Metropolitan Washington Council of Governments
National Capital Region Transportation Planning Board

Summary of the State of the Practice and State of the Art of Modeling Peak Spreading

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Executive Summary

Traffic congestion in large metropolitan areas has become so acute that many commuters are adjusting their departure and/or arrival times for work and other destinations to avoid the worst of what is now called the "peak period". The adjustments in departure times combined with travel times that can last beyond the peak hour have led to the phenomena of peak spreading, where the peak hour demand on a particular roadway exceeds the peak hour capacity and causes demand to shift to the "shoulders" of the peak hour, or the hours adjacent to the peak hour. This situation is so pronounced in the TPB region, that most of the major freeways in the areas have peak periods that last from roughly 6 AM to 10 AM in the morning and 3 PM to 7 PM in the evening where stop and go traffic is common throughout.

The Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board (TPB) engaged Vanasse Hangen Brustlin (VHB) to review and summarize the state of the practice and the state of the art with regards to modeling peak spreading at the MPO level. VHB began this effort by reviewing the recent MPO survey and following up with staff at large MPOs with characteristics similar to the TPB to gain further insight and documentation into their peak spreading modeling efforts. The results of this research are summarized into state of the practice (most typical) and state of the art (new or unique approaches).

In addition to synthesizing the results of the research, VHB also conceptualized additional approaches to modeling peak spreading at the regional level that may benefit TPB in the future. One uses the existing regional model network, and another uses dynamic traffic assignment (DTA) and a more detailed network. As developing a regional network for a DTA model would require a significant investment on TPB's part, it is recommended that the regional model approach be tested initially as this would require much less effort and results could be presented several months after project initiation. In the longer run, TPB may want to evaluate using a DTA model for the 4th step in the modeling process and/or developing a state of the art logit model for evaluating the effects of peak spreading.

Current TPB Practice

TPB currently uses time-of-day factors to divide the daily trip tables into three time periods, AM peak, PM peak, and off peak time periods. These trip tables are then assigned to the regional network using congested skims for the peak periods and free flow skims for the off peak assignment. TPB uses a series of volume-delay functions for assignment with the primary outputs being link volume and speed. TPB then utilizes a post processing procedure where the final assignments are divided into hourly increments and if the hourly volume exceeds the capacity of a particular link, the excess volume is shifted to adjacent hours and the link speeds updated. The post-processing procedure is typically only run for air quality analyses.

State of the Practice

Most metropolitan planning agencies use time-of-day factors which are applied to the daily trip tables output from the mode choice model. The factors are typically derived from household survey data and validated to some degree with traffic counts. There are a number of limitations to this approach including:

- Regional time-of-day factors do not capture the temporal variations in demand throughout the region. For example, in the Washington region, I-270 in Montgomery County would have different peaking characteristics than US 50 in Prince George's County.

- The time-of-day factors are applied for the entire peak period which does not capture the variation of demand within the peak period. A number of large MPOs in addition to TPB use this method, including SCAG (Southern California Association of Governments, BMC (Baltimore Metropolitan Council), and SEMCOG (Southeastern Michigan Council of Governments).

- The time-of-day factors do not "see" congestion. For example, the same factors are applied throughout the Washington region despite the large variation in congestion patterns. The factors are not adjusted based on congestion because there is currently no feedback from assignment to post mode choice where these factors are applied.

As volume delay functions are used to calculate speeds associated with link v/c ratios, the impacts of traffic control and roadway constraints at specific points in the network are not explicitly considered. This constraint, combined with high v/c ratios that prevail in oversaturated networks such as the TPB network, often result in unrealistic speeds which necessitates further post processing to link volumes and speed during the air quality conformity analysis.

The research revealed several variations that MPOs use to mitigate these limitations to some degree. The North Central Texas Council of Governments (NCTCOG, the Dallas/Fort Worth MPO) uses a modified volume-delay function in the form:

Total Travel Time=
(travel time at the uncongested free flow speed) + link congestion delay.

The congestion delay consists of taking the minimum of two values: a minutes-per-mile parameter C or the v/c calculated delay using the curve shown in Figure 1:

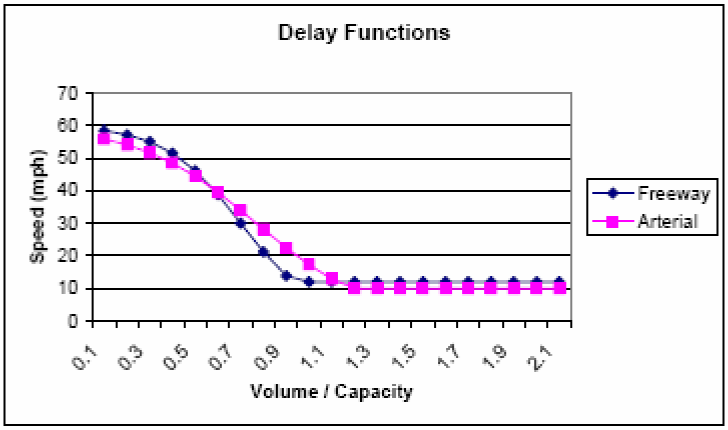

Figure 1: NCTCOG Volume-Delay Function (Source NCTCOG)

This process effectively caps the minimum speed on any link in the network to prevent unrealistically low speeds from being fed back into trip distribution and mode choice; however it is acknowledged that floor speeds violate a property of user equilibrium formulation which could lead to problematic convergence. Furthermore, these types of cliff functions or caps are problematic when it comes to New Starts applications with FTA, which is a particularly important consideration for TPB.

Another variation of the time-of-day factoring approach is used by Metro (Portland MPO), which utilizes additional time periods for assignment to better capture the peak demand within the overall peak period. In addition to the 3 hour AM peak period time-of-day factors, Metro also calculates time of day factors for the 2 hour AM peak as well. Likewise, time-of-day factors are applied for both the 4 hour PM peak period and the 2 hour PM peak. This gives a better approximation of demand in the "peak within the peak period), though is still subject to the same limitations with time-of-day factors in general.

To overcome the limitations in the regional assignment (i.e. unrealistically low speeds, over-assigned links), most MPOs post-process assignment results during conformity analysis. A typical post processing approach would look at each link in the network and divide the time period volume into each hour of the day. An analysis is completed testing if any one hour of volume exceeds the hourly capacity for the link. If this is the case, then move the excess volume to the preceding and following hour. Moreover, to overcome unrealistically low speeds output from assignment, separate speed calculations such as the one developed by Richard Dowling and Alexander Skabardonis[1] is used where:

[1] 1992.

