community Board groupings by industry (food and retail), and as a percentage of total deliveries.

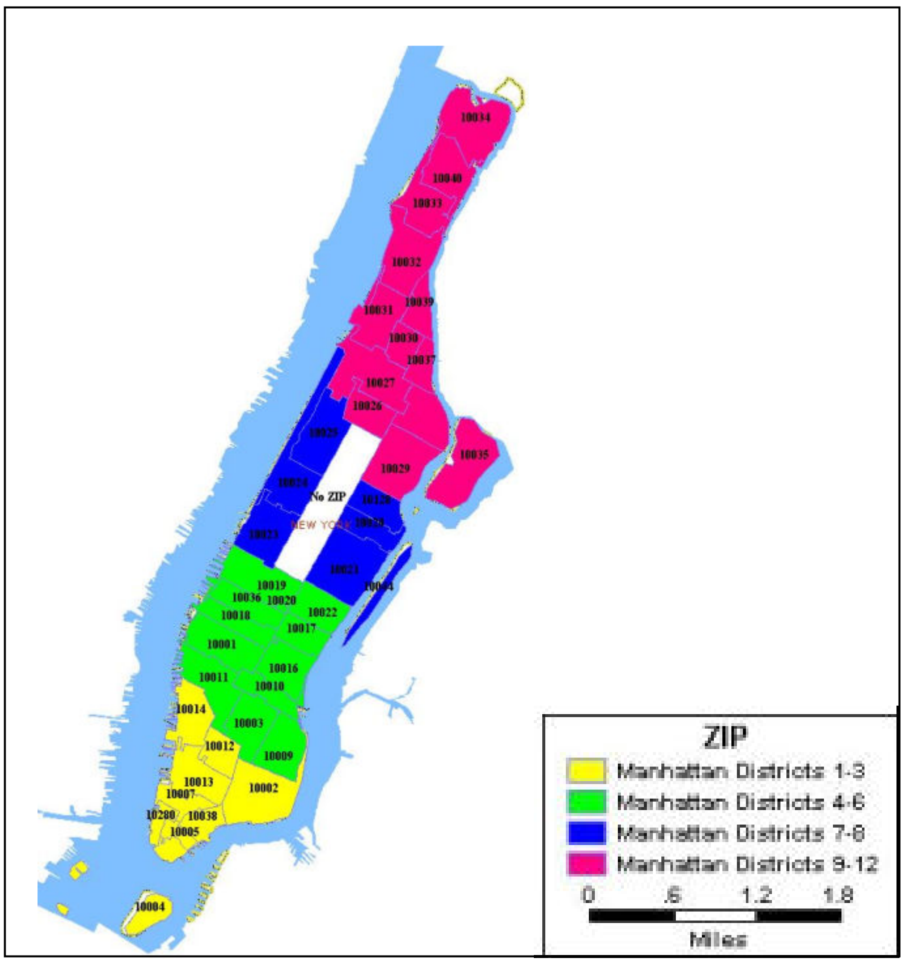


**Figure 3-4: Community Board Districts in Manhattan (from RPI)**

**Table 3-1: Proportion of Truck Traffic by Industry (from RPI)**

| Area | Food Deliveries | Retail Deliveries | Total Deliveries | Food Percentage | Retail Percentage | Food and Retail Percentage |
|---|---|---|---|---|---|---|
| Community Boards 1-3 | 12,202 | 17,244 | 92,163 | 13.24% | 18.71% | 31.95% |
| Community Boards 4-6 | 20,169 | 63,458 | 271,407 | 7.43% | 23.38% | 30.81% |
| Community Boards 7-8 | 7,778 | 10,217 | 71,277 | 10.91% | 14.33% | 25.25% |
| Community Boards 9-12 | 5,964 | 5,292 | 30,788 | 19.37% | 17.19% | 36.56% |
| **Total** | **46,113** | **96,211** | **465,635** | **9.90%** | **20.66%** | **30.57%** |

Using the data from Table 3-1 the total percentage of CMV traffic responding to the incentive of this program can be calculated. This calculation assumes that all CMV trips destined for Manhattan are deliveries.

### *3.4 CMV Demand Shift Model*

While the NYBPM offers some advantages over other four-step demand forecasting models with feedback, an iterative planning process, and micro-simulation components, it still does not exactly accommodate all the needs of this study. For example, it cannot automatically re-assign and redistribute traffic based on predicted changes. Therefore, the methodology must be modified to account for the intricacies of the model. In NYBPM, the traffic assignment module is run without user control, with vehicles choosing the best routes between their origin and destination at their onset *(20)*. Therefore changes to truck behavior and routing will be represented by manipulating the number of truck trips between each origin-destination pair for each time period. Once the existing truck and commercial van OD matrices within NYBPM are altered, the traffic assignment module of NYBPM will be re-run, and the results of the assignment based on the altered OD demands can be compared against the results of the base assignment. Alterations to the truck and commercial van OD matrices are accomplished with shift factors calculated from the behavioral data.

### 3.4.1 Destination Zones

Most of the commercial activity in New York City is located in the borough of Manhattan. Manhattan also has the highest population density and traffic in the city, and is the focus of other proposed traffic control programs such as congestion pricing. Manhattan can further be subdivided into districts, based on geography or commercial density. Being an island with very limited entry points, Manhattan is additionally easy to isolate from a transportation modeling perspective.

The level of detail and size of zones are subject to two input constraints: the zone system of the traffic simulation model and the zone system used by the behavior modules. NYBPM employs a zonal system loosely based on census tracts, resulting in 3,586 transportation analysis zones for the entire New York region. Out of these, 2,374 are located within New York City and 318 inside Manhattan. The number of deliveries is known for market segments for all unique zip codes in Manhattan. These zip code areas can be grouped by their community boards, and into four general zones in Manhattan, as seen in Figure 3-4. The zones used by NYBPM can be similarly grouped to roughly approximate the four general groups of community boards.

Shift factors calculated from the behavioral data are applied to OD demands between all originating zones outside of Manhattan and destination zones within Manhattan. In addition to these simulation runs, 24 additional runs are conducted when the shift factors were only applied to OD demands when the destination zone was in Downtown or Midtown Manhattan. Defined here as “Lower Manhattan”, these zones comprise community board groupings 1-6, and comprise the two central business districts of Manhattan. These areas also contain the bulk of the commercial establishments in

Manhattan and over 75% of the deliveries that take place within Manhattan occur in these areas.

### 3.4.2 Time Periods

The shift factors, $\alpha_J$, developed from the behavioral data are used to factor the commercial vehicle origin-destination demand, $x_{ij}$, as follows:

$$x^p_{ij(new)} = x^p_{ij(old)} \times \alpha_j$$

*where* $x_{ij}$ *= CMV trip demand between origin 'i' and destination 'j'*

$\alpha_J$ *= shift factor for trips with destination in zone J*

$$p = \begin{cases} \text{1 for AM Peak Period} \\ \text{2 for Midday Period} \\ \text{3 for PM Peak Period} \\ \text{4 for Overnight Period} \end{cases}$$

The results of the behavioral module are not time period specific, and they apply to all daytime hours. Thus the same $\alpha_J$ factor is used for the demands of the three daytime periods.

Since the purpose of this study is to model and assess the impact of time-of-day shifts in freight traffic, particularly shifting daytime traffic to the off-hours, it will be assumed that all freight traffic reduced from the three daytime periods will be shifted to the overnight off-hour period. Therefore the total daily commercial vehicle demand between an OD pair, $X_{ij}$, remains constant for the entire 24-hour day for the base (existing) and shifted scenarios, regardless of the values of $\alpha_J$.

$$X_{ij} = \sum_{p=1}^{4} x^p_{ij} \text{ is constant for all ij pairs}$$

As a result, no $\alpha_J$ factor is applied to the period 4 (overnight). Instead, the demand for the overnight period will be equal to the existing demand combined with the shifted demands from the three other times periods. So for each OD pair, the new overnight off-peak demand is as follows:

$$x_{ij(new)}^{4} = x_{ij(old)}^{4} + \alpha_J \left( x_{ij(old)}^{1} + x_{ij(old)}^{2} + x_{ij(old)}^{3} \right)$$

### 3.4.3 Assignment of Shift Factors

A destination zone refers to the end point of trips in the model, with trips being contained in an origin-destination matrix before being assigned to the network. Thus to apply a shit factor to a certain group of zones, all OD pairs with destination in the group of *J* zones being considered will receive the factor. This implies that for freight traffic from all origins bound for Manhattan (or a particular area of Manhattan), a certain percentage will shift to the off-peak hours. Computationally, all OD trip shifts are done exogenously in a MATLAB script which required modification to update the zones of the model having trip shifts.

To apply the shift percentages, the following scheme was used. The qualifying OD pairs were those with the origin as all zones in the network, Zones 1-4000, and the destination was within Zones 1-300*, (i,j) = (1:4000,1:300)*. This signifies that even trips originating within Manhattan are shifted. This was done purposely to account for chained trips, and to maintain the link between 'deliveries' and 'trips.' Thus 24 shift factors accounted for the nearly 1,200,000 OD pairs receiving a shift factor. For this purpose, the percentage of commercial vehicle traffic shifting to off-hour deliveries can be represented as a shift factor, $\alpha_J$, calculated as follows:

$$\alpha_J = \sum_e \rho_J^e \omega_J^e$$

*where J = destination zone where receivers are located*

*e = industry segment {retail, food}*

*ρ = percentage of deliveries from industry 'e' shifting to off-hour*

*ω = proportion of total deliveries associated with industry 'e'*

For the scenarios simulated in NYBPM, the shift factors shown in Table 3-2 were used. The average shift factor for all of Manhattan, calculated by taking the weighted average of the shift factors for each community board grouping J, according to the proportion of total Manhattan deliveries per grouping, can be seen per tax incentive level in Figure 3-5.

**Table 3-2: Shift Factors by Scenario**

| Scenario | Tax Incentive | Community Boards, J | Retail Proportion, $\rho^R$ | Food Proportion, $\rho^F$ | Retail Percent, $\omega^R$ | Food Percent, $\omega^F$ | Shift Factor, $\alpha_J$ |
|---|---|---|---|---|---|---|---|
| 1 | $5,000 | 1, 2, 3 | 16.47% | 12.83% | 4.59% | 22.21% | 3.60% |
| 2 | | 4, 5, 6 | 21.45% | 7.15% | | | 2.57% |
| 3 | | 7, 8 | 11.82% | 10.11% | | | 2.79% |
| 4 | | 9, 10, 11, 12 | 14.34% | 17.13% | | | 4.46% |
| 5 | $10,000 | 1, 2, 3 | 16.47% | 12.83% | 10.44% | 52.92% | 8.51% |
| 6 | | 4, 5, 6 | 21.45% | 7.15% | | | 6.02% |
| 7 | | 7, 8 | 11.82% | 10.11% | | | 6.58% |
| 8 | | 9, 10, 11, 12 | 14.34% | 17.13% | | | 10.56% |
| 9 | $15,000 | 1, 2, 3 | 16.47% | 12.83% | 18.39% | 74.75% | 12.62% |
| 10 | | 4, 5, 6 | 21.45% | 7.15% | | | 9.29% |
| 11 | | 7, 8 | 11.82% | 10.11% | | | 9.73% |
| 12 | | 9, 10, 11, 12 | 14.34% | 17.13% | | | 15.44% |
| 13 | $20,000 | 1, 2, 3 | 16.47% | 12.83% | 26.71% | 83.55% | 15.12% |
| 14 | | 4, 5, 6 | 21.45% | 7.15% | | | 11.70% |
| 15 | | 7, 8 | 11.82% | 10.11% | | | 11.60% |
| 16 | | 9, 10, 11, 12 | 14.34% | 17.13% | | | 18.14% |
| 17 | $25,000 | 1, 2, 3 | 16.47% | 12.83% | 36.39% | 86.17% | 17.05% |
| 18 | | 4, 5, 6 | 21.45% | 7.15% | | | 13.97% |
| 19 | | 7, 8 | 11.82% | 10.11% | | | 13.01% |
| 20 | | 9, 10, 11, 12 | 14.34% | 17.13% | | | 19.98% |
| 21 | $50,000 | 1, 2, 3 | 16.47% | 12.83% | 74.80% | 87.12% | 23.49% |
| 22 | | 4, 5, 6 | 21.45% | 7.15% | | | 22.28% |
| 23 | | 7, 8 | 11.82% | 10.11% | | | 17.65% |
| 24 | | 9, 10, 11, 12 | 14.34% | 17.13% | | | 25.65% |

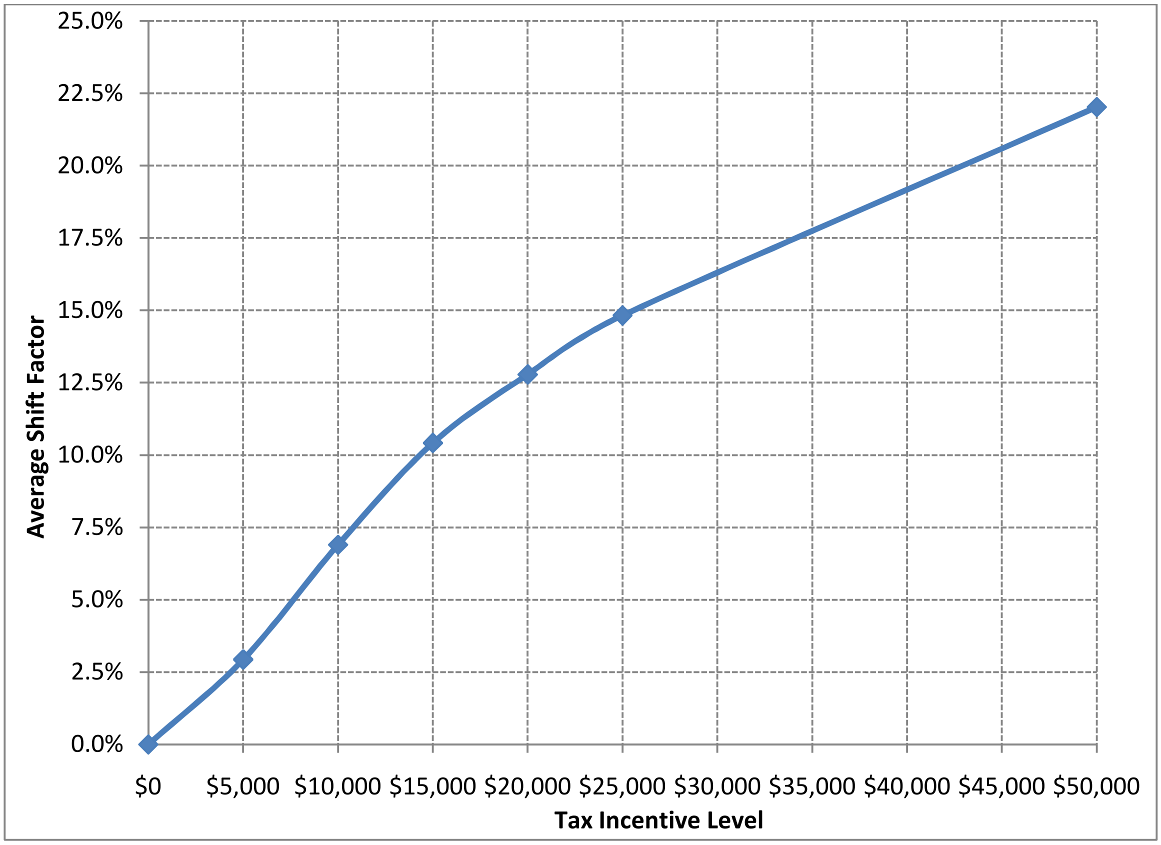


**Figure 3-5: Average Shift Factor by Tax Incentive Level**

Scenarios are run for when receivers accept tax deductions of $5,000, $10,000, $15,000, $20,000, $25,000, and $50,000. A set of these 6 scenarios are run for when these incentives are extended to food and retail receivers throughout Manhattan, as well as another set of 6 scenarios when the deduction is only offered to food and retail receivers in Midtown and Downtown Manhattan (Community Boards 1-6). The results of these scenarios compared to a base-case where no OHD program exists can be seen in Chapter 5 and Chapter 6. First Chapter 4 details efforts to calibrate the traffic model so that it is suitable for testing the OHD program evaluation methodology.

# 4. Calibration

The traffic model chosen to study the effects of the off-hour delivery program was the New York Best Practice Model (NYBPM). Before implementing the research methodology in NYBPM the model must be calibrated to suit the needs of the study. First the model is studied to absorb the proposed methodology and then the truck volume underestimation issue described in the previous chapter is corrected.

## *4.1 Model Testing*

### 4.1.1 NYBPM Trips Generated

Even before the assignment results are compared, the results of model trip generation can be analyzed to observe whether the expected effects of the commercial vehicle (CMV) origin-destination (OD) demand modifications described by the methodology are correctly implemented. Due to the iterative nature of NYBPM, trip generation rates for non-commercial vehicles (grouped as 'autos') are affected by changes to commercial vehicle traffic. Therefore if commercial vehicles are shifted away from a period (AM Peak, Midday, PM Peak) auto trips are likely to increase due to better conditions.

Figure 4-1 shows the change in auto trip generation based on the percentage shift in commercial vehicle demand (trends based on data points at 10%, 20%, 50%, and 100% shift of CMV demand). As expected, auto trip generation increased for the AM Peak, Midday, and PM Peak periods as a larger percentage of CMVs were shifted away from these periods. An unexpected result was that similar trends were observed even for the night period, since if shifting commercial vehicles away from a time period is thought to encourage more auto activity shifting more CMVs to the other time period was expected to reduce the number of auto trips generated. NYBPM's pre-assignment processor which distributes the generated trips throughout the day maintains a similar distribution of trips throughout the day, regardless of actual traffic conditions *(20)*. Or more simply, NYBPM generates more auto trips as a result of decreased truck activity, but distributes them throughout the day the same way every time. This represents a weakness in the model's suitability to the study, and necessitated a revision to the proposed methodology.

