TRAFFIC IMPACT ANALYSIS OF AN URBAN OFF-HOUR DELIVERY PROGRAM
USING MACROSCOPIC AND MESOSCOPIC SIMULATION MODELS

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ABSTRACT

This paper describes the usage of a regional travel demand model and an extracted mesoscopic sub-simulation model in tandem to model and observe the traffic impacts of an off-hour delivery program. The study is based on OHD-participation behavioral data for the New York City borough of Manhattan, with traffic impacts measured throughout the New York metropolitan region. Analysis is conducted to determine the effectiveness and impacts of the scenarios modeled; focusing on the changes predicted by the traffic models, with link travel time and speed changes as the key measure of output. The results from both models are compared and analyzed, and a discussion on the usage of these models for this purpose is presented.
INTRODUCTION

Freight traffic constitutes a significant component of a region’s traffic system. Given its considerable increase in recent years, commercial vehicles (CMVs) have become a primary target for planners and policymakers in mitigating traffic congestion. Much work has been done regarding the quantification of the traffic impacts of congestion mitigation programs but less has been conducted 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 (1). The effects of trucks and commercial vehicles on highway networks are known to be negative, specifically causing congestion due to their nature as large vehicles generally traveling 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 (2).

Holguin-Veras et al. (2006) 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 (3, 4). These claims are supported by research into the effects of illegal parking on traffic congestion which show that illegal parking (primary conducted by CMVs) 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 either value pricing measures or by introducing off-peak delivery programs. Both ideas are gaining popularity in the United States but their degrees of success are yet unknown.

An off-hour delivery (OHD) program is expected to provide benefits to the highway network, since fewer trucks and commercial vehicles 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. 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 and delivery vans, which use the same highway
infrastructure as all other vehicles. This paper focuses solely on trucks and delivery vans, and
since any changes to their travel patterns will affect the entire highway network, this paper also
considers the effect on turn passenger cars. To fully assess traffic impacts throughout the region,
a model is required that considers both passenger and freight travel. Comprehensive travel
demand models developed by state and regional agencies consider many trip types and many
modes. This paper uses a regional travel demand model to estimate the effects of an off-hour
delivery (OHD) program.

Yannis, et al. (2006) used a transportation model to estimate the impacts of an OHD program
in the city of Athens. They presented a methodology to model modified commercial vehicle
origin-destination (OD) demands on a highway network when delivery operations within the city
of Athens were restricted (6). The study described modeling of the city’s roadways under
observed and modified commercial vehicle demands, accomplished by first observing existing
traffic conditions to collect sufficient data to build a comprehensive roadway network,
calibrating the collected data against actual conditions, and implementing the OHD program
changes into the model. Using 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 (7).

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 where 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.

This paper describes the usage of the New York Best Practice Model (NYBPM), a regional
planning model developed by New York Metropolitan Transportation Council (NYMTC), to
study the impacts of a proposed off-hour delivery program on the traffic network of the New
York City metropolitan region (8). The availability of NYBPM eliminates the need to create a
new network model for this study. Some of the shortcomings of a large-scale travel demand
model can be overcome by extracting a detailed localized sub-model which can be used for
further analysis in a mesoscopic simulation tool. In this case, a mesoscopic sub-network of
Manhattan, the most densely populated and commercial county in the city and region, is
extracted from the NYBPM for detailed simulation and analysis. Once the models’ results are
obtained analysis is conducted to determine the effectiveness and impacts of the off-hour
delivery scenarios modeled. The results from both models are compared and analyzed, and a
discussion on the usage of these models is presented.

The OHD program studied provides incentives for businesses within Manhattan to accept
their deliveries during the off-peak overnight hours instead of the daytime hours. Data from prior
behavioral studies is used to determine the percentage of business willing to accept incentives
based on a tax incentive amount, from which scenarios are constructed to measure traffic impacts
based on levels of receiver participation. Based on the receiver participation levels, CMV traffic
corresponding to the receivers’ deliveries is shifted from the daytime to the overnight hours
within the traffic models used. The models are then run with modified demands and the outputs
are compared to the base (existing) case to analyze the potential effects of the OHD program.