Average Link Speed = Average Queue Speed * (Average Queue Length/Length) + uncongested speed * (1-Average Queue Length/Length))

WHERE:
Uncongested Speed = 1.24 * Survey Speed (fc,h)/ (1+ (V/C) ^ 11
Fc= functional class
H= hour of day
Avg. Queue Speed= Capacity/lane * 25 feet/vehicle
Avg. Queue Length= Average Queue * 25 feet/vehicle
Average Queue= (Q1 + Q2)/2
Q1= Queue at start of time slice
Q2= Q1 + (1 hour traffic/lane – 1 hour capacity/lane)

State of the Art

While time-of-day factoring procedures are considered as state of the practice, there are a few innovative, state of the art approaches to modeling peak spreading. The Puget Sound Regional Council (the Seattle-Tacoma MPO) has two mechanisms that account for peak spreading within the modeling process. In the AM and PM peak (3 hour) assignments, the delay functions incorporate a factor ranging from 0.455 (at v/c=0.0) to 0.333 (at v/c=1.0) to allocate the 3-hour volume to the worst hour for calculating delay. This accounts for flattening of the peak hour within the peak period on a link-by-link basis.

The model also includes a time-of-day model which calculates the shares of trips in each time period by direction for auto trips within each homed based purpose which accounts for spreading outside the 3-hour peak periods, on a TAZ-to-TAZ basis. The schematic of the time-of-day model is shown in Figure 2:

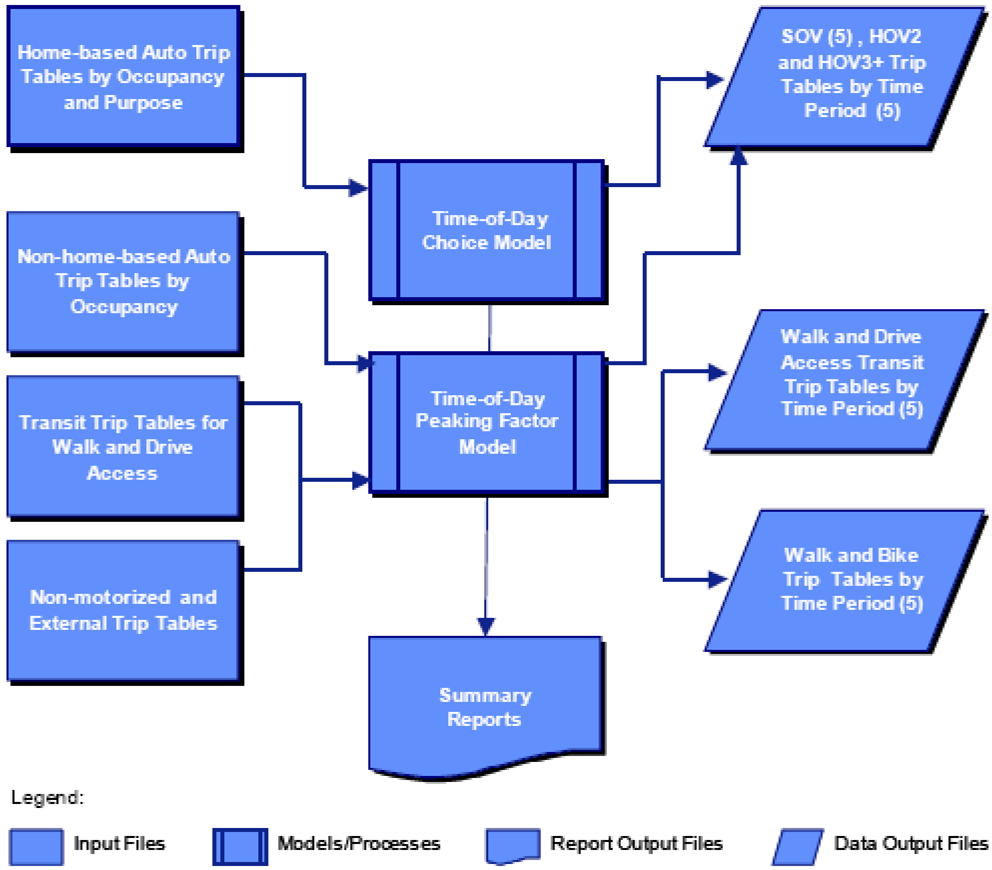

Figure 2: PSRC Time-of-Day Model (Source: PSRC)

The Metropolitan Transportation Commission (MTC) is the metropolitan planning organization for the nine-county San Francisco Bay area; MTC has also developed a logit model to address peak spreading. The model is a binomial logit choice model with the choices of AM peak (two-hour) period departure and non-AM peak period departure. The choice is estimated using data from the 1990 Bay Area household travel survey, using data variables such as free-flow and AM peak period congested travel time, trip distance, household income, and dummy variables for bridge crossers, carpooling and retail employment. Highway assignments were calibrated and validated against 1990 daily and peak period traffic volumes and peak period speeds.

This peak-spreading model has a tendency to divert trips from the peak period to the shoulders of the peak period due to increased congestion levels. The result is that the peak period traffic volumes are sometimes lower than the peak shoulder period traffic volumes, yielding too fast speeds in the peak period and too slow speeds in the shoulder period. This was called the “snow plow” effect by MTC, with traffic piling up on the shoulders to allow traffic to flow during the peak period. The quick fix to this problem was to prepare a four-hour AM period traffic assignment based on peaking factors derived from the household travel surveys. The slower of the two-hour and four-hour AM peak period assignments are used to feed back to all mode choice models for purposes of forecast equilibration.

Many theoreticians believe that activity-based modeling is the answer to most of the time-of-day questions the profession faces, including peak spreading, with the idea being that if a model is estimated based on daily activities, some with time constraints others without; then we will be able to better model household's responses to future congestion levels. For example, if a person in a household has to be at work at 9 AM and also currently engages in the activity of purchasing coffee at 8:30 AM on the way to work, the person may well eliminate the non-mandatory coffee purchasing activity in the future just to make it to the required activity (work) by 9 AM.

The Mid-Ohio Regional Planning Commission (MORPC, the MPO for Columbus, Ohio) developed one of the first regional activity-based travel forecasting models in the United States. The model is a disaggregate tour-based model applied with the microsimulation of each individual household, person, or tour, mostly using Monte Carlo realization of each possibility estimated by the models, with the use of a random number series to determine which possibility is chosen for that record.

The model consists of nine separate models that are linked and applied sequentially. In order, these nine models are: Population Synthesis, Auto Ownership, Daily Activity Pattern (mandatory tour generation), Joint Tour Generation, Individual Non-Mandatory Tour Generation, Tour Destination Choice, Time of Day Choice, Tour Mode Choice, and finally, Stops and Trip Mode Choice.

The Tour Destination Choice, Time of Day Choice and Tour Mode Choice models are all logit based and applied together. The "LogSum" composite impedance measure from the mode choice model is available to the other choice models, making them sensitive to changes in travel times due to congestion. The Time of Day (TOD) model is based on the "time windows" concept, accounting for the use of a person's time budget over the day (16 hours available per person). These models are applied at the tour level, yielding the primary destination, time of day, and mode choice for the entire tour, and consider both the out-bound and in-bound portions of the tour.