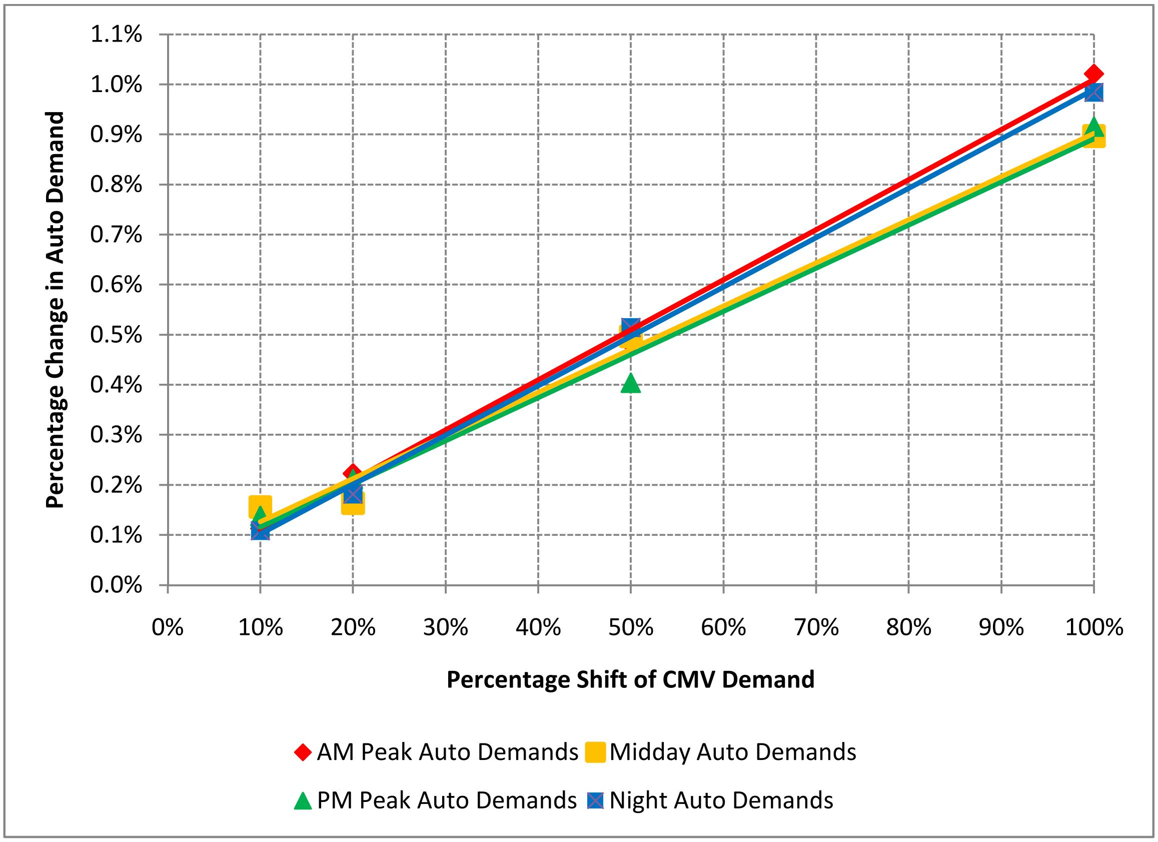


**Figure 4-1: Change in Auto Trip Generation due to CMV Shift**

### 4.1.2 Modeling Around NYBPM Trip Splits

Increases in auto demands are also seen for the night period, even when commercial vehicles are shifted to the night period. The similar linear relationship of auto demand changes for all four periods shows that the model was insensitive to the time of day commercial vehicle shifts. Had the model functioned properly, the Night Auto Demands line in Figure 4-1 should have had a negative slope. It was found that the distribution of traffic to time periods in NYBPM was based on preset time-of-day factors, rather than through a more dynamic process. While NYBPM's auto trip generation is very comprehensive, it has one major weakness that affects its usage for modeling time-of-day shifts. NYBPM utilizes fixed time-of-day factors to split generated daily journeys into individual OD trips throughout the day *(20)*.

As described in the NYBPM manual *(20)* a time-of day processor converts all journeys into individual trips between zones (so that they may be read as an origin-destination matrix by TransCAD). Journeys are converted to trips based on a cumulative arrival time distribution and a cumulative activity duration distribution for each journey purpose. There are 63 passenger journey types, based on journey purpose and mode. Additionally there are 9 classes of commercial vehicle and external auto journeys. These journeys are generated with a much simpler procedure, but are also aggregated by day and assigned arrival times. The aggregated trips for each journey type, with their assigned arrival times, are split into trips within 48, ½-hour time periods, weighted using constant factors given in a 76 (journey types) x 48 (time periods) matrix. The trips for each ½-hour time period and 76 classes are then re-aggregated into OD matrices for 4 model time periods (AM Peak, Midday, PM Peak, Night), each split into 6 highway vehicle classes and 4 transit classes. Trips are also assumed to be exclusive to those time periods (no overlap).

The developers of NYBPM mention in their final report that "it would be desirable to incorporate more flexible timing considerations. This would allow for better replication of individual travel patterns (in terms of journey sequencing and scheduling) as well as make the modeling system more sensitive to policy measures aimed at congestion relief" *(20).* In response to the inability of the NYBPM time-of-day splits to correctly model truck time-of-day shifts, shifts to CMV traffic will be made manually (and exogenously) and only the highway assignment module of the model will be re-run for each scenario. This is accomplished by exporting the truck and commercial van trip matrices from TransCAD to data files. Using MATLAB, the changes to the trip matrices described in the shift model are applied. Then the datasets are imported into TransCAD trips matrices ready for use in NYBPM Highway Assignment.

The trip generation, distribution, and mode split modules are thus ignored. Assignments will differ since the origin-destination matrices will be manually manipulated before the assignment. This result models short-term effects since shifts in truck traffic would not immediately result in changes to travel patterns or trip generation. Such changes would only develop over time, so changes to assignment only will represent immediate near-future results. In terms of long-term trends, changed network conditions should affect trip generation, which would not be modeled using this solution. This study will focus on short-term effects of the OHD program.

### *4.2 Origin-Destination Matrix Assessment*

The sub-section describes the calibration of the origin-destination (OD) matrices used to assign truck trips onto the regional highway network in the New York Best Practice Model (NYBPM). The OD matrices used in the model were first developed and calibrated in the 1990s, and during preliminary testing of NYBPM was observed that truck volumes seemed to be underestimated. Link volume data was acquired for highway links throughout the New York metropolitan area and compared against the assigned volumes of NYBPM. This check found that the existing model under-assigned trucks throughout all zones in the network. Several procedures were developed and tested to adjust the existing NYBPM truck OD matrices without necessitating the collection of any new data. The OD matrices were adjusted so that the output of the model's assignment closely matched the up-to-date field data, and finalized for usage as a base-case scenario of the model. The following describes the data acquired and the procedures used.

### 4.2.1 Origin-Destination Matrix Adjustment Methodology

Much information exists in the literature regarding origin-destination matrix estimation and calibration. A very brief summary is presented followed by strategies to efficiently implement an effective solution. Strategies utilized to calibrate origin-destination matrices based on field data are of particular interest. Since NYBPM is the focus, the problem is further narrowed to only static cases. OD estimation techniques can be broadly classified into three categories: trip generation adjustments using extensive data surveys, trip distribution models, and non-assignment based adjustment using volume data *(23)*. The third strategy is simplest and most easily implementable given the current data sources and study limitations. One disadvantage of this method is that since the proportion of links with data to total network links is so low (321 to 50,000+), the problem is severely underspecified. Thus a number of potential OD matrices can be estimated based on the link flows *(24)*.

New York Best Practice Model's truck OD matrices were originally developed through a trip generation approach with support for input of link counts. Beginning with a target trip matrix, OD estimation must satisfy the following general condition *(24)*:

$$min\ \frac{1}{2}\left(\sum\left(g-g^{*}\right)^{2}+\sum\left(v-v^{*}\right)^{2}\right)$$

*where g = demand matrix,*

*g* = adjusted demand matrix,*

*v = link flows (vehicles per hour),*

*v* = adjusted link flows (vehicles per hour),*

This condition can be simply described as minimizing the total differences between the initial and target trip matrices, as well as the given and assigned link flows.

While NYBPM is further advanced in freight modeling than typical travel demand models – with inclusion of class-stratified Origin-Destination matrices, class-stratified generalized costs, and Multi-Class Assignment – freight modeling still was not the main focus of the model. The developers of NYBPM explain that:

> *....while addressing commercial traffic as part of the overall NYBPM regional models was considered essential, the emphasis for the initial NYBPM was clearly on developing an advance set of private passenger travel models. The resources for development of the commercial travel element were significantly more limited. Consequently, rather than grounding these models in the overall framework of freight or goods movement analysis, the methodology aimed directly at an empirically oriented modeling of truck and other commercial traffic that would make maximum use vehicle class traffic count and origin-destination data in the region (20).*

To estimate truck origin-destination (OD) flows to be used in NYBPM, an optimization technique was employed to incorporate collected field data based on counts and surveys into model estimation *(20)*. NYBPM originally estimated commercial vehicle OD matrices based on a combination of surveys and link volumes. Additionally, the process was begun in 1988, and final estimation was made only for the base NYBPM year of 2002. With the availability of more recent freight data, it is beneficial to evaluate and update the NYBPM commercial trip matrices to match current freight volume levels. Comprehensive link volume data from area transportation agencies was acquired and the results of NYBPM's assignment checked. After finding that the model did not perform adequately a number of quick but effective procedures were developed to adjust the OD matrices. These were narrowed down to re-estimation of the OD matrices using the acquired data, manually inflating the OD matrices, or a hybrid approach.

TransCAD software package has an in-built OD matrix estimator that conveniently runs with the NYBPM network as input. It functions through an iterative process where a matrix is estimated and assigned to the network several times, until convergence is reached that satisfies an initial condition. Through its utilization it is not necessary to change the NYBPM truck trip generation procedures. Instead the matrices can be re-estimated by updating the volume counts in the NYBPM assigned network. There are also several simpler alternatives to this, including scaling link flows and re-estimating OD matrices, or a manual approach of exogenously altering the OD matrices and not using TransCAD's OD estimator. These techniques were tested using the acquired data described in the following section.

#### 4.2.2 Data Acquired for Calibration

Real data on truck volumes throughout the New York metropolitan area was acquired for the purpose of validating and calibrating the output of NYBPM. The following sources of data were identified for acquisition:

- New York & New Jersey State Departments of Transportation Weight-In-Motion (WIM)/Volume Data
- New York City Bridge and Tunnel Counts [From New York City Department of Transportation (NYCDOT), Metropolitan Transportation Authority (MTA), and Port Authority of New York & New Jersey (PANYNJ)]
- New Jersey Turnpike Truck EZ-Pass Volumes at All Interchanges
- Other available reports and studies

Weight-In-Motion stations are located on highways throughout the region, where class-wise volume data is collected by time of day. Aggregation and filtration of this data enables determination of the average volume for a given link by vehicle class. In addition to this data, weigh stations where trucks must stop to be weighed also count the number of trucks stopping and the times of their stops is collected, and stored in a database. Access to these databases enables aggregation of truck volumes by hour or period, which can then be taken to be the truck volume for the link that the station is located. Then the counted volume on that link can be compared to the assignment output of NYBPM for the same or nearly similar link on the highway network.

New York State and New Jersey Departments of Transportation were contacted to obtain data from year 2007 (the most recent available year at the time). A sample of the hourly data obtained from New Jersey WIM stations is shown in Figure 4-2. The collected data was aggregated and post-processed to obtain average link volumes for the links in network, for all the hours of the day. In many cases, truck volumes are split by axle or size of truck. However for the purpose of comparison to the output of NYBPM, these volumes need to be aggregated. NYBPM classifies freight vehicles into two classes:

trucks and commercial vans. Similar designations are also used by some agencies, for example NYCDOT, but others use different classifications.

Normalized Time Distribution_DRM_Unfiltered_3_15_2006_SB

Selected Day: 3/15/2006

| Time of Day | Large Trucks | Others | Large Trucks(%) | Others(%) |
|---|---|---|---|---|
| 0-1 | 2 | 22 | 0.37% | 0.67% |
| 1-2 | 0 | 29 | 0.00% | 0.89% |
| 2-3 | 0 | 33 | 0.00% | 1.01% |
| 3-4 | 4 | 31 | 0.74% | 0.95% |
| 4-5 | 8 | 58 | 1.48% | 1.78% |
| 5-6 | 8 | 198 | 1.48% | 6.06% |
| 6-7 | 10 | 282 | 1.86% | 8.63% |
| 7-8 | 12 | 282 | 2.23% | 8.63% |
| 8-9 | 8 | 211 | 1.48% | 6.46% |
| 9-10 | 31 | 270 | 5.75% | 8.26% |
| 10-11 | 44 | 246 | 8.16% | 7.53% |
| 11-12 | 56 | 284 | 10.39% | 8.69% |
| 12-13 | 78 | 188 | 14.47% | 5.75% |
| 13-14 | 84 | 197 | 15.58% | 6.03% |
| 14-15 | 49 | 220 | 9.09% | 6.73% |
| 15-16 | 39 | 187 | 7.24% | 5.72% |
| 16-17 | 27 | 136 | 5.01% | 4.16% |
| 17-18 | 26 | 134 | 4.82% | 4.10% |
| 18-19 | 22 | 92 | 4.08% | 2.82% |
| 19-20 | 10 | 56 | 1.86% | 1.71% |
| 20-21 | 7 | 28 | 1.30% | 0.86% |
| 21-22 | 4 | 37 | 0.74% | 1.13% |
| 22-23 | 7 | 26 | 1.30% | 0.80% |
| 23-24 | 3 | 20 | 0.56% | 0.61% |
| Total | 539 | 3267 | | |

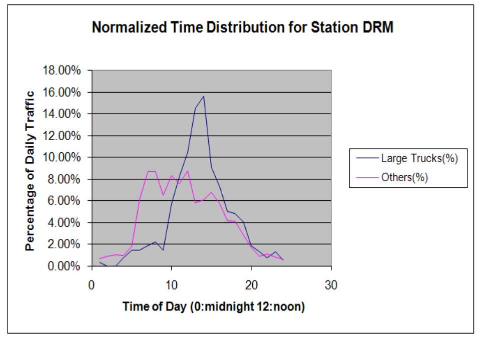


**Figure 4-2: Aggregated Time-of-Day WIM Data**[2]

For the purposes of this study, New York City Department of Transportation's Bridge and Tunnel Volume datasets *(25)* are most useful since the focus area is Manhattan. Since it is an island, counts are available at all entry points into Manhattan. However the collected data does not perfectly hold suit for comparison to NYBPM output; several agencies own and operate the crossings into Manhattan and collect and provide data differently. For example NYCDOT counts are only available hourly from 7am to 7pm, whereas NYBPM assignments are for 6 – 10am, 10am – 3pm, 3 – 7pm, and 7pm – 6am. Additionally data is not split for trucks or commercial vehicles at all crossings. Comparisons to NYBPM output can be incomplete in some cases. A description of the different ways agencies collect data can be seen in Table 4-1.

In order to use the collected data classes of vehicles had to aggregated into two large categories: trucks and commercial vans. To account for lack of data and for

[2] From "Advanced Software for Statewide Integrated Sustainable Transportation System Monitoring and Evaluation for Weigh-in-Motion Sensors," ongoing study with New Jersey Dept. of Transportation

simplification only the Trucks category was used in calibration. Additionally some links could not be used for calibration since data was not collected, especially during overnight hours. Looking at only individual link volume differences is not suitable since differences in volumes for parallel crossings could be due to NYBPM traffic assignment and not whether the origin destination demands of NYBPM are accurate. A comprehensive comparison where all crossings were aggregated together is necessary and was conducted for year 2007 data, along with comparisons throughout the region using all of the other available data sources.

**Table 4-1: Manhattan Crossings Volume Data Difference by Agency**

| Agency | Crossings | Time Splits | Class Splits (FHWA Class) |
|---|---|---|---|
| NYCDOT - East River Bridges | Brooklyn Br., Williamsburg Br., Manhattan Br., Queensboro Br. | Hourly, 24 Hrs. | Commuter/Commercial Vans/Pickups/Large SUV (3), Single Unit Truck (5-7), Tractor Trailer Truck (8-13) |
| NYCDOT - Harlem River Bridges | Hamilton Br., Broadway Br., Macombs Dam Br., Madison Ave Br., 3rd Ave Br., University Heights Br., Washington Br., Willis Ave Br., 145th St Br. | Hourly, 7AM-7PM | Commuter Vans, Commercial Vans, Trucks |
| MTA | Midtown Tunnel, Battery Tunnel | Hourly, 24 Hrs. | Commuter/Commercial Vans/Pickups/Large SUV (3), Single Unit Truck (5-7), Tractor Trailer Truck (8-13) |
| MTA | Triborough Bridge | Hourly, 24 Hrs. | No Classwise Data |
| PANYNJ | George Washington Bridge | Hourly, 1AM-5AM Missing | Small Trucks, Large Trucks |
| PANYNJ | Lincoln Tunnel | Hourly, 1AM-5AM Missing | Commuter/Commercial Vans/Pickups/Large SUV (3), Single Unit Truck (5-7), Tractor Trailer Truck (8-13) |
| PANYNJ | Holland Tunnel | Hourly, 24 Hrs. | Commuter/Commercial Vans/Pickups/Large SUV (3), Single Unit Truck (5-7), Tractor Trailer Truck (8-13) |
| **NYBPM** | **All** | **4 Time Periods** | **Trucks, Other Commercials** |

The New Jersey Turnpike, a major carrier of truck traffic in the New York metropolitan area, collects EZ-Pass data for vehicles entering and exiting the system at every interchange. Extrapolation from this data, estimates vehicle flows for every link of the system by class. Data for the New Jersey Turnpike is available for all hours of the day, thus it can aggregated and directly compared to the output of NYBPM. An initial analysis shown in Table 4-2 reveals that the difference between link truck volumes from actual 2006 counts on the New York-area section of the New Jersey Turnpike to those predicted by the NYBPM 2002 output were significant. Year 2002 output of NYBPM were expected to be lower than 2006 NJ Turnpike data due to increases in truck traffic, but they were significantly higher than expected. In general, NYBPM largely underestimates truck flows on the NJ Turnpike, similar to the New York City data analysis. A full comparison with 2007 data is conducted in the following sub-section.