The paper is organized as follows: first an overview of each of the models and
methodologies used is provided, then the scenarios studied and modeled in both the NYBPM and
the mesoscopic simulation models are detailed, and the findings and results of each presented.
Finally a comparison of traffic impacts obtained from both models is conducted before
conclusions are discussed.
METHODOLOGY

Models Utilized

If commercial vehicle traffic is shifted from one time period of day to another – from peak periods to off-peak periods – it is critical 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. As mentioned, the New York Best Practice Model (NYBPM), the travel demand model used by New York-area planners (9), is employed for region-wide analysis. It covers 28 counties in the New York area, and allows for studying the full effects of the OHD program to the complete highway network of New York City and its surrounding areas.

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 (9). The input origin-destination (OD) matrices for highway assignment are six-fold, one for SOV, HOV2, HOV3+, truck, and other commercial. 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. 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 (10).

The assignment portion of the model is a collection of four models for four periods of the day. The four periods, each with their own networks and origin-destination (OD) matrices, are AM Peak Period (AM; 6–10am), Midday Period (MD; 10am–3pm), PM Peak Period (PM; 3–7pm), and Overnight Period (NT; 7pm–6am). The defined network periods and separate OD matrices allow for modeling to be based on shifting demand from the daytime periods to the overnight period, as described by the OHD program. Changes to CMV (trucks and other commercials) behavior are represented by manipulating the number of CMV trips between each origin-destination pair for each time period. Once the existing CMV OD matrices within NYBPM are altered the models’ outputs are compared to the base-case. The NYBPM modeling methodology is illustrated in Figure 1.
Figure 1: Research Methodology
The New York Best Practice Model, running in TransCAD, also allows for transfer of the highway network to TransModeler, both software tools developed by Caliper. While TransCAD is a static traffic assignment tool, TransModeler is a traffic simulator that is capable of performing simulations at a microscopic and mesoscopic level. In order to conduct more detailed analysis at the vehicle-level, the simulation is performed on an extracted sub-network of Manhattan and its access facilities (bridges and tunnels). Figure 2 shows the NYBPM highway network and the sub-network of Manhattan used for mesoscopic simulation.

The methodology for mesoscopic simulation consists of two simultaneous procedures (Figure 1): developing a model for the base case and scenario generation. Since NYBPM has been designed for modeling macro-scale static behavior, it cannot be directly used as an input for meso-simulation, since only major intersections in the local network have intersection geometry details. However, it is still appropriate for mesoscopic simulation provided that the NYBPM has the necessary road class information, free flow speeds, capacities, number of lanes, etc. Hence the network can be imported directly to TransModeler for the main features of the network. Once imported, the network is calibrated to assure a minimum exit-flow and avoid queues and spillovers.

Figure 2: NYBPM Highway Network with Manhattan Sub-network Highlighted
The mesoscopic simulation uses hourly OD matrices, with three classes being simulated: passenger cars, trucks, and other commercial vehicles (pickups, vans). In all cases, simulations are performed by the four general time periods with preloading the state of the previous simulation period (e.g., end-state of AM is preloaded for MD). The route choice model uses the default stochastic shortest path with response to high delay embedded in TransModeler (11). Under this method, paths costs are randomized based on different parameters such as perception of shortest path error and behavior parameters that have been calibrated according to the available data. The simulation also reroutes vehicles when their delays (different with respect to their free flow travel times) are too high. Thus the paths are initially fixed but are allowed to vary when congestion is high. However since the simulation requires a good estimate of the travel times, historical travel times are obtained from the base case using a sample of five runs and aggregating the travel times following an averaging procedure akin to the method of successive averages - MSA (11).

**Shift Model**

A model is developed to translate off-hour delivery participation levels into traffic demand changes, to study the traffic effects of the OHD program. Based on previous studies (12, 13, 14), there is a percentage of receivers (the data available is restricted to food and retail industries) within Manhattan willing to accept annual tax incentives to shift their delivery operations to the off-peak hours (assumed as 7pm–6am). In this section, we present the scenario generation assuming that different tax incentives are used to implement OHD. The resulting scenarios provide a shifting percentage of commercial vehicles that are shifted to the off-peak hours. In order to understand which types of industries are more likely to be willing to implement off-hours deliveries, behavioral modeling results were obtained by applying discrete choice models to scenarios discussed in detailed in Holguin-Veras et al. (13, 14). These scenarios were intended to assist in determining the types of policies that would have the greatest impact upon the willingness of carriers and receivers to participate in OHD by asking receivers how likely they would be to accept a certain percentage of their deliveries during the off-hours in return for a tax deduction.