The TOD model is a hybrid discrete choice departure time and duration model. The model has a temporal resolution of one hour for the modeled period between 5 AM and 11 PM. All tour departures before 5 AM were shifted to the 5 AM hour, and all tour arrivals after 11 PM were shifted to 11 PM. The TOD model is applied sequentially among tours, with mandatory (work, university, and school) tours being scheduled first. The model determines the departure time of each tour and the duration of the activity associated with the tour. Therefore, the 190 departure and arrival time combinations can be applied with relatively few variables. As a result of this time-windows constrained formulation, the timing of the departure and arrival times on both legs of the tour is determined by both the duration of the activities and by the travel times to and from them.

Additional Approaches

There are other potential approaches to modeling peak spreading, including feeding back congested network conditions to pre-assignment where time-of-day factors are applied. This approach would use the congested travel times and v/c ratios output from assignment to adjust the time-of-day factors until all v/c ratios are below an accepted threshold. While this approach would model peak spreading at the regional level, it would still not capture the variations in time-of-day throughout the region.

VHB staff researched and developed another procedure that could be utilized to evaluate peak spreading in the TPB region. This approach would begin with the base year validated travel model and hourly traffic count data at the regional screenlines (ADT count data is collected at the screenline level currently for validation purposes). Hourly counts are also available at many of these locations, and additional counts could be conducted as necessary to augment available count information.

The process would begin by estimating OD tables for the 2, 3, 4, and 5 hour peak periods (the 1 hour peak period is rare in the TPB region). The hourly screenline count data would be used with Cube Matrix Estimation Software to estimate the OD tables for the above referenced time periods. These OD tables would then be divided by the daily regional OD table which would lead to 4 peak period “k” factor tables or more specifically OD tables that reflect the percentage of peak period travel to daily based on existing count information in the region. The “k” factor OD tables would then be applied to the forecast year regional daily trip table, resulting in 2, 3, 4, and 5 hour forecast peak period trip tables which would then be assigned to the regional network using the congested skims.

The resulting assigned networks would represent the 2, 3, 4, and 5 hour peak periods for the forecast year. To examine the duration of a peak period on a particular roadway segment for example, the first step would be to conduct the 2 hour assignment and plotting the resulting v/c ratios (using the hourly capacity x # hours in time period). If the v/c ratio is greater than a pre-defined threshold (1.1 for example), then a 3 hour assignment would be conducted and the roadway segment re-evaluated; this process would be repeated until the v/c ratio for the peak period assignment is equal to or less than the threshold value, so for example, if the 3 hour assignment results in a v/c of 1.34, and the 4 hour assignment results in a v/c of 0.99, then the assumption would be that there would be approximately 4 hours of congested conditions on this particular roadway in the future. The procedure is illustrated in Figure 3.

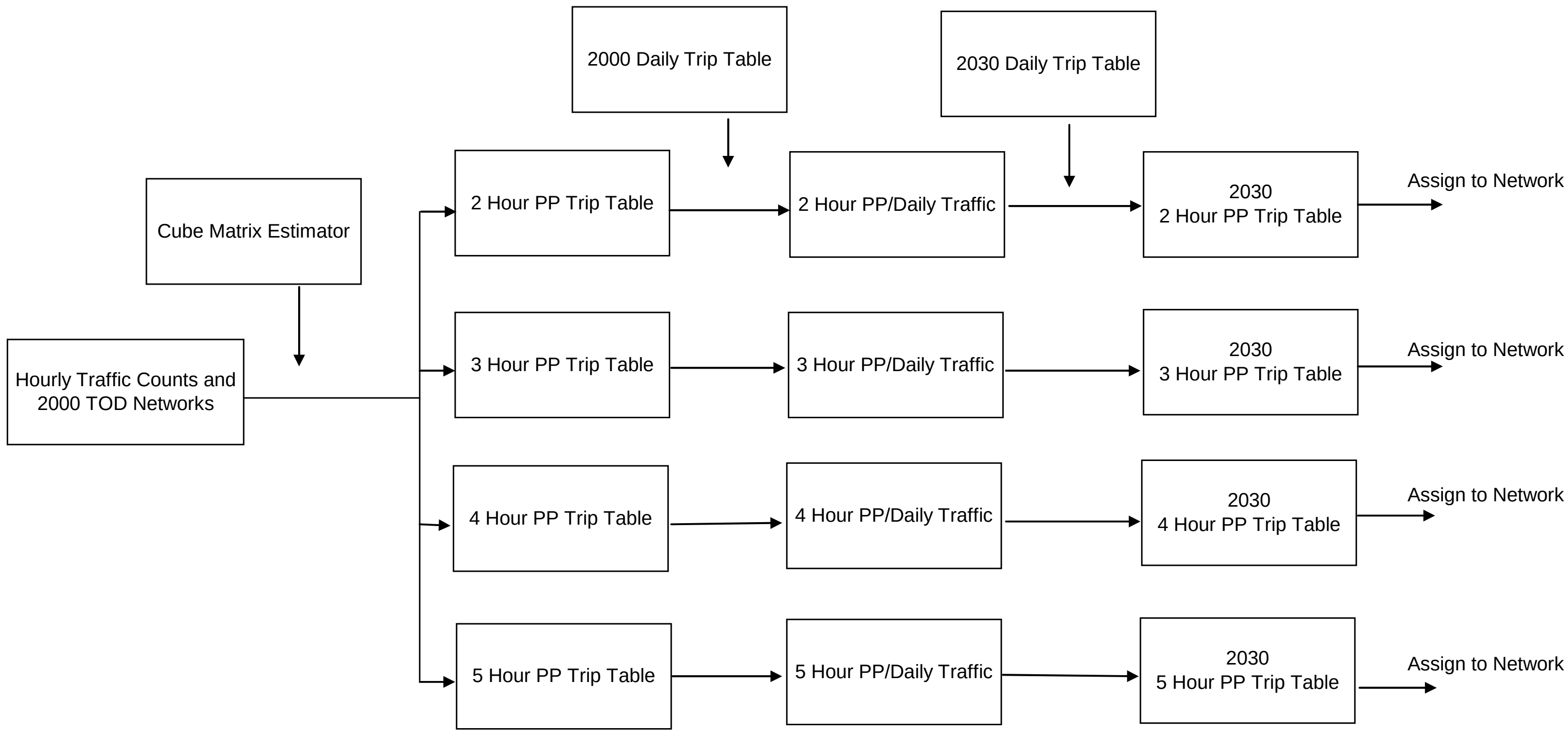

Figure 3: Proposed TPB Peak Spreading Approach

The benefit of this approach is that the time-of-day factors are based on actual count data which includes behavior not revealed in household and transit surveys, and the time-of-day factor is effectively disaggregated to the interchange level which would capture the variances in peaking patterns in a region the size of TPB.