#### 4.2.3 Full Comparison of NYBPM Output with Updated Truck Volumes

Analysis of only individual links or points on the highway network can provide misleading results, since differences might be due to variances within the assignment and not problems with the OD matrices. A 2007 Report by the Regional Plan Association *(26)* grouped traffic according to the side of Manhattan that they chose to enter. For example, all truck traffic entering Manhattan via an East River crossing below 60th Street was grouped. By considering these links as one group, questions on potential differences in assignment can be eliminated. A comparison of the truck volumes from this report with the volumes from NYBPM and those from the Bridge and Tunnel counts of NYCDOT is shown in Table 4-3.

**Table 4-2: Difference in NJ Turnpike Truck Volumes Compared to NYBPM Output**

| Link | AM Peak (6-10) | | | | Midday (10-3) | | | |
|---|---|---|---|---|---|---|---|---|
| | *Northbound* | | *Southbound* | | *Northbound* | | *Southbound* | |
| | Difference | % | Difference | % | Difference | % | Difference | % |
| Exit 7A-8 | 1731 | 51.4% | 1561 | 51.6% | 1782 | 46.3% | 2810 | 59.2% |
| Exit 8-8A | 1397 | 42.0% | 1236 | 39.5% | 1428 | 36.6% | 2436 | 51.0% |
| Exit 8A-9 | 883 | 24.2% | 872 | 23.8% | 1077 | 23.8% | 1904 | 35.5% |
| Exit 9-10 | -102 | -2.6% | 352 | 8.4% | 523 | 10.1% | 1310 | 21.7% |
| Exit 10-11 | 250 | 6.5% | -1699 | -42.9% | -633 | -12.9% | 260 | 4.5% |
| Exit 11-12 | 994 | 21.7% | 46 | 1.0% | 1402 | 23.3% | 2190 | 32.6% |
| Exit 12-13 | 1309 | 26.0% | 260 | 5.2% | 1956 | 30.5% | 2732 | 37.2% |
| Exit 13-13A | 1013 | 18.6% | 429 | 7.4% | 1737 | 24.3% | 2629 | 32.4% |
| Exit 13A-14 | 1821 | 36.1% | 326 | 6.6% | 2373 | 35.9% | 2896 | 39.8% |
| Exit 15E-16E | 768 | 35.5% | -273 | -13.7% | 49 | 2.1% | 229 | 7.8% |
| Exit 15W-16W | 570 | 17.3% | -44 | -1.3% | 746 | 17.8% | 1399 | 28.4% |
| Exit 17-18E | -224 | -14.4% | -306 | -22.5% | -683 | -44.1% | -379 | -20.9% |
| Exit 16W-18W | 500 | 21.7% | 441 | 19.6% | 774 | 28.6% | 1491 | 43.0% |
| Total | **10910** | **22.9%** | **3201** | **6.7%** | **12533** | **21.1%** | **21908** | **31.6%** |

| Link | PM Peak (3-7) | | | | Night (7-6) | | | |
|---|---|---|---|---|---|---|---|---|
| | *Northbound* | | *Southbound* | | *Northbound* | | *Southbound* | |
| | Difference | % | Difference | % | Difference | % | Difference | % |
| Exit 7A-8 | 1245 | 53.5% | 1682 | 61.3% | 1705 | 35.4% | 135 | 3.6% |
| Exit 8-8A | 1094 | 46.5% | 1503 | 56.1% | 1431 | 29.9% | -195 | -5.2% |
| Exit 8A-9 | 1020 | 37.8% | 1339 | 46.4% | 1279 | 25.4% | -225 | -5.5% |
| Exit 9-10 | 949 | 31.1% | 1186 | 38.3% | 1333 | 25.1% | -159 | -3.5% |
| Exit 10-11 | 92 | 3.4% | 1213 | 41.4% | 178 | 3.8% | -911 | -22.6% |
| Exit 11-12 | 1052 | 31.9% | 1680 | 49.5% | 1685 | 31.9% | 450 | 10.0% |
| Exit 12-13 | 1275 | 36.0% | 1998 | 53.1% | 1876 | 33.9% | 812 | 16.8% |
| Exit 13-13A | 1585 | 41.0% | 1840 | 46.4% | 1618 | 30.6% | 1914 | 33.9% |
| Exit 13A-14 | 1603 | 44.5% | 2037 | 56.2% | 1899 | 36.9% | 2136 | 39.2% |
| Exit 15E-16E | 288 | 22.6% | 780 | 51.3% | 1019 | 43.5% | 634 | 30.5% |
| Exit 15W-16W | 852 | 38.5% | 1167 | 48.5% | 1059 | 27.6% | 975 | 25.1% |
| Exit 17-18E | 131 | 14.5% | 333 | 31.4% | 530 | 34.0% | 439 | 28.6% |
| Exit 16W-18W | 660 | 46.8% | 1108 | 61.3% | 1485 | 49.8% | 1706 | 55.4% |
| Total | **11845** | **35.6%** | **17866** | **49.8%** | **17096** | **30.2%** | **7710** | **15.1%** |

**Table 4-3: New York Truck Volume Comparisons from Multiple Sources**

| **East River Below 60th St.** | RPA Report | NYBPM | | NYCDOT | |
|---|---|---|---|---|---|
| | | Difference | % | Difference | % |
| 6-10AM | *3336* | 2016 | 40% | 3700 | -11% |
| 6AM-6PM | *8741* | 4850 | 45% | 10186 | -17% |
| 24 HRs | *9653* | 5607 | 42% | | |

When bridges are grouped to the East River crossings, the NYBPM severely underestimates truck traffic. (It should be noted that these NYBPM flows and NYCDOT counts are for year 2002, with the RPA report being for year 2006). For year 2007, a complete aggregation of all collected was made for full comparison. All combined the average hourly truck volume counts for 321 links in the regional network were used, mostly concentrated in and immediately around New York City. The links with available truck counts are shown in the NYBPM network in Figure 4-3.

**Figure 4-3: New York City Area Links with 2007 Truck Volume Counts**

While this study considers the highway network of the entire region, the focus of the program is on Manhattan. One of the weaknesses of the data acquired is that there is minimal truck volume data available for links within Manhattan. However, since Manhattan is an island, counts are available at all entry points; the bridges and tunnels. For the sake of evaluating NYBPM output, the 2007 volumes were compared with the assignment output of a 2007 NYBPM scenario. Since NYBPM is really a collection of four separate models, representing the four separate time periods, analysis is conducted separately for each. Figure 4-4 shows NYBPM predicted truck flows plotted against the actual truck volume counts for all the links where data is available. It can be seen that the majority of the data points are to the right or below the 1:1 ratio line, indicating that the actual truck volume counts are higher than the NYBPM predicted volumes. The discrepancy is most noticeable during the PM Peak period, where nearly all links are underestimated.

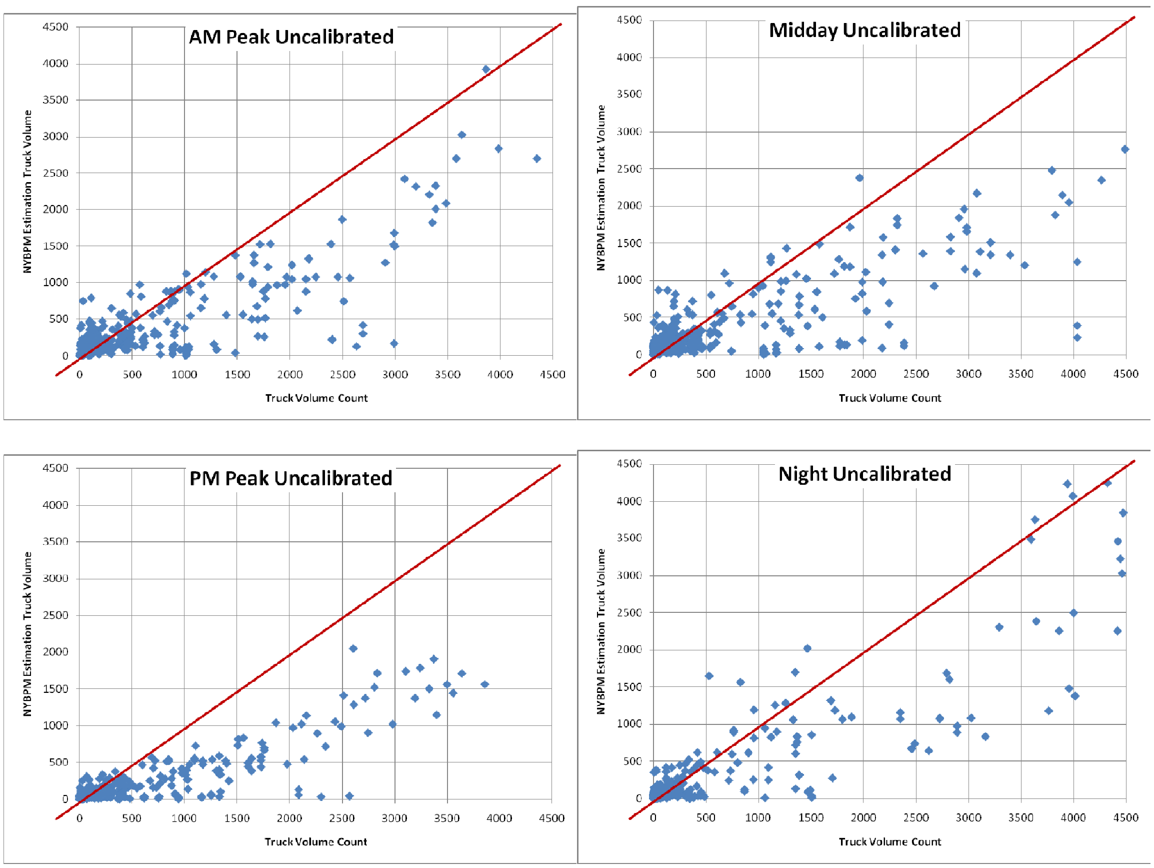


**Figure 4-4: 2007 Truck Volumes vs. NYBPM Assigned Flows**

Table 4-4 shows a further breakdown of NYBPM underestimation by geography. The percentages listed are the differences between 2007 NYBPM assigned truck link flows and 2007 truck volume counts from the acquired data. The underestimation is fairly constant throughout the network for a all time periods. From the data comparison, it is clear that the old NYBPM truck OD matrices, even when projected for a 2007 model run, are resulting in significantly fewer truck trips throughout the network than what is observed from 2007 data counts. The following section focuses on efforts to fix the problem and ensure that the estimates of NYBPM accurately suit the needs of the study.

**Table 4-4: Underestimation of 2007 Truck Volumes by NYBPM by Region**

| Truck Link Volumes | Manhattan Crossings | Other New York | New Jersey |
|---|---|---|---|
| AM Peak | -25% | -43% | -34% |
| Midday | -31% | -44% | -43% |
| PM Peak | -53% | -69% | -54% |
| Night | -56% | -42% | -32% |

### *4.3 Origin-Destination Matrix Calibration*

Three techniques were tested to calibrate the 2007 truck origin-destination (OD) matrices of NYBPM: re-estimation of the OD matrices using TransCAD, manual inflation of the matrices, and an iterative inflation of the matrices. After usage of the OD estimator, the subsequent techniques were only employed do the ineffectiveness of the estimator to produce reasonable estimates within the time constraints of the study. The following describes the trials and calibration of the final OD matrices.

#### 4.3.1 TransCAD OD Estimation

TransCAD software suite has a built-in OD estimation procedure that conveniently uses the existing NYBPM OD matrices and NYBPM assignment output as inputs. Since NYBPM already functions within the TransCAD environment it facilitates an easy transfer to estimate and calibrate new OD matrices. The New York Best Practice Model assigns four OD matrices – that function independently – for highway assignment: AM Peak (6 – 10am), Midday (10am – 3pm), PM Peak (3 – 7pm), and Night (7pm – 6am). Thus it is necessary to run four independent matrix estimation routines for a scenario run. Since each OD estimation routine requires approximately 3 hours each, combined with NYBPM assignment and pre- and post-processing, each scenario took approximately three days to run. The scenarios themselves were designed to integrate the available link counts from data sources to produce OD matrices that could themselves closely match the link counts once they were assigned in NYBPM. Since the results of NYBPM assignment were not expected to completely replicate existing conditions, links were aggregated for analysis purposes. They were grouped into three categories: Manhattan crossings, Other New York and New Jersey links. Performance of the newly estimated OD matrices was gauged based on how closely the combined truck link flows for each grouping matched the data from the observed truck link volumes.

Scenarios used the discrepancy between assignment results and observed volumes on data links to scale other links' truck volumes, in order to estimate OD matrices that are close to the observed volumes. To begin with, the truck input volumes for all links within the regional groupings defined were scaled by the average observed volume-to-link count difference. For example if observed volumes for the AM Peak period for New Jersey links was 30% greater than NYBPM results, all NJ link truck volumes were increased by 30%, to estimate a new OD matrix. The results of this method can be seen in Table 4-5, as the 'Regional Scale' scenario. The values in the table are the differences between observed truck volumes and re-estimated and assigned truck link flows from NYBPM. This produced OD matrices that over-estimated truck volumes on the links where counts were available, except for two of the cases, so a different strategy was implemented. This scenario divided the regional groupings into sub-groupings based on county. This time truck link volumes were scaled according to the average difference between observed volumes and assigned flows for each county. The results, seen in the county scale rows of Table 4-5, show that the OD matrices were over-estimated to an even greater extent.

**Table 4-5: Re-estimated Truck Flow/Observed Difference**

| Period | Scenario | Manhattan Crossings | Other New York | New Jersey | All |
|---|---|---|---|---|---|
| AM Peak | *Uncalibrated* | *-25%* | *-43%* | *-34%* | ***-37%*** |
| | Regional Scale | 91% | 31% | 91% | **64%** |
| | County Scale | 169% | 133% | 172% | **154%** |
| Midday | *Uncalibrated* | *-31%* | *-44%* | *-43%* | ***-43%*** |
| | Regional Scale | 76% | 22% | 46% | **38%** |
| | County Scale | 162% | 173% | 59% | **114%** |
| PM Peak | *Uncalibrated* | *-53%* | *-69%* | *-54%* | ***-61%*** |
| | Regional Scale | -33% | -57% | -10% | **-33%** |
| | County Scale | -26% | -54% | -1% | **-28%** |
| Night | *Uncalibrated* | *-56%* | *-42%* | *-32%* | ***-37%*** |
| | Regional Scale | -6% | 48% | 114% | **85%** |
| | County Scale | -3% | 64% | 149% | **112%** |

Due to the poor results of the previous OD estimations, conducting the same scaling, but only for truck flows on major highways and arterials, was attempted. In these scenarios, rather than scaling the truck volumes on all links by their average county discrepancy, only major highways and arterials were scaled, since they are the heaviest carriers of truck traffic throughout the highway network. These re-estimated matrices produced assigned flows closer to observed volumes; however some major discrepancies still existed, particularly in regional analysis. The experience with re-estimating new OD matrices proved to be ineffective in conforming to observed link volumes. Due to its ineffectiveness, as well as its long running time, other ways of updating the truck matrices of NYBPM were tested.

### 4.3.2 Manual Scaling of OD Matrices

As a precursor to running the OD estimation procedure within TransCAD, the effects of a direct scaling of the OD matrices was tested. In this process, the average difference between NYBPM assigned volumes and actual volume counts on the links data were available for were calculated. This single average percentage difference was used as a multiplier to scale, or inflate, the period OD demands. For initial evaluation, all crossings into and out of Manhattan island were aggregated and the truck flows compared. The results of the scaling of the OD matrices are shown in Figure 4-5 based on the direction of entering or leaving Manhattan.