The estimates are provided for every zip code in Manhattan, which for simplicity are grouped into community board groupings. There are four main community board groupings in
Manhattan, each divided according to land use. The first two community board groupings (1-3 and 4-6) represent the two main central business districts of Manhattan, Downtown and Midtown, where most commercial establishments and deliveries take place. Community board groupings 7-8 and 9-12 (Uptown) are more residential in nature and attract fewer CMV trips. This calculation assumes that all CMV trips destined for Manhattan are deliveries.

For both models, CMV OD trips are stored in period-specific origin-destination (OD) matrices, with each cell containing the number of trips between zones per period. Once the existing commercial vehicle OD matrices are altered, the traffic assignment module of NYBPM and the mesoscopic simulation network is re-run. Alterations to the CMV OD matrices are accomplished with shift factors calculated from the behavioral data, which are applied to CMV OD demands between all originating zones outside of Manhattan and destination zones within Manhattan. The shift factors reduce AM Peak, Midday, and PM Peak period CMV OD trips by a percentage (from the behavioral data), and the sum of the reduced trips is added to the Overnight period, for each OD pair. This has been assumed to be uniformly distributed across the NT hours in the mesoscopic model. Since only food- or retail-related truck traffic is modeled, the estimate of the probability that a commercial vehicle in the traffic stream would be making food or retail deliveries is taken to calculate the percentage of trips in the NYBPM model corresponding to food or retail deliveries. The percentage of commercial vehicle traffic shifting to the off-hours can be, \( \alpha_e \), calculated by Equation 1:

\[
\alpha_e = \sum_j \rho_j e \omega_j
\]

where \( J = \text{destination zone where receivers are located} \)

\( e = \text{industry segment \{retail, food\}} \)

\( \rho = \text{percentage of deliveries from industry 'e' shifting to off-hours} \)

\( \omega = \text{proportion of total deliveries associated with industry 'e'} \)

Computationally, all OD trip shifts are done exogenously in MATLAB. To apply a shift factor to a certain group of zones, all OD pairs with destination in the community board group of \( J \) zones being considered receive the shift factor. The qualifying OD pairs are those with the origin open to all zones in the network, Zones 1-4000, and the destination within Manhattan, Zones 1-318, \((i,j) = (1:4000,1:318)\). This signifies that even trips originating within Manhattan
are shifted, to account for chained trips, and to maintain the link between ‘deliveries’ from the behavioral data and ‘trips’ in the model. For simplicity, shift factors are used corresponding to the community board groupings described to account for the more than 1,200,000 OD pairs receiving a shift factor.

**Scenarios Modeled**

For the scenarios simulated in NYBPM the shift factors shown in Table 1 are used. The shift factors are calculated for four community board groupings in Manhattan, and by accounting for both the number of food & retail receivers located in these groupings, and the participation levels predicted by the behavioral studies (12).
Table 1: Shift Factors by Scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Tax Incentive</th>
<th>Community Boards, J</th>
<th>Retail Proportion, $p^R$</th>
<th>Food Proportion, $p^F$</th>
<th>Retail Percent, $o^R$</th>
<th>Food Percent, $o^F$</th>
<th>Shift Factor, $\alpha$</th>
<th>Average Shift, $\Delta$</th>
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<td>12.83%</td>
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The scenarios studied can be interpreted in terms of the average shift factor of each scenario, which is the average of the shift factors for each community board weighted by the proportion of deliveries to each community board grouping. It can be observed that as tax incentive amount increases, the marginal increase in average shift factor decreases, due to a limit in receiver participation.