VHB completed an initial evaluation of traffic count data to determine data availability and evaluate the peaking characteristics along the I-270 corridor. This data is presented in graphical format in Appendix 1. The results of the initial analysis show that locations along I-270 already experience peak periods lasting four or five hours. Appendix 1 also contains regional maps showing the availability of observed traffic data for expanding the geographic coverage of the peak spreading analysis beyond the I-270 corridor.

Finally, with the introduction of mesoscopic, simulation based, Dynamic Traffic Assignment models, it is computationally feasible to estimate and assign an OD table on a more detailed network which would include traffic control and a more detailed network representation. This approach would estimate time dependent OD tables (15 minute intervals recommended), in a similar fashion as the previous approach; likewise the forecast peak period OD table would be calculated using k factors. The forecast peak period OD table would then be dynamically assigned to the detailed network which would more accurately reflect the roadway constraint aspect of peak spreading at point locations such as major intersections or interchanges. Additional benefits of this approach is that it could be introduced into the 4-step modeling process (the El Paso, TX MPO is testing DTA in this context currently) and allow TPB to evaluate ITS and ATMS strategies at the regional and corridor level which cannot be done explicitly with the current regional model. However, it should be noted that like any new tool, there are still a number of unknowns with DTA models and OD estimation, so TPB would benefit by testing these strategies incrementally before investing significant resources.

Next Steps

TPB could begin testing one or more of the existing approaches based on staffing and budget availability. VHB has developed additional approaches that could also be considered, one using the existing regional model network, another using DTA and a more detailed network. As developing a regional network for a DTA model would require a significant investment on TPB's part, it is recommended that the regional model approach be tested initially as this would require much less effort and results could be presented several months after project initiation. In the longer run, TPB may want to evaluate using a DTA model for the 4th Step in the modeling process and/or developing a state of the art logit model for evaluating the effects of peak spreading.

References

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Email from Deng Bang Lee, Southern California Association of Governments.

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Appendix 1: Initial Peak Spreading Procedure for TPB Region