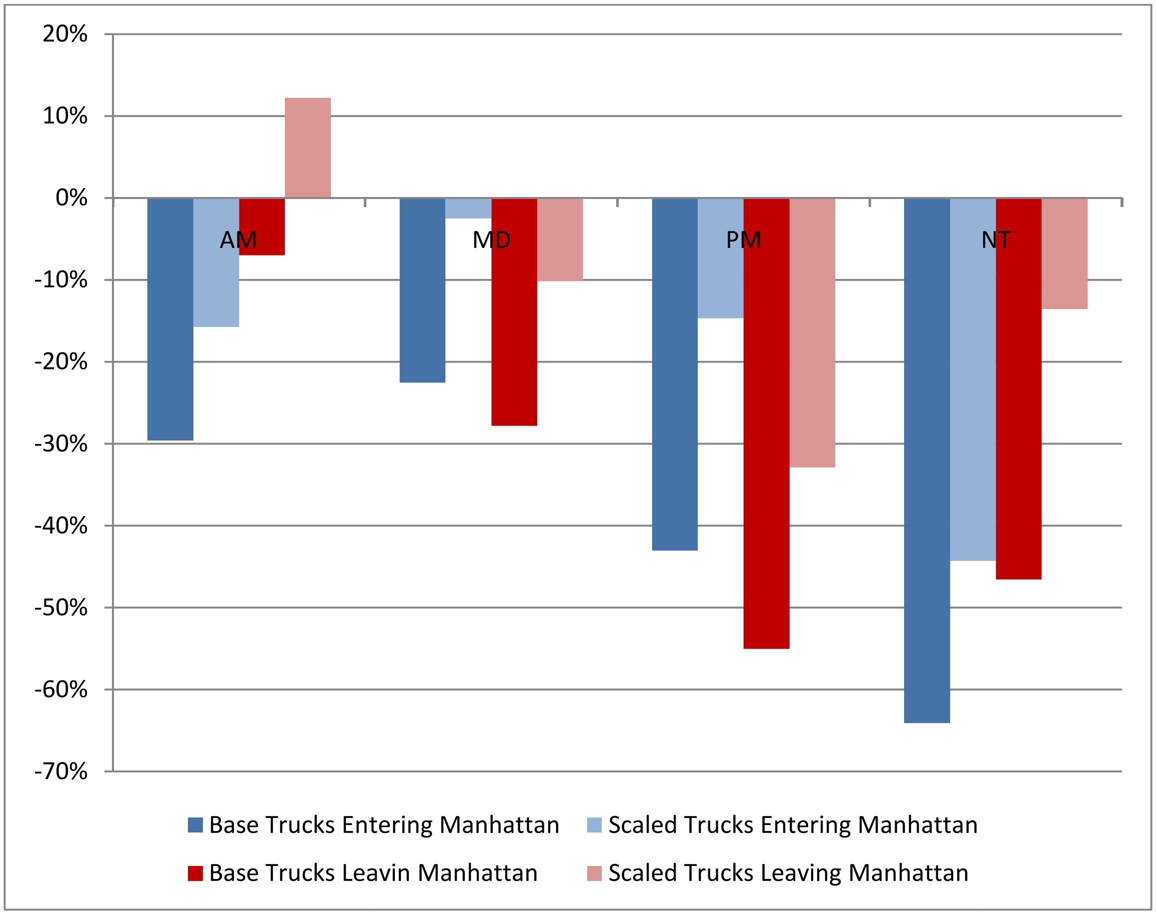


**Figure 4-5: Difference between 2007 NYBPM and Link Truck Flows**

As shown, the scaling of the OD matrices produced disparities (in the lighter shades) of lower magnitude than the base 2007 assignment link flows. In one case, the scaled matrix caused an overestimation. However, while tempered, the volume discrepancies were still not fixed. Simply scaling the matrices did not adequately eliminate the problem, particularly in the PM and Night periods. Table 4-6 further shows that there are significant disparities when conducting location-based analysis. Whereas the total combination of all links (global) estimates show a good improvement, more detailed inspection shows some areas are still performing poorly. It can be seen that some places need not have been scaled at all, and are now severely overestimating the trucks using their links. Thus a location-based estimation method was deemed necessary.

**Table 4-6: NYBPM/Truck Link Flow Differences by Location and Time of Day**

| | | AM | MD | PM | NT |
|---|---|---|---|---|---|
| East River Crossings - Inbound | Base | -22% | -21% | -35% | -38% |
| | Scaled | -7% | -1% | -3% | -1% |
| Harlem River Crossings - Inbound | Base | -12% | -9% | -45% | |
| | Scaled | 4% | 14% | -16% | |
| Hudson River Crossings - Inbound | Base | -47% | -38% | -45% | -69% |
| | Scaled | -36% | -23% | -18% | -52% |
| *Total Entering Manhattan* | *Base* | *-30%* | *-23%* | *-43%* | *-64%* |
| | *Scaled* | *-16%* | *-3%* | *-15%* | *-44%* |
| East River Crossings - Outbound | Base | 29% | -29% | -60% | -53% |
| | Scaled | 56% | -12% | -40% | -26% |
| Harlem River Crossings - Outbound | Base | -8% | 11% | -35% | |
| | Scaled | 12% | 37% | -3% | |
| Hudson River Crossings - Outbound | Base | -22% | -55% | -70% | -44% |
| | Scaled | -6% | -43% | -56% | -9% |
| *Total Leaving Manhattan* | *Base* | *-7%* | *-28%* | *-55%* | *-47%* |
| | *Scaled* | *12%* | *-10%* | *-33%* | *-14%* |
| ***All Manhattan Crossings*** | ***Base*** | ***-20%*** | ***-25%*** | ***-50%*** | ***-57%*** |
| | ***Scaled*** | ***-3%*** | ***-7%*** | ***-25%*** | ***-32%*** |

When the origin-destination matrices of NYBPM were originally being analyzed, the first attempt to update them was to simply inflate the volumes of all the OD pairs in the matrices by a respective constant (equal to the average difference between observed and assigned truck volumes) for each period. Then the matrices were re-assigned using NYBPM's standard assignment, and the results of the assignment compared with observed link counts. However there were still many disparities between the newly assigned truck link flows and observed data volumes. To make up for these gaps, a more detailed procedure to scale the matrices was employed. Matrices were now scaled based on average regional disparities. These scaling scenarios were capable of bringing the assignments produced by the matrices very close to the observed link volumes. All of the network average differences were within 10%, and most of the regional averages were close as well, with the exception of traffic entering Manhattan in the PM and Night hours. The result of the manual scaling procedure produced OD matrices that were very close to the desired conformity levels.

### 4.3.3 Iterative Approach

In order to fine-tune the matrices created from the manually scaling procedure, an iterative approach was used. Starting with the final matrices produced from the manual approach, they were further scaled to reach a target conformity level, of having each sub-regional average difference within 10% conformity to observed data. The process consisted of repeating the manual scaling procedure with the average difference values, except by updating the difference level – before each iteration – with the new difference level produced from the assignment the previous iteration. The procedure was repeated until all average measures were within 10% conformity. This was completed within five iterations, producing matrices for all four periods that are now up-to-date with current observed truck volumes.

Figure 4-6 shows a side-by-side comparison of estimated truck link flows to observed volumes ratios for the uncalibrated and calibrated matrices. The diagonal line represents a 1:1 ratio between assigned and observed volumes. For the uncalibrated case, nearly all points are to the right of the line, showing that observed volumes are greater than assigned. The calibrated points are more evenly distributed around the equality line.

While there are still some substantial differences between observed link flows and modeled link flows for some links, this could be due to disparities in the assignment process, which was not adjusted. The overall sum link flows for the calibrated areas now match the observed data. To assess the impact of this process the overall change to the matrices were calculated. The sums of the origin-destination matrices for all OD pairs compared to the base matrix size are shown in Table 4-7, along with the average difference between assigned flow and actual truck volumes for each of the calibrations.

**Table 4-7: Matrix Change to Flow Difference Change Comparison**

| **Scenario** | | AM Peak | | Midday | | PM Peak | | Night | |
|---|---|---|---|---|---|---|---|---|---|
| | | Matrix | Flows | Matrix | Flows | Matrix | Flows | Matrix | Flows |
| *Base* | *Uncalibrated* | *0%* | *-37%* | *0%* | *-43%* | *0%* | *-61%* | *0%* | *-37%* |
| TransCad OD Estimator | Regional Average | 123% | 64% | 100% | 38% | 44% | -33% | 146% | 85% |
| | County Average | 387% | 154% | 203% | 114% | 55% | -28% | 139% | 112% |
| | Highways & Arterials | 36% | 63% | 37% | 39% | 12% | -37% | 43% | 69% |
| | Highways Only | 8% | 32% | 7% | 17% | 2% | -41% | 28% | 52% |
| Manual Scaling | Full Network Average | 46% | -9% | 53% | -13% | 86% | -27% | 48% | -3% |
| | NJ O-Ds Only | 19% | -30% | 27% | -34% | 41% | -52% | 14% | -30% |
| | NJ & Manhattan O-Ds | 23% | -27% | 34% | -31% | 56% | -47% | 38% | -22% |
| | All Pairs | 59% | 0% | 70% | -3% | 161% | 0% | 63% | 6% |
| Iterative Approach | 2nd Iteration | 60% | -1% | 75% | 0% | 171% | 0% | 60% | 4% |
| | 3rd Iteration | 62% | 0% | 75% | 2% | 176% | 0% | 57% | 2% |
| | 4th Iteration | 62% | 1% | 70% | 0% | 177% | 0% | 55% | 1% |
| | **5th Iteration** | **63%** | **1%** | **71%** | **0%** | **180%** | **1%** | **53%** | **1%** |

The final calibrated matrices are considerably larger than the uncalibrated matrices, particularly for the PM Peak case, where the sum of the new matrix is more than two times larger than the previous truck OD demand matrix. However it is important to emphasize the fact that these OD matrices are not unique; they are one of many possible OD matrices that can generate similar conformity results based on the initial matrices and the scaling approaches employed. This issue of the non-uniqueness of OD matrices is true for any OD matrix estimation method in the literature.

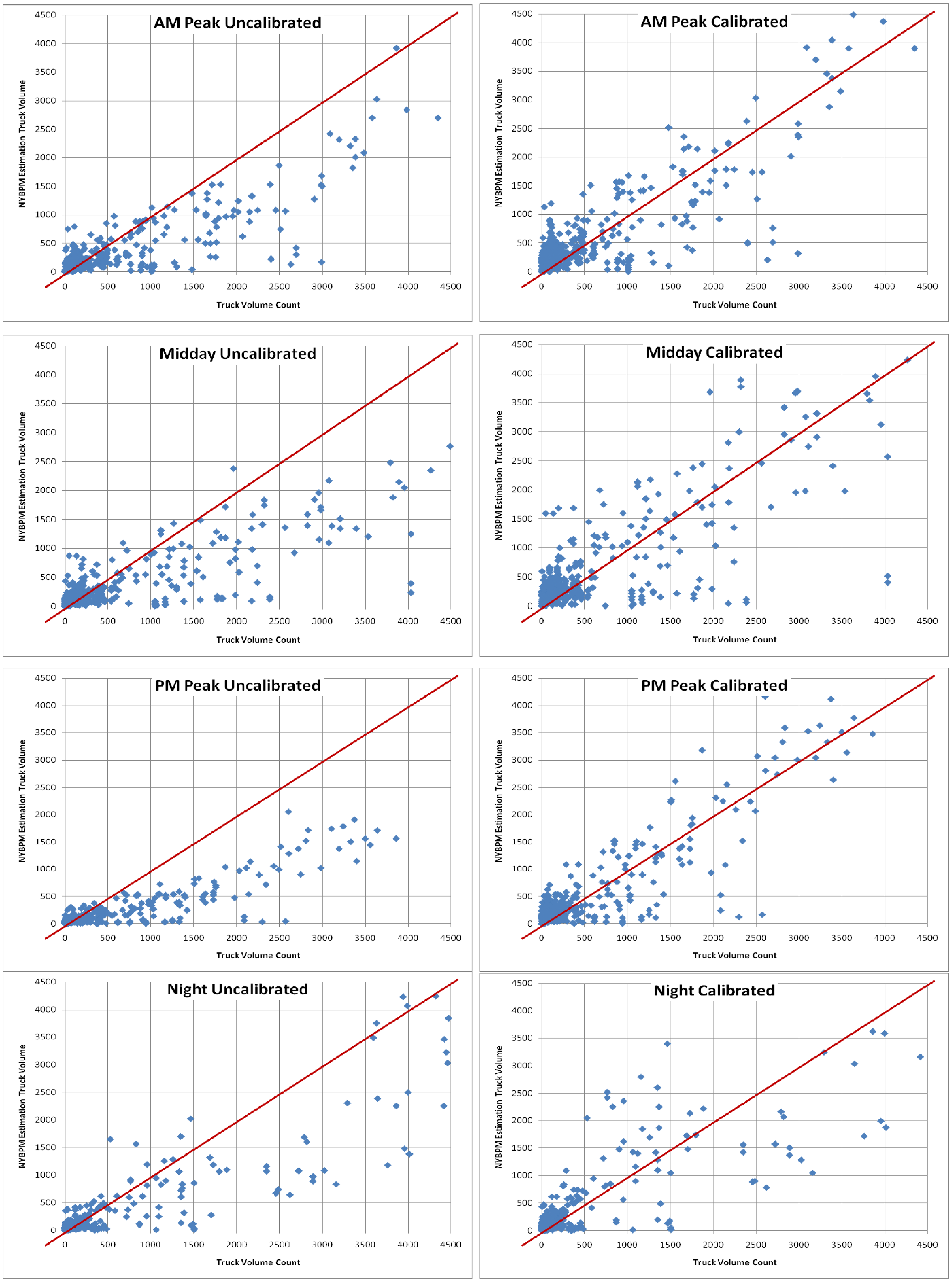


**Figure 4-6: Comparison of Uncalibrated and Calibrated Matrices**

# 5. Results

Once the calibration described in Chapter 4 was complete the methodology described in Chapter 3 could now be implemented in the New York Best Practice Model (NYBPM). To summarize, an off-hour delivery program to food and retail industry businesses in Manhattan was simulated in NYBPM by shifting the truck and commercial van origin-destination (OD) trips bound for Manhattan from the three daytime periods (AM Peak, Midday, PM Peak), covering 6am – 7pm, to the Night period (7pm – 6am). The percentage of trips shifted is determined from a behavioral study, which estimates the percentage of receivers (and by extension deliveries) that would be willing to accept an annual tax deduction of certain amounts to shift their delivery operations to the off-hours. The following are results aggregated from the NYBPM highway assignment.

## *5.1 CMV Shift Model Results*

The commercial vehicle (CMV) shift model described in Chapter 3 was applied to shift the origin-destination (OD) demands from the three daytime periods, AM Peak (6 – 10am), Midday (10am – 3pm), and PM Peak (3 – 7pm) to the overnight period (7pm – 6am). The OD demands that were shifted were commercial vehicles (trucks & commercial vans) from all originating zones and with a destination in Manhattan. This includes trips originating in Manhattan, and accounts for chained trips for delivery vehicles originating outside Manhattan and making multiple stops within Manhattan. A breakdown of the geographic location of where CMV trips bound for Manhattan originate (excluding those originating in Manhattan) can be seen in Figure 5-1. The majority of commercial trips headed to Manhattan originate in the other four boroughs of New York City. The next highest number of trips come from New Jersey and points west. Trips originating north of the city make up slightly less than 10% of total trips bound for Manhattan, and the fewest trips come from Long Island to the east.

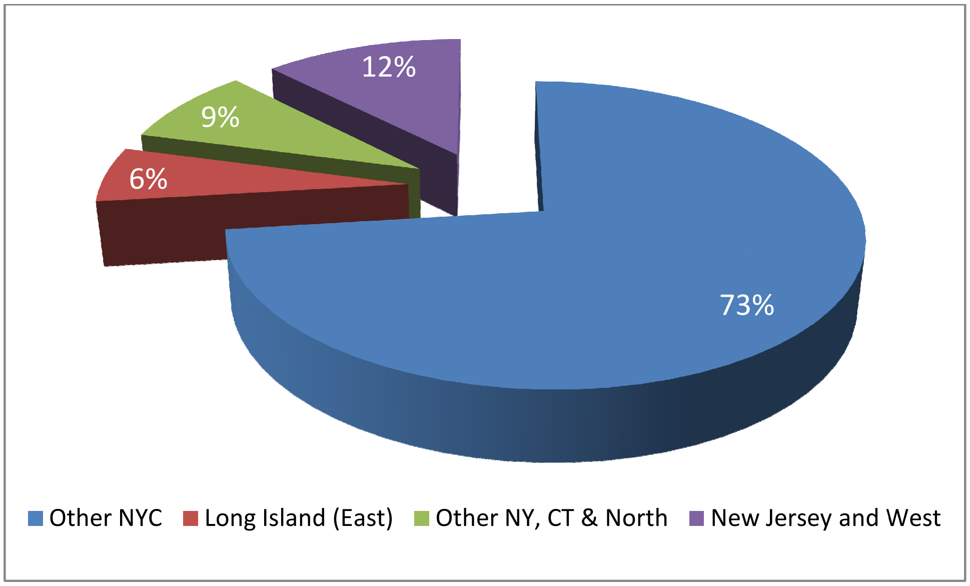


**Figure 5-1: Origin of CMV Trips Destined for Manhattan**

The shift factors developed in Table 3-2 were applied equally to all CMV trips regardless of zone of origin or time of day (6am – 7pm). The final number of trips shifted and their percentage among all CMV trips in the entire New York region can be seen in Table 5-1 for the all-Manhattan scenarios. The relationship between tax incentive and number of trips shifted follows that of Figure 3-5.

**Table 5-1: CMV Trips Shifted – All-Manhattan Scenarios**

| Tax Incentive | CMV Trips Shifted | % of all CMV Trips |
|---|---|---|
| $ 5,000 | 7,262 | 0.31% |
| $ 10,000 | 15,982 | 0.68% |
| $ 15,000 | 23,617 | 1.00% |
| $ 20,000 | 28,634 | 1.21% |
| $ 25,000 | 32,856 | 1.39% |
| $ 50,000 | 47,605 | 2.02% |

The resultant matrices from the shift model were input to NYBPM highway assignment. The network results from the highway assignment are shown in the following sections.