The six scenarios shown are modeled in NYBPM, while the first three are simulated in the extracted mesoscopic sub-network. Prior to this, both models undergo a substantive calibration process using available up-to-date data. The truck OD matrices of NYBPM are inflated to current levels, while the mesoscopic network of Manhattan is calibrated to existing conditions. Both models are refined to represent an accurate base case, since the results of each scenario run are compared with the base-case, and presented in the following section.
RESULTS

NYBPM Results

The macroscopic network model’s (NYBPM) assignment output contains information for all 53,000 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 or 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 3a shows the change in vehicle miles traveled (VMT) by a shifting scenario’s assignment on the network, then Figure 3b shows the changes to vehicle hours traveled (VHT). The figures show the resulting output from the entire New York area network of all links in the NYBPM. The total 24-hour day (sum of all four periods) change in vehicle miles traveled (VMT) as a result of a specific scenario’s assignment is represented by the heavy black line, while the gray line represents only the three daytime periods from when truck traffic is subtracted.

The full-day results show that as the average shift levels increase vehicle miles traveled and vehicle hours traveled for all vehicles in the network both decrease. However they also show that as the proportion of deliveries shifted increases the marginal benefits decrease. For example beyond a 15% average shift the net benefits are only minimally increased. Figure 4 also shows the change in volume to capacity ratio (v/c), a measure of congestion, for Manhattan roads based on the scenarios of demand shift. Daytime congestion (volume/capacity ratio) in Manhattan is estimated to reduce in excess of 1.5% for significant demand shifts.
Figure 3: NYBPM Network Change in (a) VMT, (b) VHT by Shift Scenario
The 24-hour net changes in VMT and VHT are aggregated and the net changes from the base-case scenario can be seen in Figure 5a for all network links, and in Figure 5b for changes in Manhattan links. Manhattan, being the target of the program, covers a large proportion of the total network effects and Lower & Midtown Manhattan are the core central business districts of the city. In many scenarios, half of the reduction in VHT is experienced in Manhattan.

While the expected benefits from network assignment are expected to resemble the general relationship between tax incentive and average percentage of freight traffic shifted, 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 that are less congested which might still save them time, as they seek to minimize their total trip costs. Vehicle hours traveled however do incrementally decrease with increasing tax incentives and decreased freight traffic in most cases. For some scenario-to-scenario comparisons, reducing the amount of CMVs using the network does not always result in a decrease of vehicle hours traveled. Since NYBPM employs user-equilibrium assignment instead of system-optimal, the effect to the entire system is not always desirable.

Figure 4: Change in Manhattan Links’ Volume/Capacity Ratios
Figure 5: Scenario Net Benefits: (a) All Network Links, (b) Manhattan Links
Mesoscopic Model Results

The NYBPM, being a regional macroscopic model, is not largely sensitive to small changes in the number of CMVs assigned during periods. To measure the effects of the OHD program at a more detailed level, a mesoscopic sub-network of Manhattan is extracted and the OHD program modeled. The results are presented with statistics calculated at a path level, where travel times and speeds are computed from the beginning of vehicle trips until vehicles reach their destinations. The results of the focused Manhattan sub-network account for changes in the travel times and speeds for both an individual average trip and for the aggregated effect in total travel times. The results are also aggregated to find the overall effect per day and per period of time (AM, MD, PM, NT), which accounts for network effects in a more consistent fashion.

As expected the results show an inverse relationship between percentage shifts and travel times (Figure 6), as well as speeds (Figure 7). ‘Daytime’ aggregates the results for the three peak periods (AM, MD, and PM) in which the truck and other commercial vehicle demands are reduced by the OHD model. These periods show a decrease in total travel time under all scenarios, with the AM period showing the highest decrease in total travel time. The results also show a monotonic increase in travel times for all scenarios, up to 4.2% in Scenario 3 (which represents an average shift of 10.42% of the daytime CMVs) in the NT period. However, this increase in travel time is in all cases outweighed by the reductions in the other daytime periods. This is expected given that the NT period has much less volume than the daytime periods, and the increase is not as significant because the vehicles can move at slightly decreased speed. In particular the effects are largest during the AM Peak and Midday periods, as compared with the reduction in the PM peak, which has a more compact distribution of trips.