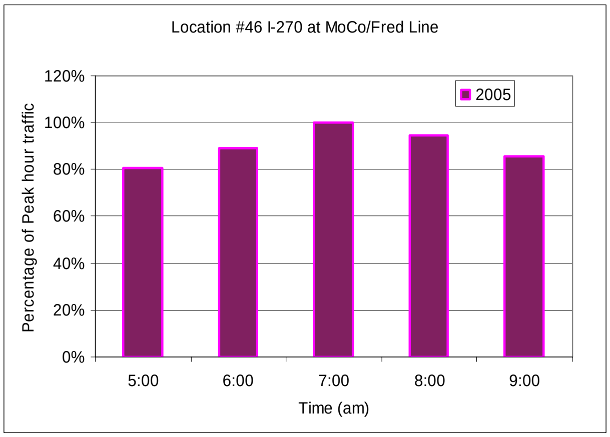

Figure 4: Screenline 25 AM Peak Hour Analysis – I-270

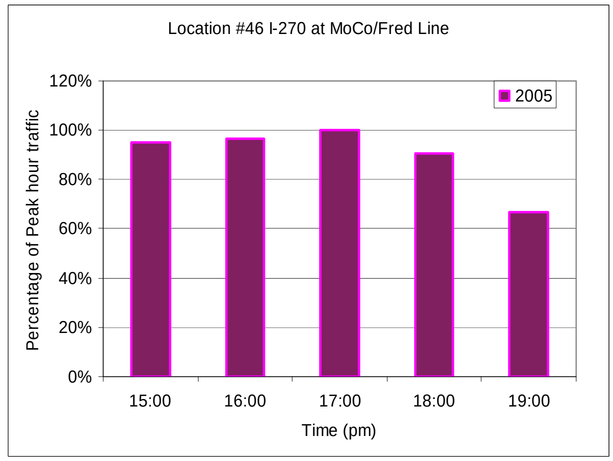

Figure 5: Screenline 25 PM Peak Hour Analysis – I-270

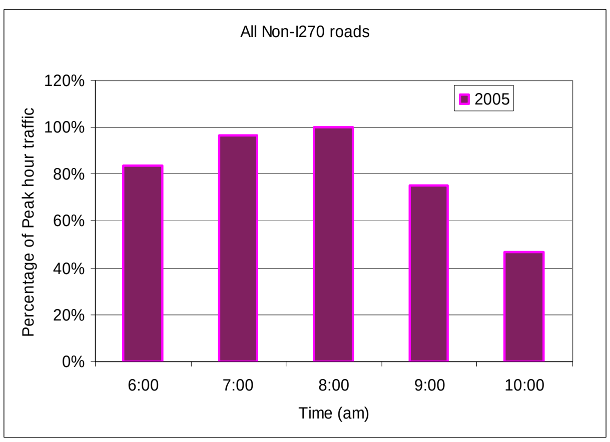

Figure 6: Screenline 25 AM Peak Hour Analysis Non-Freeways

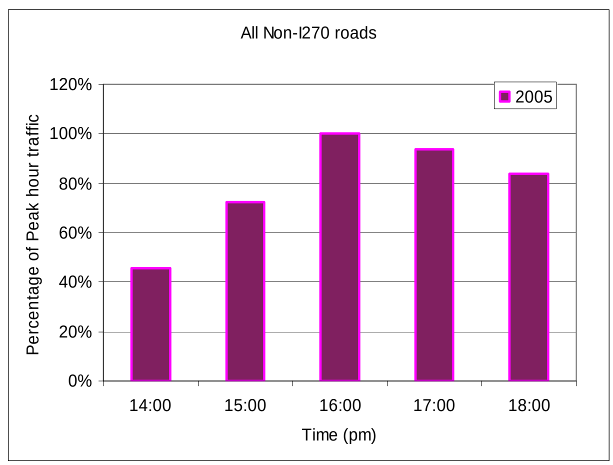

Figure 7: Screenline 25 PM Peak Hour Analysis Non-Freeways

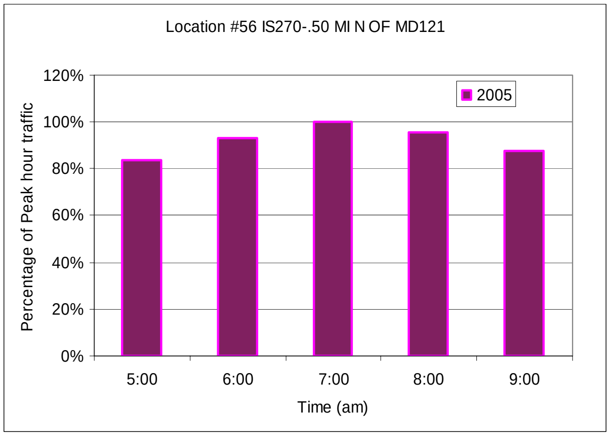

Figure 8: Screenline 23 AM Peak Hour Analysis – I-270

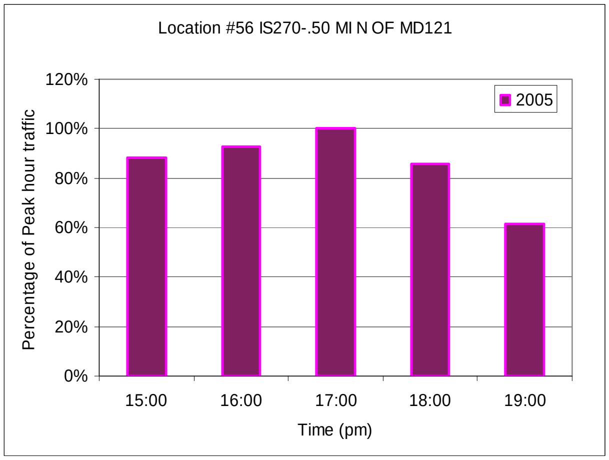

Figure 9: Screenline 23 PM Peak Hour Analysis – I-270