### *5.2 Network Assignment Results*

The model output contains information for all 55,000+ links in the highway network, including vehicle flows by class, travel time, and average speed. Two of the important parameters for measuring traffic effects can be calculated from this output: Vehicle Miles Traveled (VMT) and Vehicle Hours Traveled (VHT). VMT gives an idea on the total distance traveled by all vehicles in the region on a typical day, while VHT is a convenient method of measuring travel times, and by extension, congestion. While changes to VMT do not clearly indicate whether the network is more of less congested, this conclusion can be reached from observing changes to VHT. For example vehicles may take longer paths to avoid congested links, and in turn reducing their overall travel time, thus saving time and reducing VHT while increasing VMT.

The results show the net differences between output parameters from the calibrated year 2007 base model and the shift scenario model, and percentage changes of the output parameters. First Figure 5-2 and Figure 5-3 show the change in vehicle miles traveled (VMT) as a result of a specific tax incentive scenario's assignment on the network, for scenarios where all Manhattan-destined demands where shifted or only Lower Manhattan (Midtown & Downtown) destined demands, respectively. Then Figure 5-4 and Figure 5-5 are the changes to vehicle hours traveled (VHT) for the two cases of scenarios.

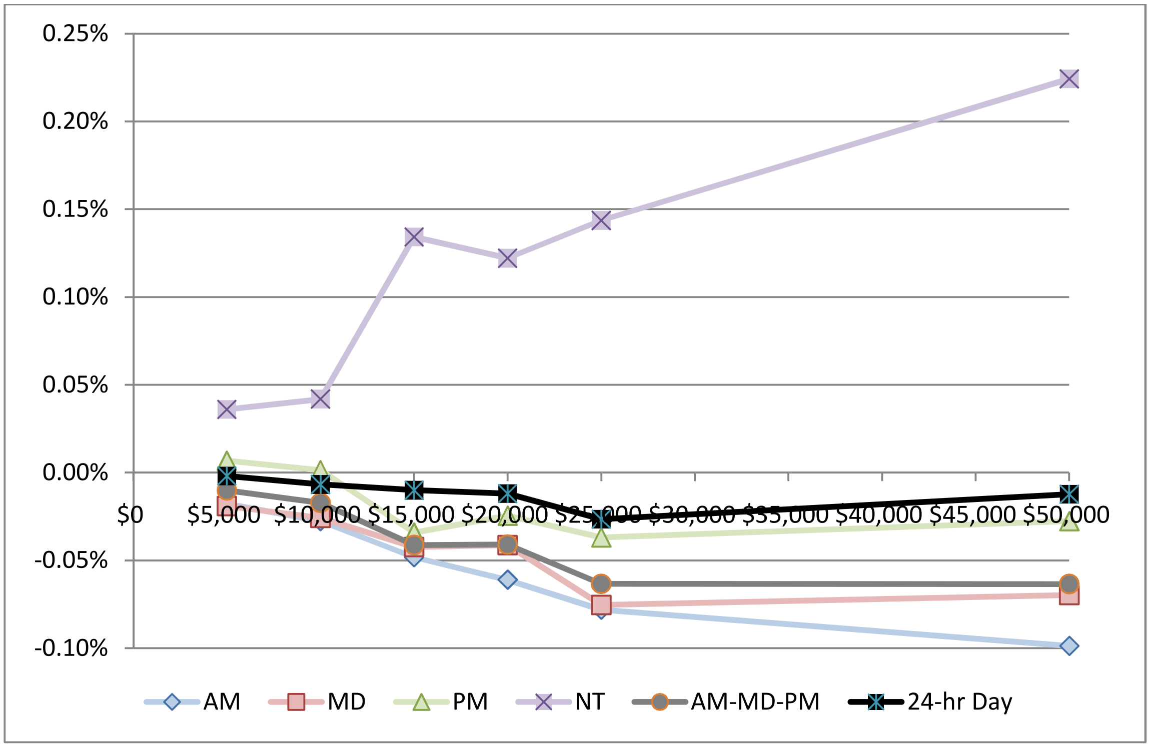


**Figure 5-2: Change in VMT – All Manhattan Destinations Shifted**

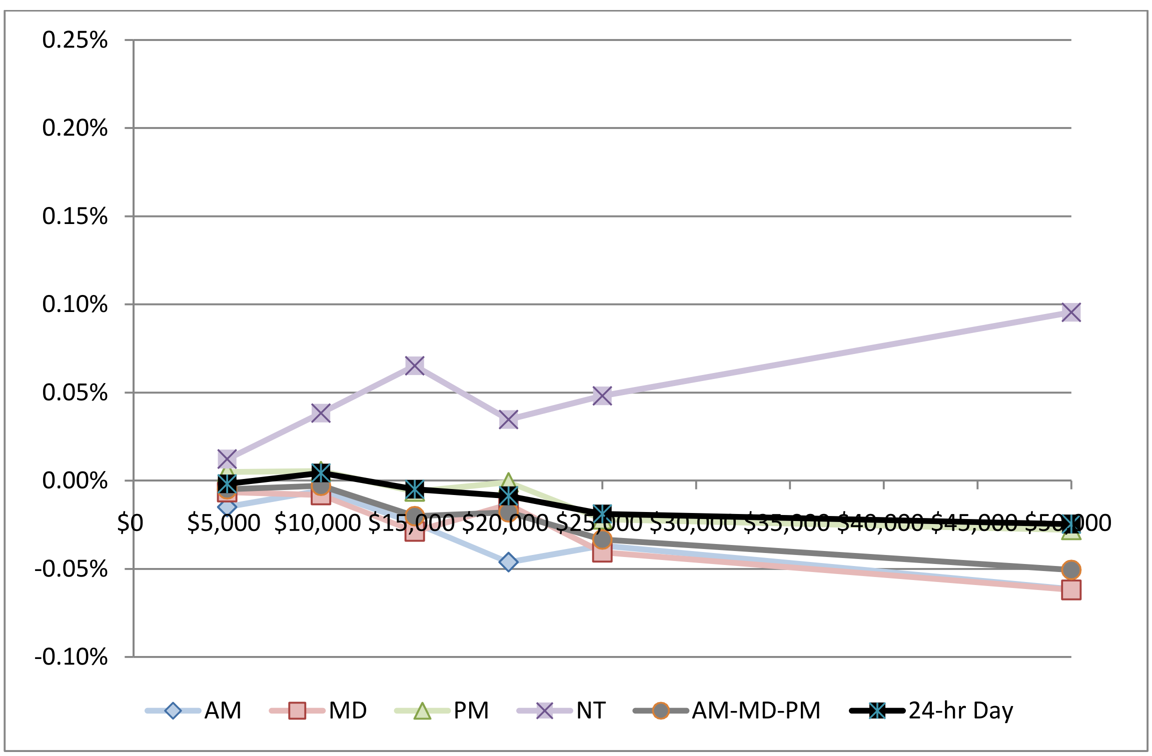


**Figure 5-3: Change in VMT – Lower Manhattan Destinations Shifted**

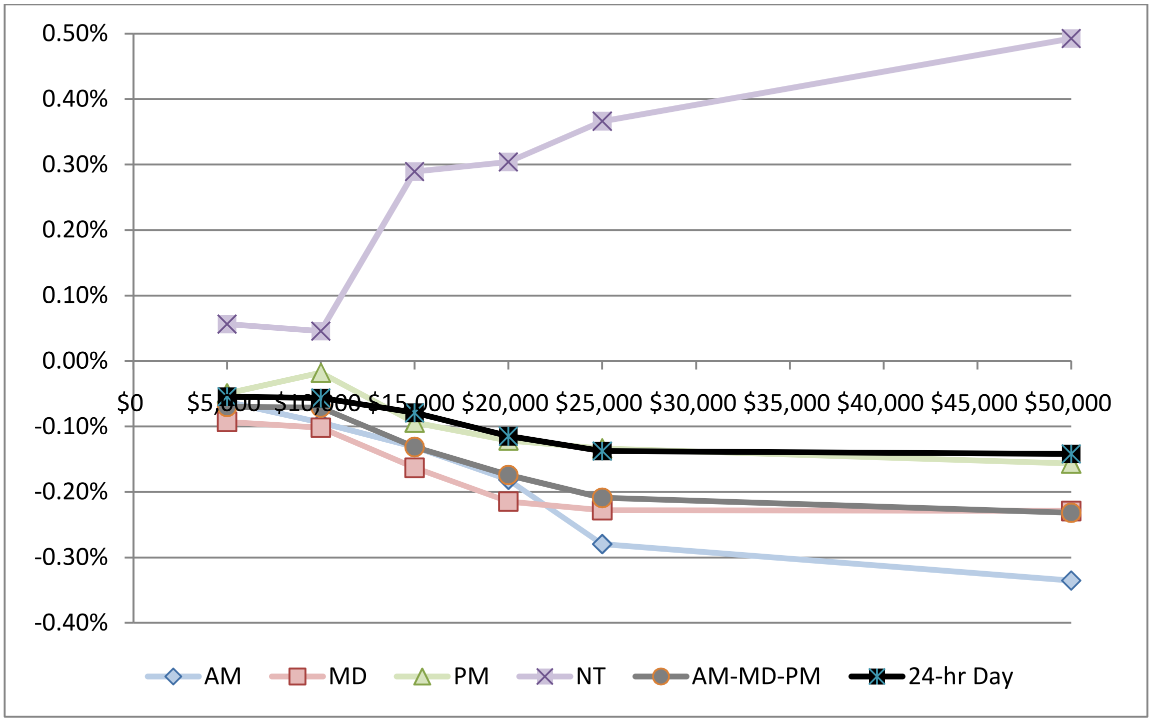


**Figure 5-4: Change in VHT – All Manhattan Destinations Shifted**

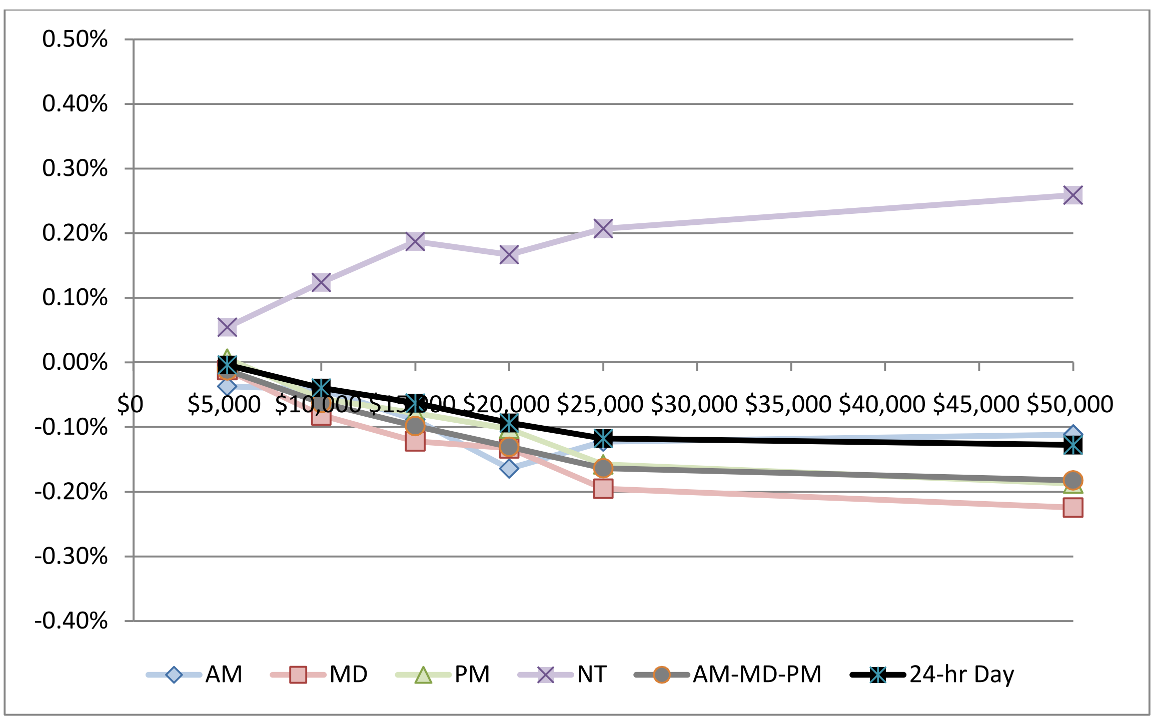


**Figure 5-5: Change in VHT – Lower Manhattan Destinations Shifted**

The plots show the resulting output from the entire New York area network of all links in the NYBPM. In Figure 5-2 and Figure 5-3 the total change in vehicle miles traveled (VMT) as a result of a specific tax incentive scenario's assignment for an entire 24-hour day (sum of the other four periods) is represented by the heavy black line, while the gray line represents only the three daytime periods from when truck traffic is subtracted. Similarly Figure 5-4 and Figure 5-5 are the changes to vehicle hours traveled (VHT) for the two cases of scenarios respectively.

The composite full-day trends show that as tax incentive amounts are increased vehicle miles traveled and vehicle hours traveled for all vehicles in the network both decrease. However they also show that increases in tax incentives have decreasing marginal benefits. For example it can be seen that beyond a $25,000 tax incentive the net benefits are only minimally greater. The 24-hr day net changes in VMT and VHT for the scenarios where all Manhattan-destined truck OD demands and only lower Manhattan-destined truck OD demands were shifted can be aggregated. These net changes from the base-case scenario can be seen in Figure 5-6 for all network links and in Figure 5-7 for only Manhattan links. Manhattan, being the target of the program, covers a large proportion of the total network effects. It should be noted that these results are for changes to links within the network, and not all roads in the region are represented by links in the NYBPM network. Net VHT savings increase with tax incentive increase, but net VMT does not always follow the relationship. It can be concluded that as more trucks are shifted away from a period the congestion decreases, however the trip-lengths that vehicles take to minimize their travel time might not always decrease.