Figure 8 shows the congestion pattern for the 24 hours of the simulation, and it can be observed that the scenario with the lowest average shift (2.93%) has a similar pattern as the base case (no shift). However, once the shifts are larger (6.90% or 10.42%) the congestion reduces significantly between 7–10 am and between 12–3 pm. During the NT hours (7pm–6am) congestion is increased slightly due to the new traffic added during these hours. The shifts have significant effects during the peak hours of each period, when the traffic is reduced. The overall reduction in total travel times within the Manhattan sub-network over a 24-hour period are 0.93% for Scenario 1 (2.93% average shift), 2.93% for Scenario 2 (6.90% average shift), and 4.2% for Scenario 3 (10.42% average shift).
Figure 6: Sub-network Change in Total Travel Time by Period

Figure 7: Sub-network Change in Average Speed per Vehicle for Trips Completed
Regional Model/Sub-network Traffic Impact Comparison

A comparison between NYBPM and the sub-network simulation results is difficult to perform since the mesoscopic simulation accounts for results and effects within Manhattan, while the NYBPM aggregates the results of the overall regional network. Moreover, there is some accuracy lost due to the reduction of the area of scope in the mesoscopic model. Even if the results of only the Manhattan links of NYBPM are compiled, the output will differ from the sub-network links’ results due to the interactions with the neighboring regions’ links in the larger model. In addition the results obtained through the TransModeler simulation are path–based, while the NYBPM provides results at a link level from the traffic assignment nature of the model. In order to perform the comparison TransModeler path-based results obtained are converted into link-based results. Using the information from paths, the total travel times in segments corresponding to the links of the NYBPM are obtained. These results per link are aggregated by time period and presented in Figure 9, compared with NYBPM results for the three scenarios (average shifts of 2.93%, 6.90%, and 10.42%) run in both models.

It can be observed that the mesoscopic simulation shows far greater travel time savings during the daytime than the NYBPM. These differences are also reflected in the 24-hour results.
for all scenarios, where the mesoscopic simulation is observed to provide larger changes, percentage-wise, compared with NYBPM. The results indicate that the mesoscopic sub-network is more sensitive to the reduction in daytime truck traffic than the NYBPM. These differences are due to how each model manages congestion and the traffic flow model used. For instance a macro-model, such as NYBPM, uses a simplified traffic flow model, while the mesoscopic simulator uses a more sophisticated traffic model and accounts for more realistic ways to compute and aggregate delays. During the NT period, this difference is not significant because the period does not have significant congestion. However the daytime periods have significant congestion, which causes differences in the model output. For the sake of completeness the results of the path-based results were included, and it can be observed that in general the link-based results of the simulations slightly overestimate the travel times saved. Overall the mesoscopic model is seen to be more sensitive to the OHD program studied, while the NYBPM, being a large-scale model, is not as sensitive.

![Figure 9: NYBPM-Sub-network Comparison (Manhattan Links)](image)

**CONCLUSION**

This paper presents the results of modeling an off-hour delivery program for New York City in
two traffic modeling tools. Both networks are calibrated to the needs of this study and behavioral
modules representing the behavior of freight carriers responding shifting their deliveries to
overnight hours were implemented following the methodology. Based on the response to certain
tax incentives by businesses within Manhattan, commercial vehicles providing deliveries to them
shift their trips to the overnight period. Both a macroscopic regional travel demand model and a
mesoscopic sub-simulation network show a measurable impact to congestion and network
conditions. During the daytime hours, as trips are shifted away, travel times improve and link
speeds increase; while in the overnight period conditions deteriorate due to additional
commercial vehicle trips. However the benefits (in terms of travel time) observed during the
daytime hours in both modeling tools are greater than the losses to network efficiency observed
in the night hours. Therefore the OHD program is projected to have a net positive effect on the
traffic network.

Since both tools provide different type of results, the path based data obtained from the
mesoscopic simulation model is converted to link based data in order to compare the results of
both models. In general terms, the overnight period, where traffic is accommodated after the shift,
provides similar results. Differences arise in the daytime period, which are periods with
significant congestion. In these cases the mesoscopic model is more sensitive to the reduction in
the traffic congestion. This difference is expected because static models, such as NYBPM, do not
completely accounts for congestion effects in traffic. The mesoscopic simulation is more
appropriate for studying the detailed effects of traffic changes on vehicles, but extension to the
full regional network is impractical due to the simulation time. The usage of both models allows
for studying the OHD program’s effects on a large area while still understand the maximum
beneficial effects at a detailed, mesoscopic scale.

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