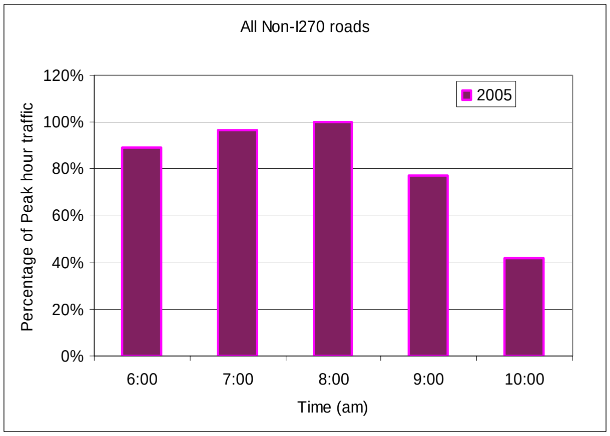

Figure 10: Screenline 23 AM Peak Hour Analysis Non-Freeways

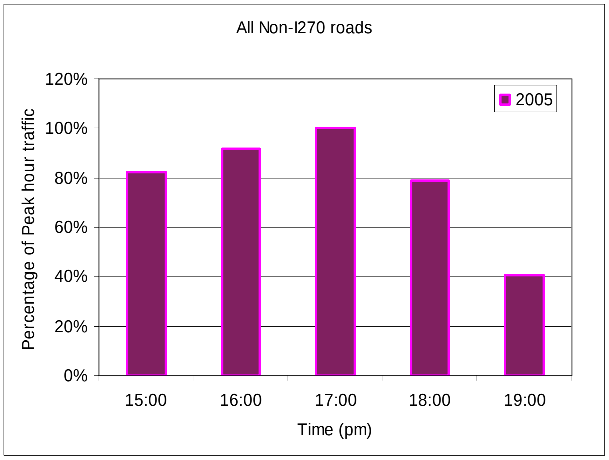

Figure 11: Screenline 23 PM Peak Hour Analysis Non-Freeways

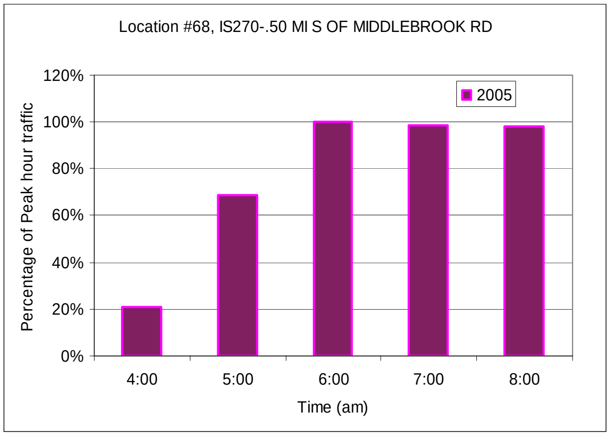

Figure 12: Screenline 22 AM Peak Hour Analysis – I-270

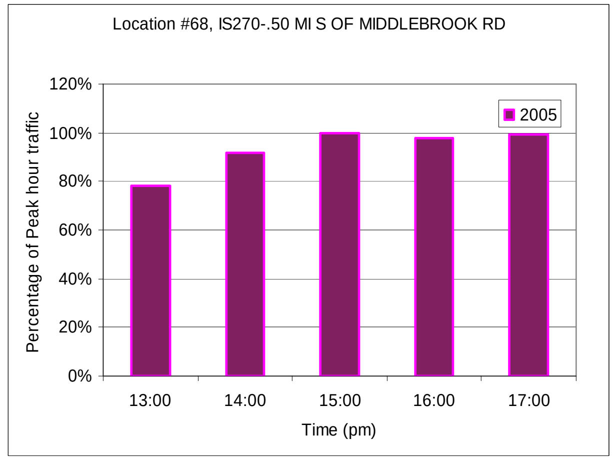

Figure 13: Screenline 22 PM Peak Hour Analysis – I-270

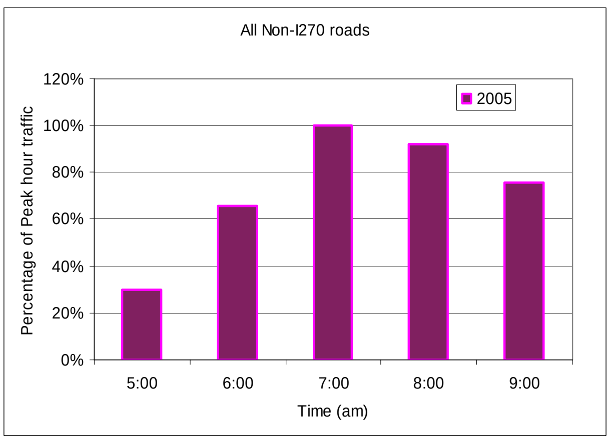

Figure 14: Screenline 22 AM Peak Hour Analysis Non-Freeways

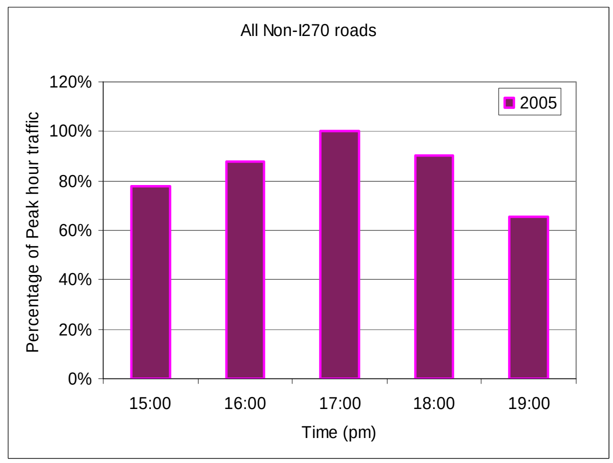

Figure 15: Screenline 22 AM Peak Hour Analysis Non-Freeways