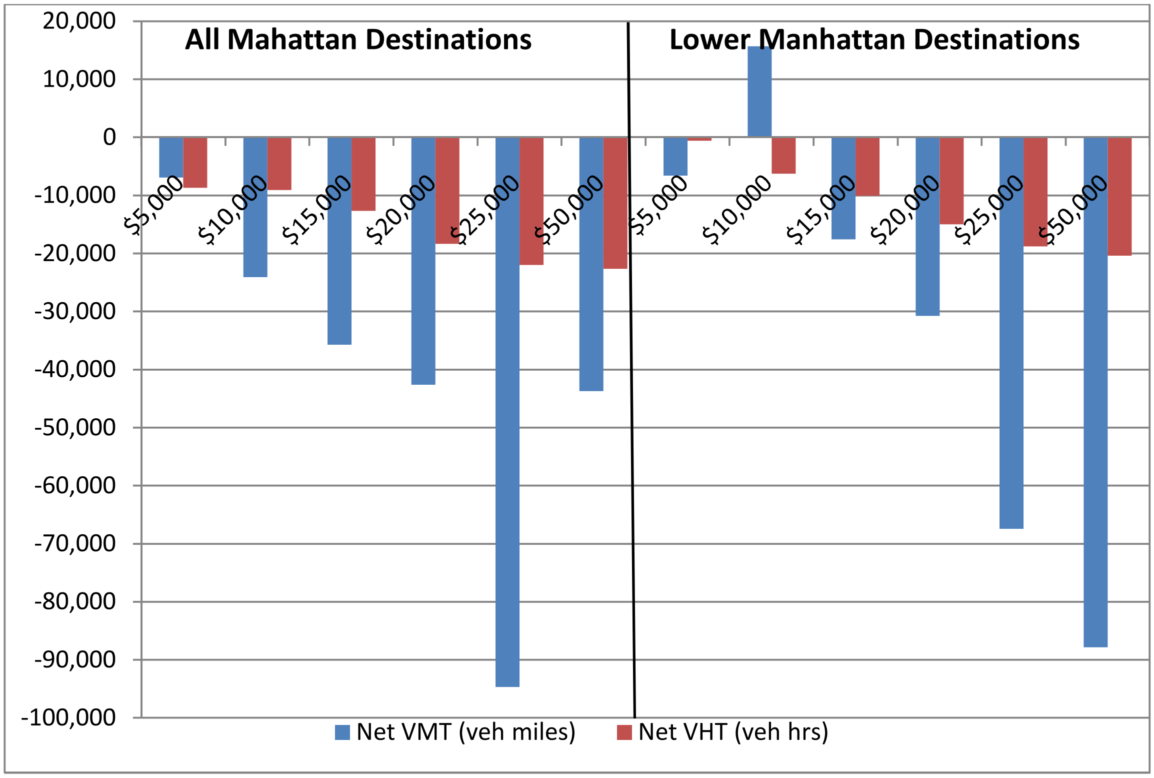


**Figure 5-6: Scenario Net Benefits – All Network Links**

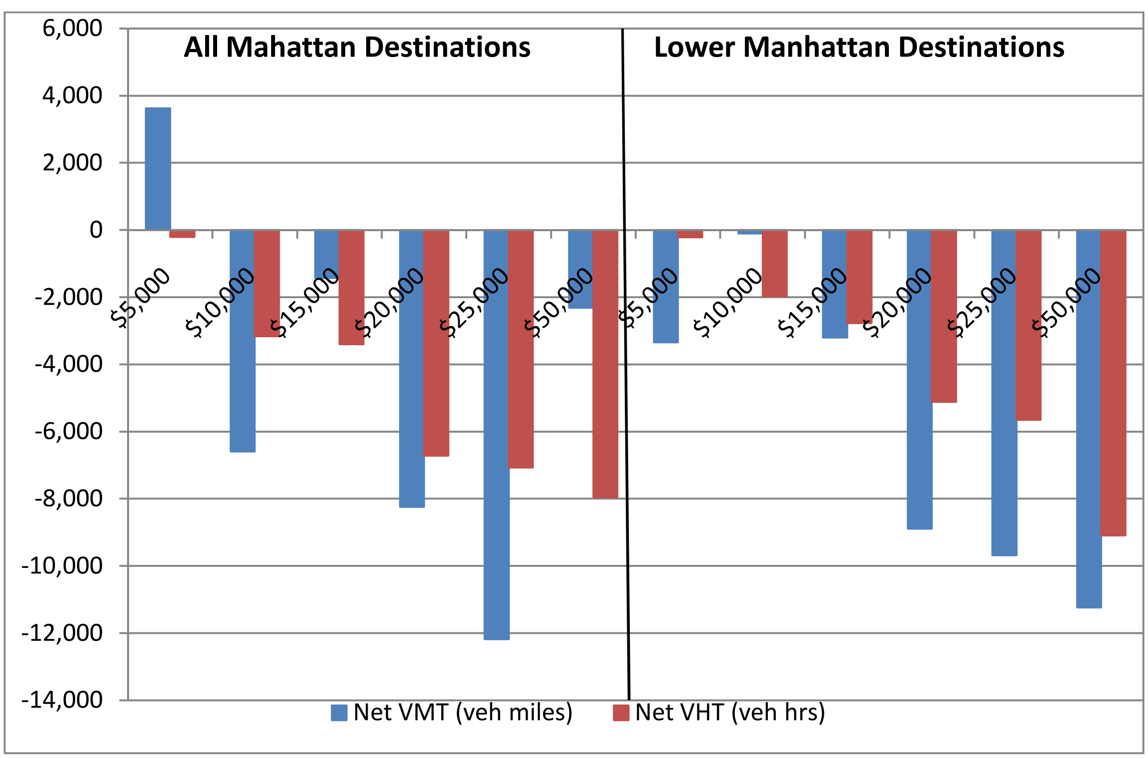


**Figure 5-7: Scenario Net Benefits – Manhattan Links**

While the expected benefits from network assignment were expected to resemble the general relationship between tax incentive and percentage of freight traffic shifted shown in Figure 3-5, the exact relationship cannot be followed due to network assignment affects. Particularly, vehicle miles traveled do not always decrease with decreased levels of traffic. Specifically this can be explained as vehicles taking longer paths which might save them time, as they seek to minimize their total trip costs. Vehicle hours traveled however do incrementally decrease with increasing tax incentives and therefore decreased freight traffic in most cases. However for some scenario-to-scenario comparisons, reducing the amount of CMVs using the network does not always result in a decrease to Vehicle Hours Traveled. Since NYBPM employs user-equilibrium assignment instead of system optimal assignment, the effect to the entire system is not always desirable.

### *5.3 Path-Based Analysis*

Further analysis of network impacts was conducted by isolating specific paths taken by vehicles serving a destination in Manhattan. Using a post-processing tool developed to take NYBPM output and calculate shortest paths between OD pairs (ASSISTME), changes to these shortest paths from one scenario's network assignment to another can be analyzed *(27)*. A sampling of 50 random OD pairs (Figure 5-8) was selected where the origin node was anywhere in the network and the destination node was in Manhattan. The shortest paths for these same 50 OD pairs were calculated for each scenario for all four network periods, and the average results calculated. The average change to travel times between these 50 nodes was calculated for each period in each scenario, and the differences between the average for a scenario and the base-case summarized in Figure 5-9.

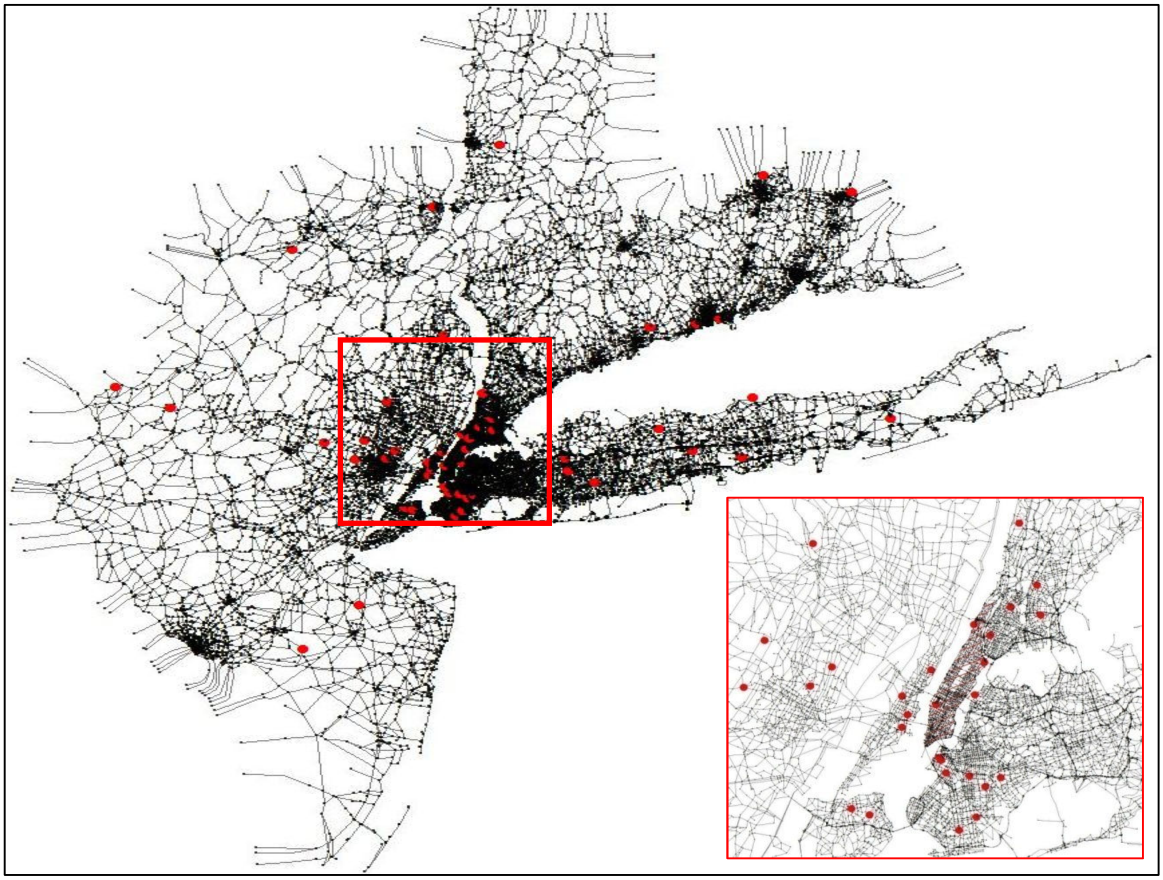

**Figure 5-8: Sampled OD Pairs**

Figure 5-9 shows the decrease in average travel times for the AM Peak and Midday periods. As the incentive amount was increased, the average of the travel times for the shortest paths between sampled OD pairs decreased. For the PM Peak case, the differences were very minor, and in some cases even increased. For the Night cases, travel times predictably rose as more CMVs were added. Further analysis specifically relating to reduced costs and economic benefits is conducted in the following chapter.

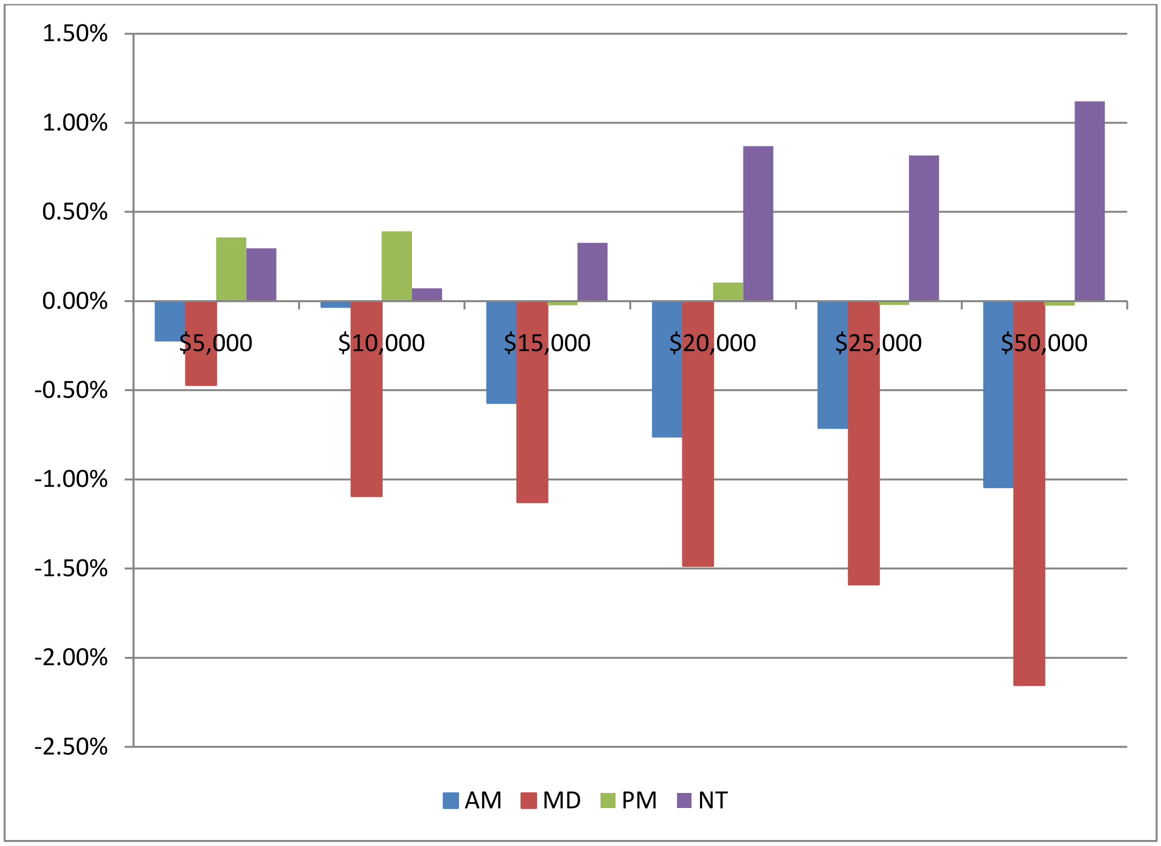


**Figure 5-9: Changes to Average Travel Time for Sampled Paths**

# 6. Analysis

## *6.1 Cost-Benefit Analysis*

Further evaluation of the full effects of a tax incentive can be accomplished by aggregating the network effects of all periods of the day and comparing them with the costs of the scenario. In the case of tax incentives a true cost/benefit analysis cannot be conducted since no money is being paid to implement the program under study. Instead cost/benefit analysis is conducted by assuming the costs are lost tax revenue for the government. In order to calculate the total lost revenue of the program the number of receivers willing to accept the incentive is multiplied by the level of each incentive. This number is then compared with the traffic benefits, which can be quantified following a procedure developed by Ozbay et al. *(28)*.

### 6.1.1 Costs of Travel

By analyzing historical data Ozbay et al. estimated the true costs of travel in Northern New Jersey (part of the NYBPM region) *(28)*. These costs include vehicle ownership costs, travel time and congestion costs, accident costs, air pollution costs, noise costs, and others. Based on previous studies and data collected, functions were developed to estimate the full costs of travel for a highway network with a number of input variables, including distances, speeds, travel times, volumes, and values of time. A tool was then developed to take the output of transportation planning models, such as NYBPM, and estimate the link costs for all or some links in the network. Using this tool network costs for each of the scenarios simulated were calculated. These costs included operating costs, congestion costs, accident costs, air pollution costs, and noise costs. By taking the difference between the costs for each scenario and the base-case scenario, the traffic results can be put into monetary terms.

### 6.1.2 Value of Time

In 2005 the New York Metropolitan Transportation Council (NYMTC), the same agency that developed and uses the New York Best Practice Model, released a report placing a value of time assumption for 2001 at $20.46/hr and for 2005 at $23.00/hr *(29,30)*. Based on these estimates, results quantifying savings in vehicle hours traveled have been calculated with a value of time of $25.00/hr for all vehicles. Figure 6-1 shows the contrast between annual tax incentive cost (or lost revenue) and annual VHT savings for the cases of incentives being offered to all receivers in Manhattan (blue) and only receivers in Lower Manhattan as previously defined (red). The VHT savings are calculated by simply multiplying the total network VHTs by the Value of Time ($25/hr) and taking the differences between scenarios and the base-case. While there is a strong direct relationship between tax incentive and scenario cost the relationship is far less strong between tax incentive scenario and VHT savings benefits. Or, greater tax incentive increases result in diminishing VHT benefits.

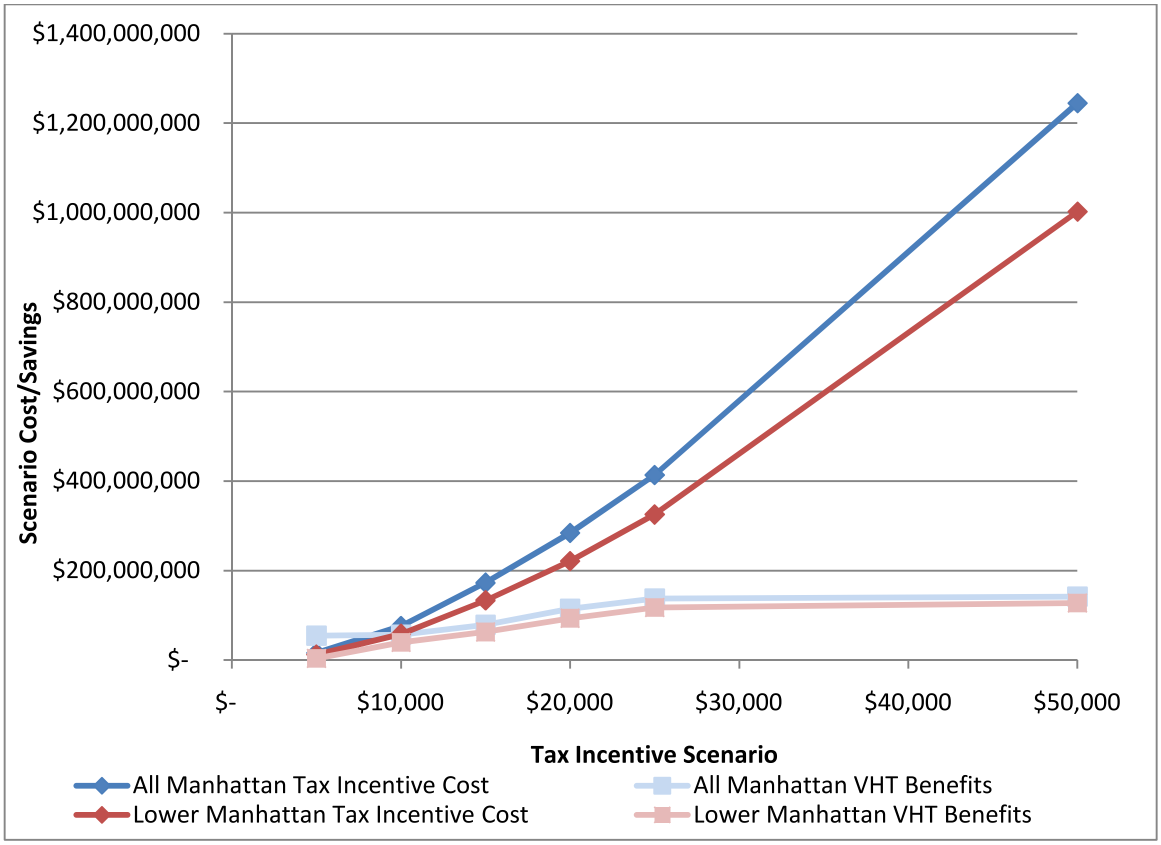


**Figure 6-1: Annual Tax Incentive Costs and Congestion Savings**

By dividing the total network cost savings described in 6.1.1 by the tax incentive scenario's total cost (incentive amount multiplied by number of receivers accepting incentive), the benefit/cost ratio can be determined, which can be used to determine which scenario is most attractive in terms of lost revenue and benefits to society. It should be remembered that the benefits used in the calculation are only operating costs, congestion costs, accident costs, air pollution costs, and noise costs. The benefit/cost ratios by scenario can be seen in Table 6-1. Offering a $5,000 tax incentive to receivers throughout Manhattan is the only scenario where benefits outweigh the costs, while it can be observed that the benefit/cost ratio decreases as the tax incentive increases, showing that higher tax incentives offered have lesser benefits. For the cases of offering the incentive to only receivers in Lower Manhattan, often the effects are so minimal that only minor changes are seen, or in some cases costs increased. Below the $15,000 incentive level network costs increases, suggesting some volatility in the model results, since the scenario compares to the base-case, when more trucks were in the network.