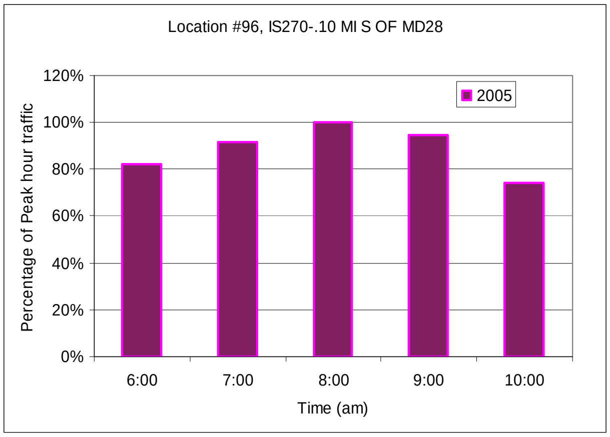

Figure 16: Screenline 8 AM Peak Hour Analysis – I-270

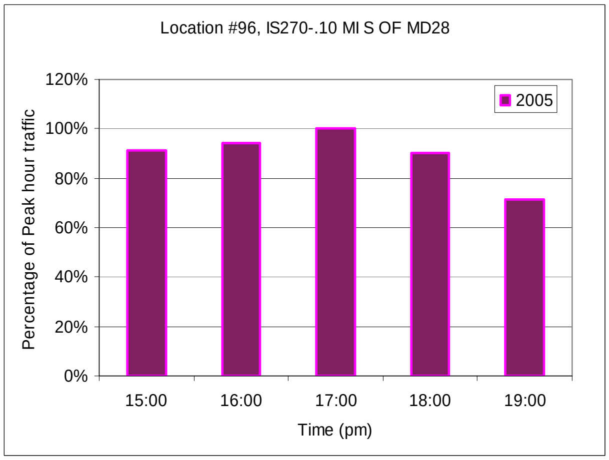

Figure 17: Screenline 8 PM Peak Hour Analysis – I-270

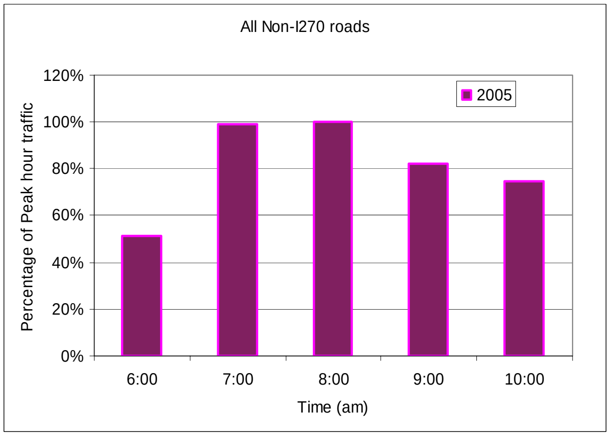

Figure 18: Screenline 8 AM Peak Hour Analysis Non-Freeways

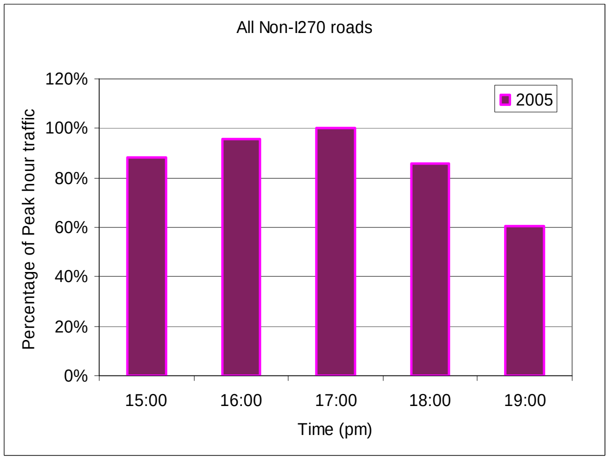

Figure 19: Screenline 8 PM Peak Hour Analysis Non Freeways

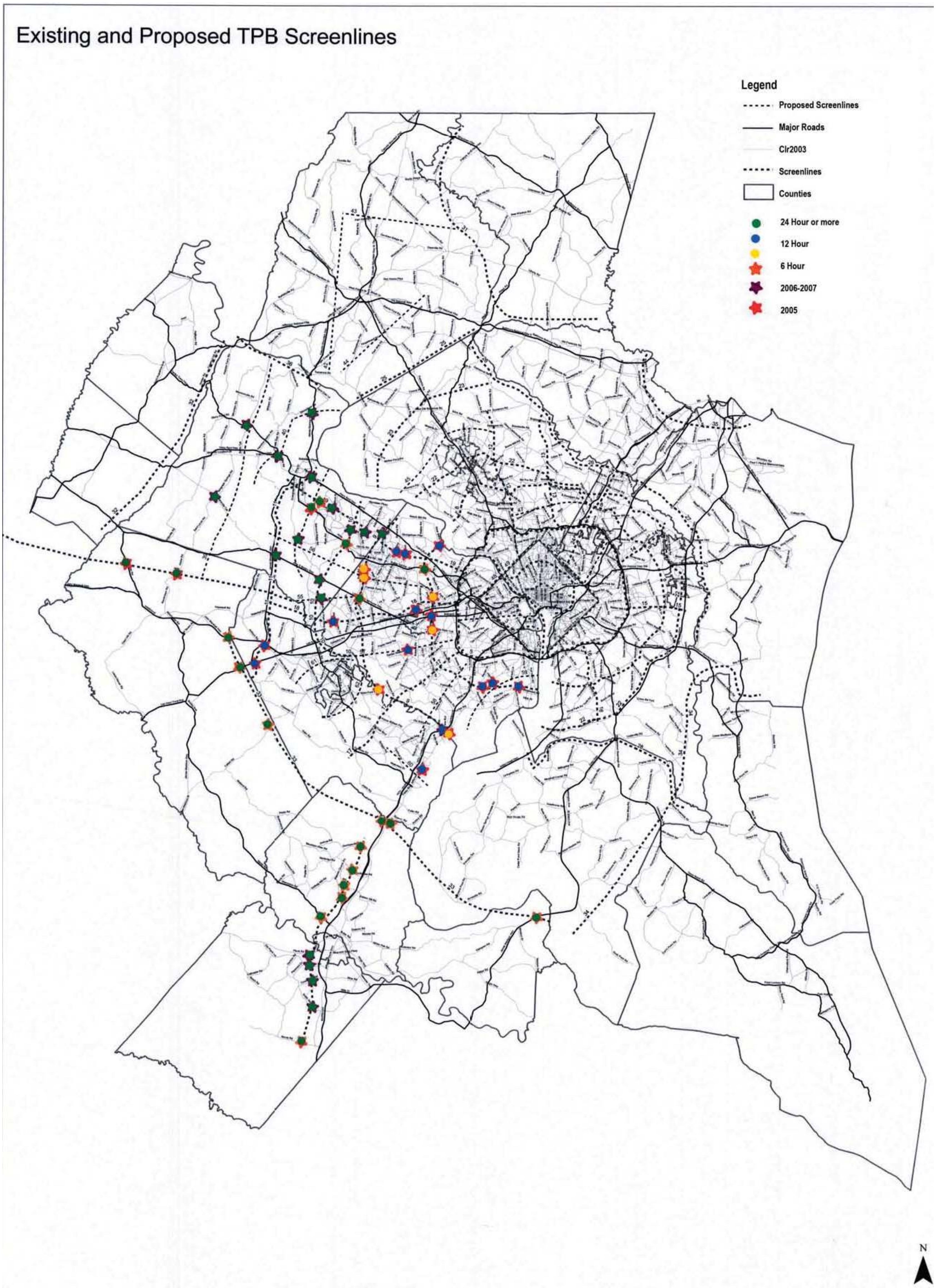

Figure 20: Virginia Traffic Count Inventory

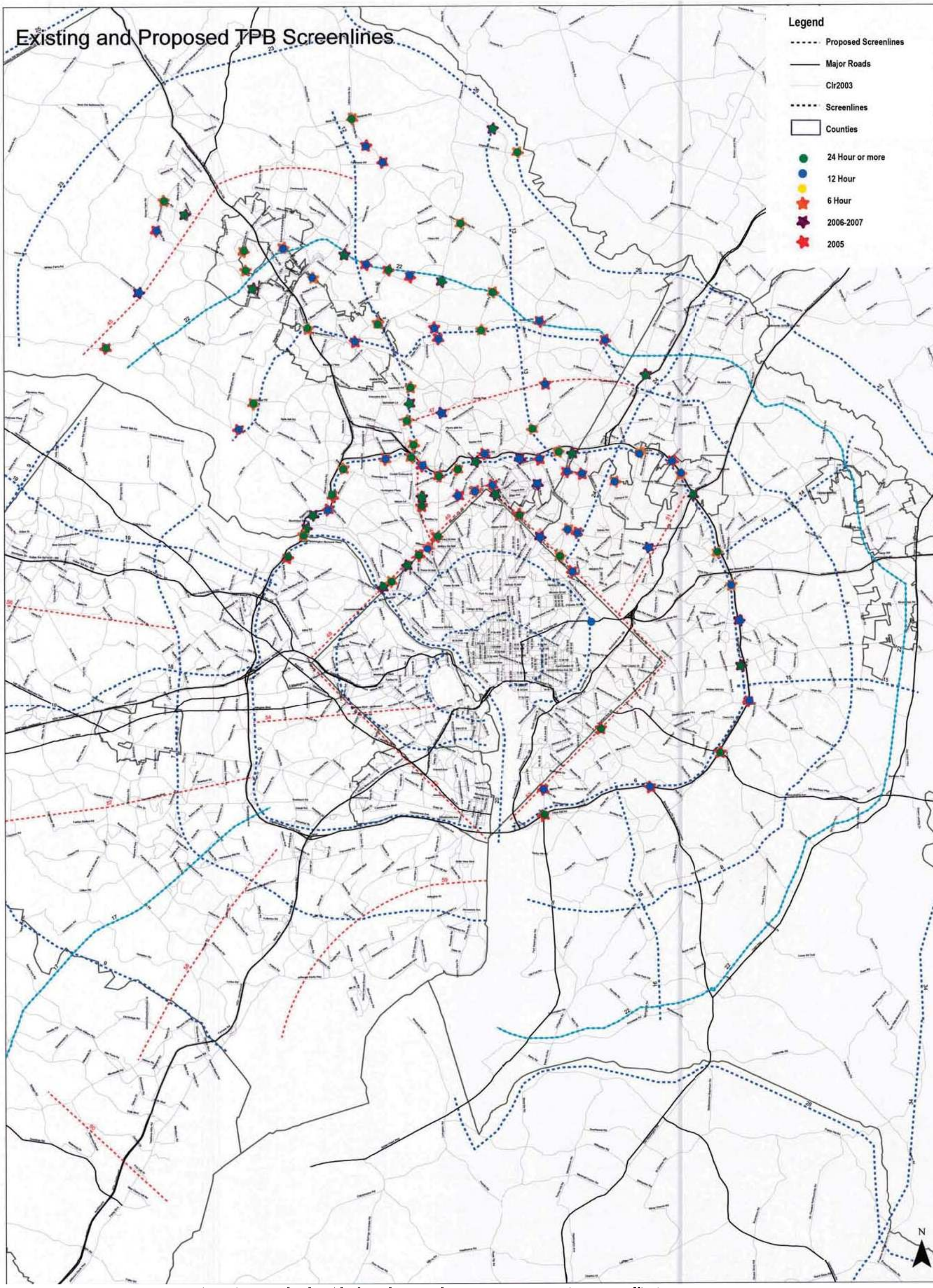

Figure 21: Maryland Inside the Beltway and Lower Montgomery County Traffic Count Inventory