**Table 6-1: Benefit/Cost Ratios by Scenario**

| Tax Incentive Offered | Annual Tax Incentive Cost | Annual Benefits | Benefit/ Cost |
|---|---|---|---|
| **All Manhattan** | | | |
| $ 5,000 | $ 16,195,324 | $ 56,603,642 | 3.50 |
| $ 10,000 | $ 76,071,530 | $ 62,246,196 | 0.82 |
| $ 15,000 | $ 172,907,041 | $ 84,240,776 | 0.49 |
| $ 20,000 | $ 284,129,356 | $ 122,711,258 | 0.43 |
| $ 25,000 | $ 413,720,584 | $ 100,696,444 | 0.24 |
| $ 50,000 | $ 1,244,386,372 | $ 147,849,215 | 0.12 |
| **Lower Manhattan** | | | |
| $ 5,000 | $ 12,437,587 | $ (13,489,101) | -1.08 |
| $ 10,000 | $ 58,337,851 | $ (1,376,435) | -0.02 |
| $ 15,000 | $ 133,504,175 | $ (3,765,333) | -0.03 |
| $ 20,000 | $ 221,281,555 | $ 67,873,747 | 0.31 |
| $ 25,000 | $ 325,301,734 | $ 99,960,167 | 0.31 |
| $ 50,000 | $ 1,001,989,072 | $ 85,562,418 | 0.09 |

### *6.2 Toll Model*

Another way of evaluating a scenario is by finding what increase in toll revenue is needed to balance the loss in tax revenue from businesses accepting the tax incentive deduction. There are administrative considerations that render this concept impractical, for example highway tolls are collected by several agencies in the metropolitan area, and they are all locally based, while the incentive results in revenue lost for the federal government, but it is employed as a way to conduct scenario assessment. Understanding the increases needed to offset the tax incentive "losses" offers a way to analyze the impacts of a certain OHD scenarios.

Implementing or increasing tolls is a common form of financing in transportation, particularly for new roads or infrastructure improvements *(31)*. However in this case the revenue collected balances revenue lost by the government, due to a new policy program. Additionally, tolls may be implemented to increase the cost and ultimately discourage the use of certain links in a transportation network, thereby either reducing demand or re-routing users in the network, with the ultimate goal usually being a reduction in total congestion *(31).* The penalty of increased tolls is therefore justified and balanced by improved network conditions for drivers, mainly, lower travel times.

### 6.2.1 Toll Model Methodology

A simplistic way to conduct this network analysis is to adjust the tolls in the NYBPM network of each OHD scenario previously modeled and iteratively conducting assignments to find out what level of toll is required to "pay" for the total tax incentives of a given scenario, which represents revenue lost. Total toll revenue is calculated as the product of the toll level charged to vehicles at a facility and the total flow of vehicles using that facility. To evaluate the proposed toll scenarios the difference between toll revenue in the base-case model and the proposed model is calculated. In order to find the optimal toll level, this net toll revenue must meet the condition that it is at least equal to the total tax incentive given to all receivers. This model can be described as follows:

$$\sum\left(T_1^f F_1^f\right)-\sum\left(T_0^f F_0^f\right)\geq\sum\left(TI\times R\right)$$

*where* $T_1^f$ *= proposed toll to be charged at a facility in a modeled scenario*

$F_1^f$ *= total flow of vehicles using a facility in a modeled scenario*

$T_0^f$ *= base toll level for a facility*

$F_0^f$ = *total flow of vehicles using a facility in the base-case simulation*

$TI$= *tax incentive amount*

$R$= *number of receivers accepting tax incentive and participating in OHD*

In order to satisfy this condition iterative assignments are required. In traffic assignment, travel patterns change due to changed toll levels, that can result in gained or lost revenue for toll agencies. In addition the prior model results show that traffic conditions generally improve from the program under study therefore toll revenue is likely to be lost by area toll agencies. Therefore net benefit assessment is done by considering the level of toll revenue from the no-shift, base-case as the base line, and requires iterative assignments from gradual increases in toll levels.

### 6.2.2 Model Construction

There are many ways to construct a likely toll implementation strategy in the New York region. There are many toll facilities in the region and also many different schemes that could be implemented. For example, these can include:

- Increase tolls for all the currently tolled facilities in the entire region vs. New York City only
- Increase tolls of facilities entering only Manhattan vs. all of New York City
- Increases at only existing tolled facilities vs. all entry points to Manhattan
- Increase truck tolls only vs. all vehicles tolls
- Increase daytime tolls only vs. all times
- Add discrete dollar increments to tolls vs. percentage increases


**Figure 6-2: Tolled Manhattan Crossings**

Initially tested scenarios modeled modified tolls at only the seven inbound tolled entrances to Manhattan from the rest of New York City and New Jersey, as show in Figure 6-2, similar to congestion pricing plans currently being debated. Additionally for the sake of simplicity only existing tolled facilities are modified, thus free inbound crossings remained free. The scenarios were constructed by adding discrete dollar amounts to existing tolls, for example increasing all tolls by $1.00 instead of increasing all tolls 10% or forcing all tolls to a uniform level, which preserves the existing toll structure maintained by area agencies. However toll increases were only enacted for the three daytime periods in the model; AM Peak (6 – 10am), Midday (10am – 3pm), and PM Peak (3 – 7pm). Night (7pm – 6am) tolls were left at current levels. Scenarios were modeled where only truck tolls were increased, as well for when tolls were increased for all vehicles. The following section shows results from these scenarios when applied to the case of $5,000 and $10,000 tax incentivized traffic networks. For comparison, Holguin-Veras et al. conducted similar analyses using behavioral estimates and found that a $2/axle surcharge to trucks during the off-hours would pay for offered incentives *(32)*.

### 6.2.3 Limitations of Static Tolling in NYBPM

The modeling is performed in the modified 2007 NYBPM network for cases of $5,000 and $10,000 incentives. First the calibrated base-2007 network needed modification to account for toll increases enacted since the model was developed in 2002, including the most recent increases in 2008[3]. The 2009 MTA toll increases[4] were not included. However the model also has some limitations being a static traffic assignment model. For simplicity, truck tolls are coded as an average value, instead of the per-axle arrangement that most toll agencies employ. Additionally the NYBPM does not easily allow for time-of-day shifting while modeling the OHD shift, as discussed in Chapter 4. Thus these toll increases during the daytime periods do not give drivers and carriers an option to shift to the off-hours or other periods. Similarly shifts to other modes are not permitted. This drawback of this approach is somewhat limited, at least for carriers, based on research results by Holguin-Veras et al. showing that freight carriers' delivery times are insensitive to tolls and instead are governed by receiver's demands *(32).* However the inflexibility of allowing passenger cars to shift to other time periods, particularly the off-peak where tolls are lower, is a weakness in this toll model. The differences in traffic assignment, and thus total revenue, are due to shifted route choices.

[3] http://www.panynj.gov/press-room/press-item.cfm?headLine_id=927
[4] http://www.mta.info/bandt/traffic/btmain.htm

### 6.2.4 Net Toll Revenues

Several scenarios were tested on the updated 2007 Base New York Best Practice Model (NYBPM). The scenarios were run to find the necessary toll increase in order for the net toll revenue gain over the base-case to be equal or greater than the total tax revenue lost by the OHD. It should be noted that net toll revenue gains were taken for all facilities within or connecting to New York City, even though the increases were only for facilities inbound to Manhattan. Due to route choice changes from the toll increases, the toll revenues for other crossings not even connecting to Manhattan can also change.

The scenarios were run for the traffic networks with $5,000 and $10,000 incentives offered to all receivers in Manhattan, and for cases where the tolls were increased for only trucks entering Manhattan during the day at existing tolled facilities, as well as all vehicles entering Manhattan during the day at existing tolled facilities. The calculation of the total incentive is summarized in Table 6-2. The net toll revenues for some of the scenarios tested can be seen in Figure 6-3 and Figure 6-4.

**Table 6-2: Total Tax Revenue Lost by OHD Scenario**

| Tax Incentive Offered | Participating Receivers | | Total Tax Incentive Cost |
|---|---|---|---|
| | Retail | Food | |
| $ 5,000 | 986 | 2253 | $ 16,195,324 |
| $ 10,000 | 2240 | 5368 | $ 76,071,530 |

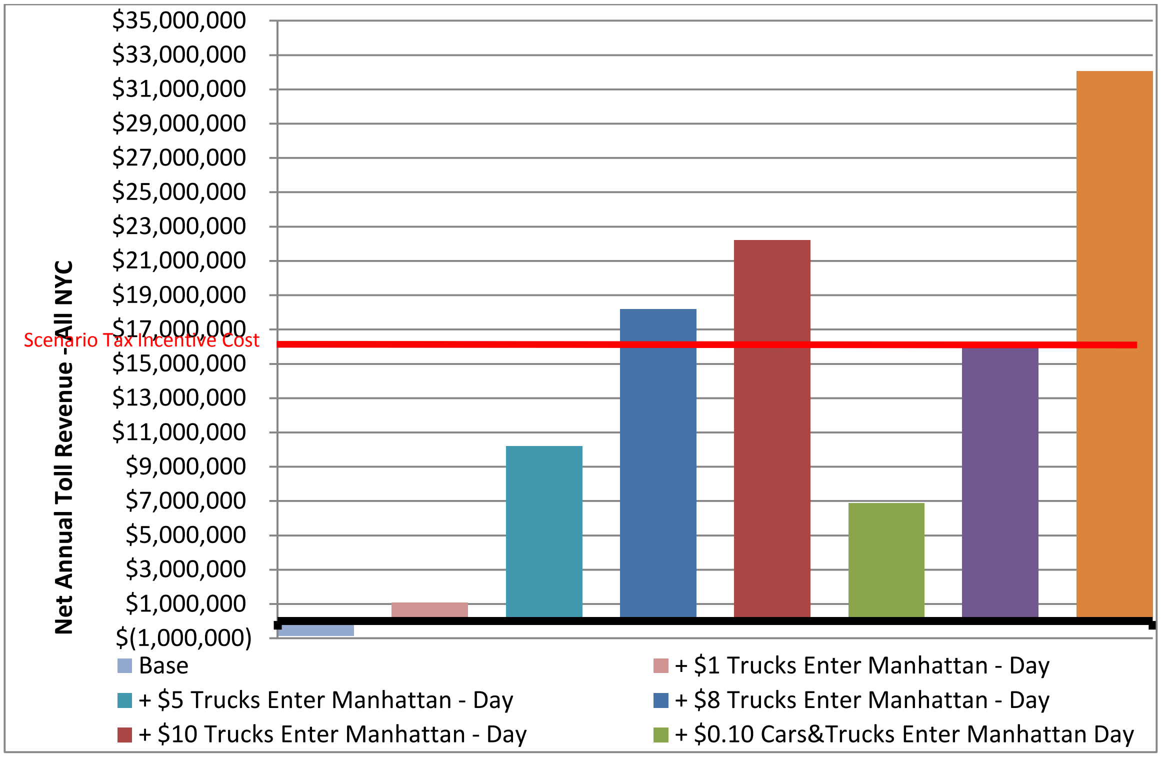


**Figure 6-3: Net Toll Revenue for $5,000 Incentive Modeled Scenarios**

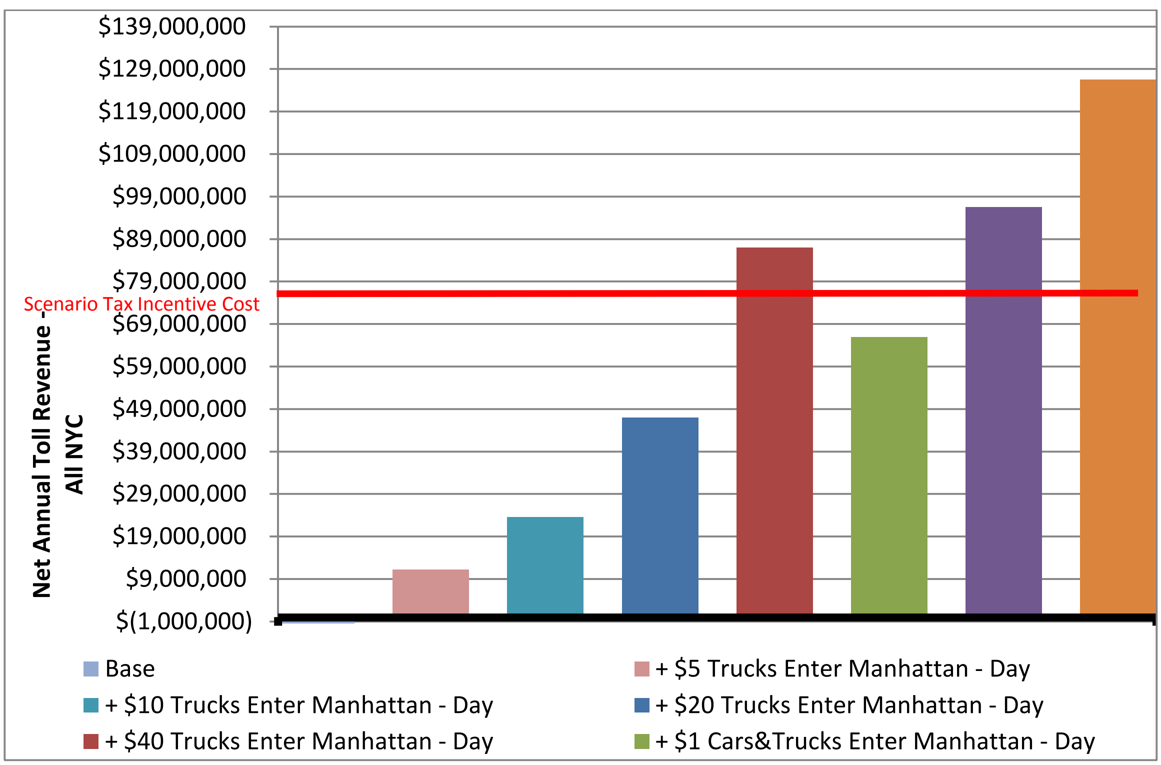


**Figure 6-4: Net Toll Revenue for $10,000 Incentive Modeled Scenarios**

### 6.2.5 Necessary Toll Increase

The necessary toll increase needed to neutralize the revenue lost from tax incentives are determined by running traffic assignments for different toll levels. Although vehicular flows at toll facilities unpredictably change in each scenario mainly due to network effects, the net toll revenue added corresponds linearly to the toll increase enacted. From this linear approximation, the toll increase necessary can be calculated at the total tax incentive paid amount. For the $5,000 tax incentive scenario the estimation of the necessary toll increase for trucks only is shown in Figure 6-5 and for all vehicles in Figure 6-6, while the estimation of the required increases for the $10,000 scenario are shown for trucks only in Figure 6-7 and for all vehicles in Figure 6-8. A summary of the results can be seen in Table 6-3, noting that the required increases would be for trucks or all vehicles, not both.

**Table 6-3: Required Toll Increases by OHD Scenario**

| Tax Incentive | Truck Toll Increase | All Vehicle Toll Increase |
|---|---|---|
| $ 5,000 | $ 7.36 | $ 0.25 |
| $ 10,000 | $ 34.34 | $ 1.19 |

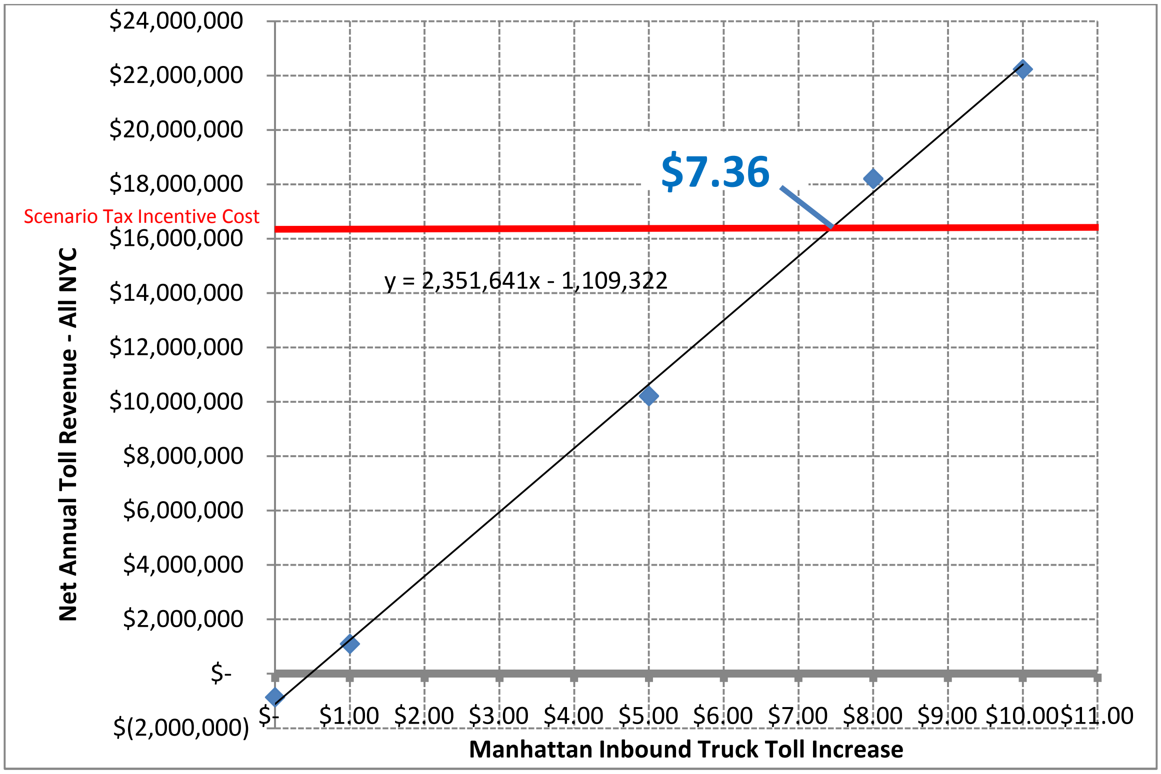


**Figure 6-5: Required Truck Toll Increase for $5,000 Incentive Scenarios**

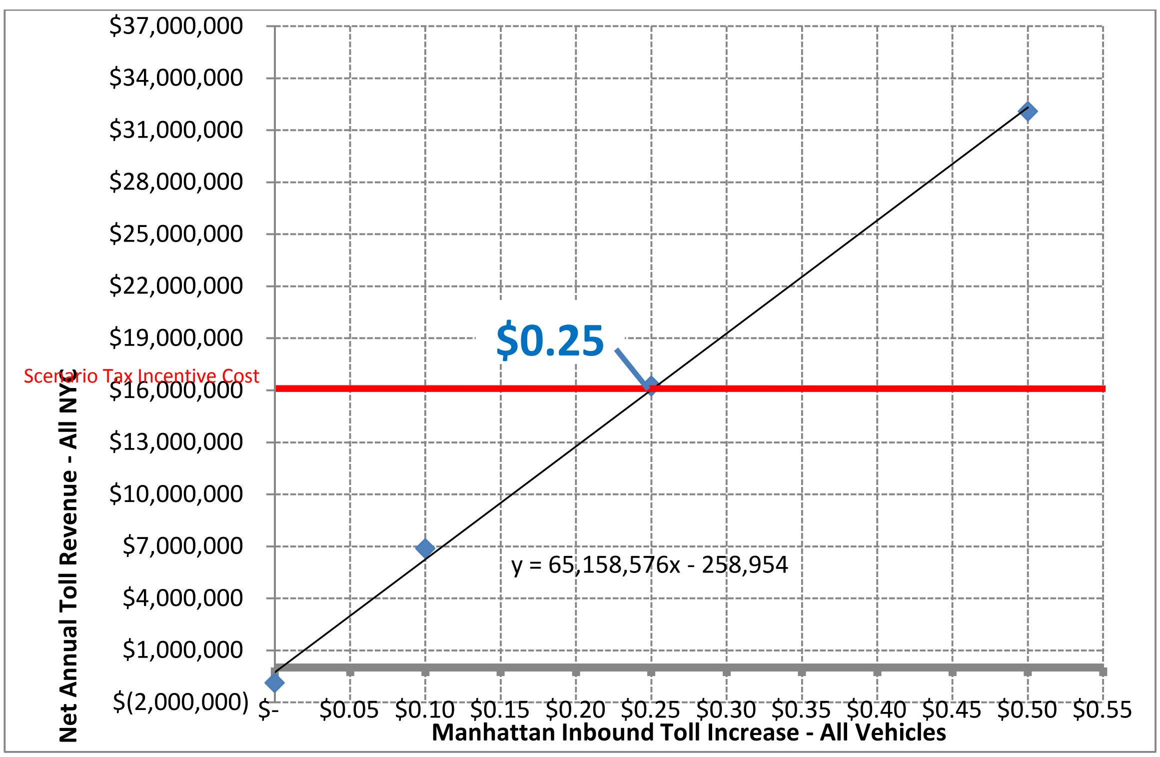


**Figure 6-6: Required Toll Increase for All Vehicles - $5,000 Incentive Scenarios**

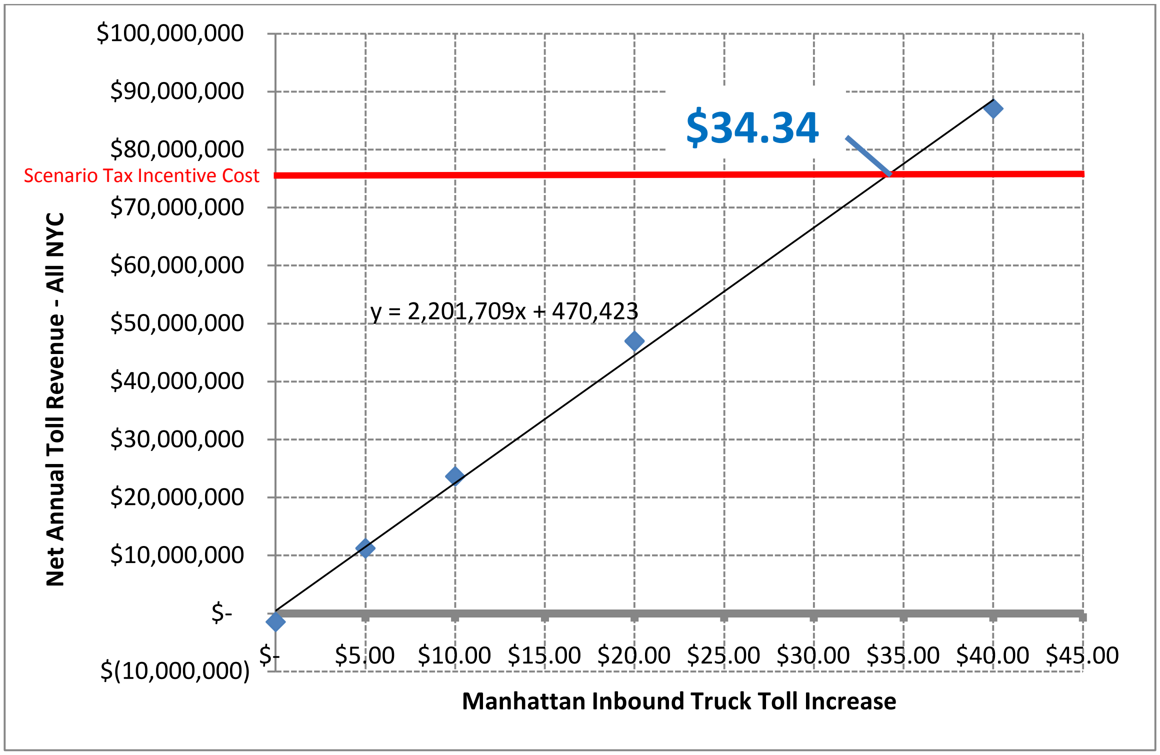


**Figure 6-7: Required Truck Toll Increase for $10,000 Incentive Scenarios**

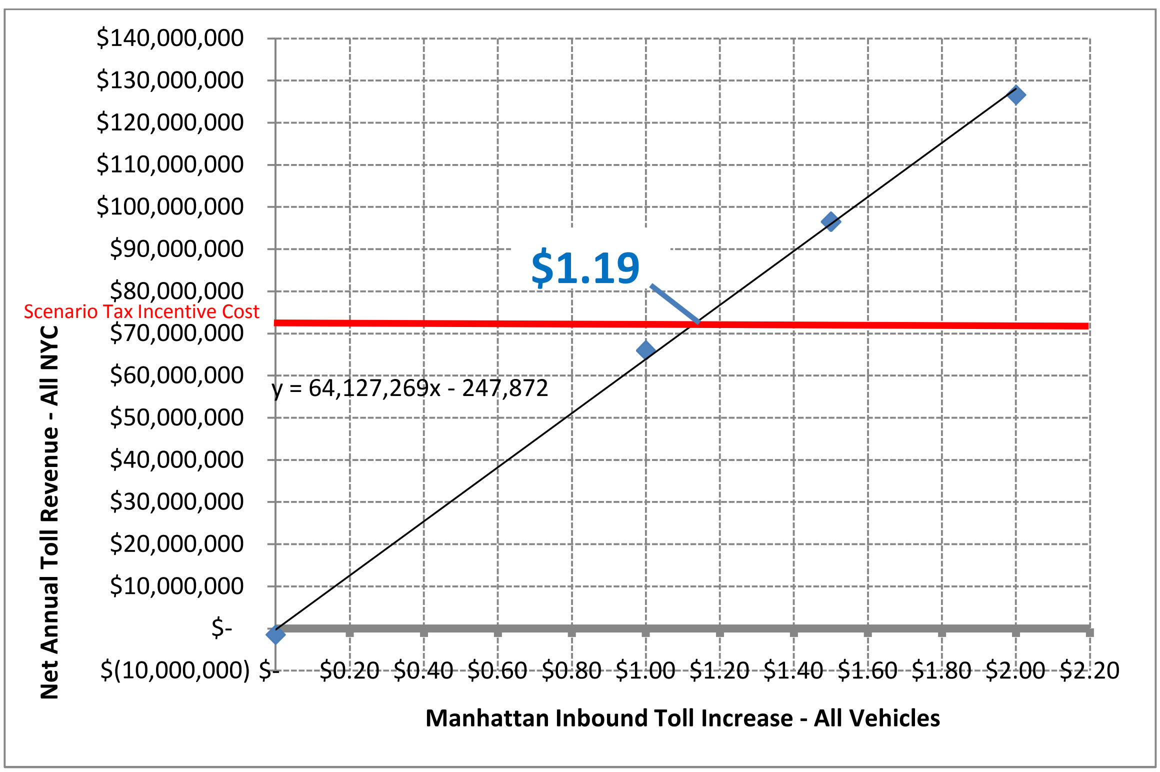


**Figure 6-8: Required Toll Increase for All Vehicles - $10,000 Incentive Scenarios**

The analysis conducted by this toll model was not extended to all of the scenarios modeled due to the excessive computational time required to run the traffic assignment model. However a $5,000 and $10,000 incentive extended to all food and retail receivers in Manhattan are assumed to be the most probable scenarios for implementation. While increasing truck tolls seems acceptable to incentivize truckers to move to the off-hours, increase tolls for autos is also justified due to their experiencing better conditions, as a result of less trucks on the road and less congestion. However it can be seen that the $5,000 incentive can be paid for with a much smaller truck surcharge than the $10,000 scenario. Similar results can be expected for the larger incentive scenarios. In either case the toll increases needed to cover the $5,000 and $10,000 incentives of the OHD are minimal relative to other toll increases enacted in the region.

# 7. Discussion

## *7.1 Validity of Results*

The results shown in Chapters 5 and 6 contain a number of inherent assumptions. Firstly the New York Best Practice Model (NYBPM) itself contains many in-built assumptions and usage of another model is likely to produce different results. Secondly only the assignment portion of the model was allowed to be re-run every time, discarding the other functionalities of the model. As discussed, these results only offer a short-term view of the implementation of an OHD program, since trip generation, distribution, and mode choice were held constant. Many modifications were made to the model in terms of its calibration, which may have caused the model to function differently than originally intended. Results using uncalibrated origin-destination matrices have shown to follow different trends, as well as assignment of other matrices. For example, the overall direct correlation between reduction in truck trips and reduction of network congestion was not always observed with other matrices.

Even among the results of this study, for individual periods a reduction in truck trips did not always correlate with a reduction in congestion. As seen in the results, VMT was seen to increase in some cases, but VHT can also increase. For example in Figure 5-5 there was a greater reduction in AM Peak (blue line) Vehicle Hours Traveled for the $20,000 incentive scenario than for the $25,000 incentive scenario, even though there are fewer truck trips during the $25,000 scenario (and constant number auto trips). This can happen in a traffic assignment model using user-equilibrium assignment, since users minimize their travel times with no consideration for the overall system travel time (as opposed to system-optimal assignment). This was also seen during the network cost calculations for the scenarios of only Lower Manhattan OD demands shifting to off-hours. For the smaller incentive and shift cases, network costs went up from the base-case. This illustrates that a reduction in truck trips does not necessarily produce a reduction in congestion. Therefore some scenarios of OHD can in fact have negative traffic impacts.

### *7.2 Usage of Traffic Simulation Models*

Changes or disturbances in the network can cause unpredictable results, since the network was originally calibrated for its base condition. Scenarios were run of traffic assignment when the networks were altered to close the Holland Tunnel towards Manhattan to trucks (to conform to a regulation currently in place[5]). When just this one link (out of 55,000+) was closed to traffic of one class, major disruptions were observed throughout the entire network. The aggregate VMT and VHT results collected did not exhibit the same trends observed with the previously modeled scenarios. Figure 7-1 shows the difference in shift model results for when the network was left unchanged versus when the inbound Holland Tunnel was closed to most trucks. The results shown are changes to VHT from the base-case when each of the shift model scenarios was implemented. When the network is unaltered the full network VHTs decrease as expected, but when the link was modified in the network aggregate VHTs did not follow the same relationship. In some of the cases VHTs increased, even though there were fewer vehicles in the network. These results illustrate the unpredictability of the model and the disturbances caused by a minor change.

[5] http://www.panynj.gov/bridges-tunnels/holland-tunnel-traffic-restrictions.html

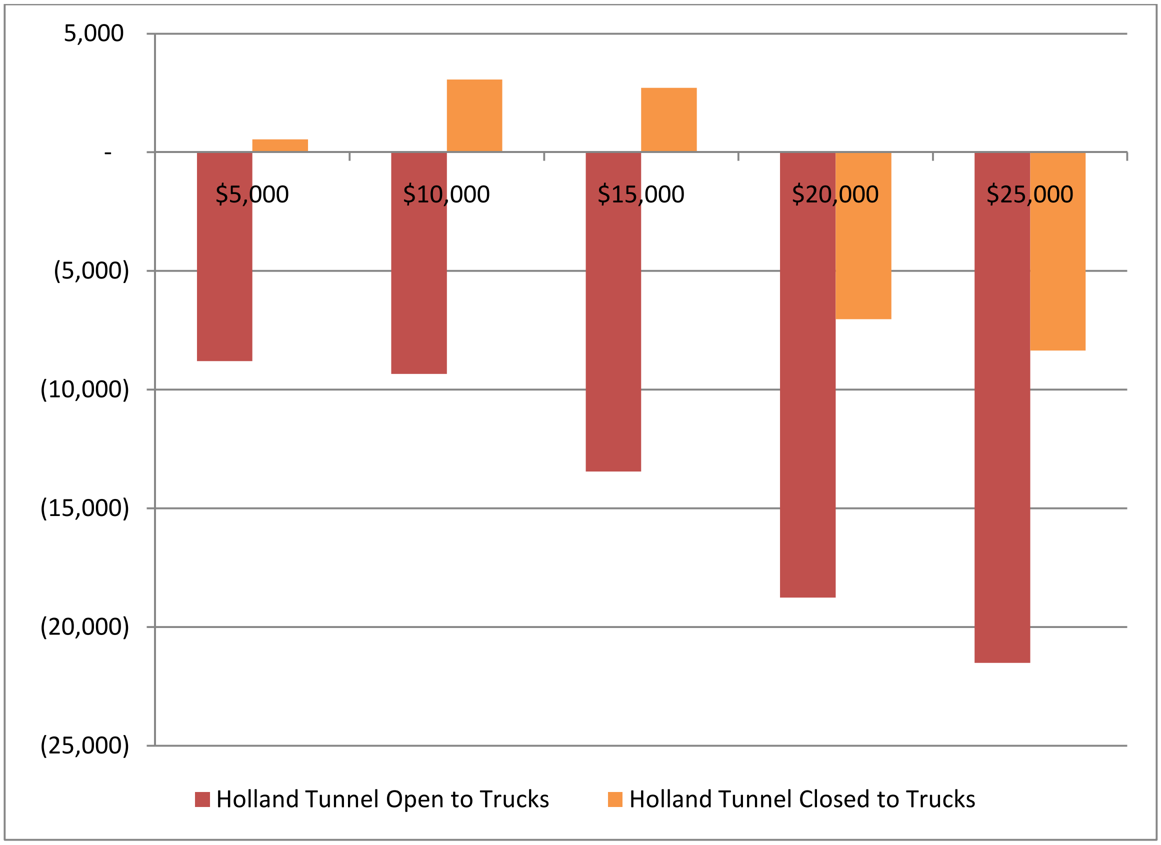


**Figure 7-1: Difference in Shift Results from Holland Tunnel Truck Closure**

With most transportation models, it is impossible to truly predict results beforehand and there is often much unknown regarding the behavior of the model. Calibration and validation of the model by agencies can only be conducted to ensure the validity of certain scenarios, such as the base-case scenario or future-year scenarios. It is impossible to ensure that the model will produce accurate results for all possible uses. To fully validate the results shown in this study, it would be useful to conduct more sensitivity analysis, as well as implementing the methodology to utilize the full capabilities of all modules of the model, instead of just highway assignment. Similar methodologies should also be run in other models, to see if the results are comparable.

## 8. Conclusion

This study developed a methodology to model an off-hour delivery program (OHD) for freight trips to the borough of Manhattan in New York City, within a regional planning model (NYBPM) developed for the city and surrounding area, with the goal of estimating its impacts to the highway network. This was achieved by shifting percentages of commercial vehicle traffic (given by models estimating the percentage of receivers willing to accept a tax deduction to shift their delivery operations to the off-hours) from the daytime hours (6am – 7pm) to the overnight hours (7pm – 6am). Scenarios were run offering tax incentives of $5,000, $10,000, $15,000, $20,000, $25,000, and $50,000 to food and retail businesses throughout Manhattan, as well as only those in Midtown & Downtown Manhattan.

The results showed that as greater tax incentives were offered, congestion (measured by Vehicle Hours Traveled) decreased throughout the region's highway network. However as greater tax incentives were offered the marginal benefits to the traffic network decreased as well. Similarly, when the incentive was only offered to businesses in Lower Manhattan the congestion benefits were fewer. Cost/Benefit analysis was conducted comparing the savings in VHT with the lost revenue of providing the tax incentive for each scenario. Under this criterion, the only scenario deemed profitable was for a $5,000 tax incentive offered to food and retail businesses throughout Manhattan. A static toll model was constructed to use the NYBPM traffic assignments to find what toll increases would be necessary to make up for the lost tax revenue for some of the scenarios. It was found that a very small toll increase to vehicles entering Manhattan during the daytime would be enough to make up for the lost revenue of the OHD program.

Finally, the validity of the model's results was discussed, including the effects of various calibration measures conducted on the model, as well as small changes that have potentially large and wide-reaching impacts. For further validation of the results in this study, more scenarios with different conditions should be run using this model. Additionally the full model should be run with the shift scenarios – a time-consuming endeavor – but results may show the model's adaptability to overcome changes made to the model. Other models should also be employed with similar methodologies and their results used to supplement those given by this study. While the results presented in this study are valid, it should be understood that they represent the output of only the highway assignment module, and that they are specific to the model used.

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