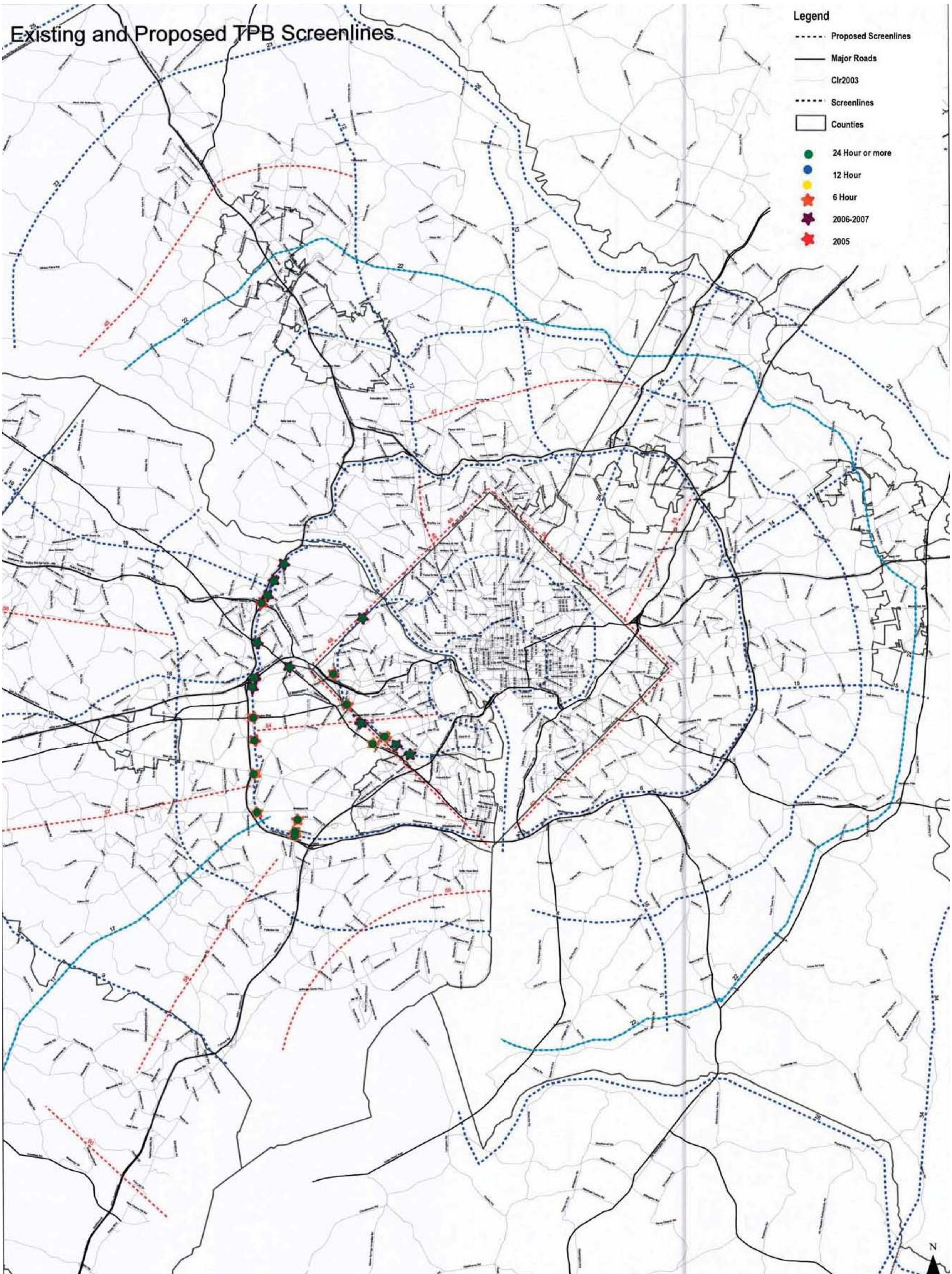

Figure 22: Virginia Inside the Beltway Traffic Count Inventory

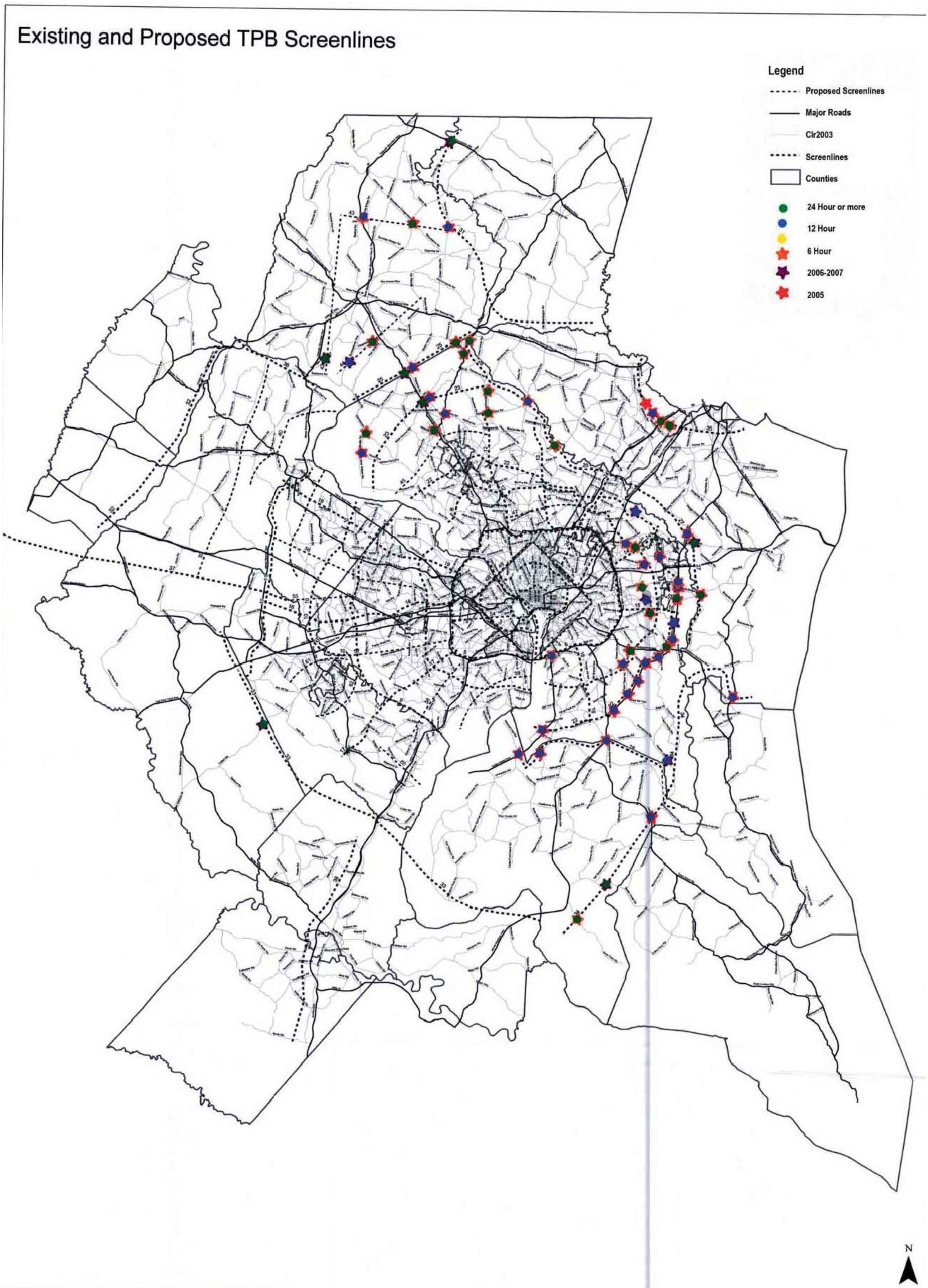

Figure 23: Outer Areas Traffic Count Inventory