pennsylvania
DEPARTMENT OF TRANSPORTATION

Freeway Ramp Management in Pennsylvania

FINAL REPORT

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16. Abstract

This research identified the opportunities to implement ramp management strategies on freeways in Pennsylvania. The research explored the need to integrate local arterial traffic signal systems with ramp management strategies to reduce the impacts of ramp management on local roadways. The report recommends a definition of freeway congestion and screening criteria for candidate ramp management freeways in Pennsylvania. In addition, a case study was performed for the I-376 tunnel bottleneck in the City of Pittsburgh to identify potential ramp management strategies, their impact on local roadways, mitigation strategies for local traffic signal systems and the relative benefits and costs of implementing such a project on I-376. Transportation planning and simulation models were used to evaluate travel pattern changes and measures of performance of the I-376 freeway with ramp management strategies in place.

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Executive Summary

Purpose of Research

Ramp management has gained acceptance in many area throughout the United States. The Federal Highway Administration (FHWA) and several State DOT's have developed ramp management systems that show positive benefits to reducing congestion on urban freeways. Their years of operational experience can benefit PennDOT in addressing urban freeway congestion throughout the Commonwealth.

Many of the urban freeway congestion and safety problems targeted by ramp management are found on urban freeways throughout Pennsylvania. These characteristics include insufficient ramp acceleration lane length, close spacing of ramps, and deficient mainline capacity during peak periods. Ramp management is a low cost, high benefit solution that can help alleviate localized and corridor congestion, improve safety, and improve travel perception and satisfaction. Ramp management is also a way to improve freeway operations while preserving the existing infrastructure. Communication among different agencies is a consequential benefit of ramp management, as communication plays a key role in effectively implementing ramp management strategies. A large part of the decision making process for ramp management implementation depends on the individual project context. Ramp management strategies are not necessarily right for every situation.

Past research provides little information on the coordination of freeway ramp management systems and arterial traffic signal management systems. One hypothesis of this research is that if these systems can be integrated, ramp management will have less of a negative impact on the operating characteristics on the local roadways resulting in greater acceptance by local municipalities.

FHWA has identified four ramp management strategies for freeway ramps: ramp closures, ramp metering, special use treatments, and ramp terminal treatments. For freeway entry ramps, the most common type of ramp management strategy is ramp metering. In some locations, ramp metering is combined with special use treatments for high occupancy vehicles (HOV) or transit vehicles. Ramp metering practices in various states were reviewed along with installation/operational/maintenance costs associated with ramp metering.

The purpose of this research was to determine the best practices available in ramp management that maybe used in Pennsylvania and to evaluate the feasibility and potentially design the concept of a ramp metering demonstration project in PennDOT District 11-0.

Findings - Defining Freeway Congestion in Pennsylvania

Based upon freeway congestion information provided by local PennDOT Districts and regional planning agencies (RPO's and MPO's), the use of a forecasted v/c ratio is recommended as a screening tool for freeway congestion. For this research, the forecasted v/c ratios were based upon 2030 or 2035 long range projections provided by the regional planning agencies. The forecasted v/c ratio was selected since it is well understood by traffic engineers and transportation planners. Using available information, with some adjustments, this measure of congestion can be applied uniformly statewide. The application of the recommended congestion criteria has identified 275 miles of congested freeways forecasted in Pennsylvania within the next 20-25 years.

With over 275 miles of congested freeway forecasted in Pennsylvania, capacity-adding projects can not be relied upon as the sole method of addressing congestion. As per the current MPO's long-range plans, approximately 62 lane-miles of the freeway are anticipated to be added (31 miles in each direction) by freeway capacity adding projects costing a total of $1.11 billion. This represents only 11% of the total freeway mileage identified as congested. Using the estimated costs for programmed projects, this approximates the capacity-adding cost to solve recurrent congestion at $17.9 million per lane mile (or $35.8 million per mile in both directions). Applying these costs to the remaining 244 miles of congested freeway segments would result in a total cost of $8.74 billion to solve recurring congestion freeway problems in Pennsylvania.

Recent studies, prepared by the State Transportation Advisory Commission in May 2010, identified numerous needs for funding projects to maintain existing infrastructure rather than capacity adding projects. In order to address freeway congestion issues in Pennsylvania the implementation of ramp management would be strategy that maximizes the use of existing infrastructure.

In addition PennDOT has adopted smart transportation principles which support the need to address freeway congestion through strategies such as ramp management. One principal of smart transportation states that "Choose projects with high value/price ratio". This research identifies the high benefit/cost ratios that can be expected with this type of management strategy.

Findings - Recommended Criteria for Freeway Ramp Management

A two-step approach is recommended to screen for potential freeway segments that could incorporate ramp management. The research of other state's practices indicates that a detailed warrant analysis is the tool typically used; however, because of the large number of congested freeway miles forecasted in Pennsylvania, an initial screening based upon freeway characteristics is recommended that measures the potential for the implementation of ramp management. The following summarizes the criteria used in the preliminary screening of congested freeways to identify candidate locations for ramp management.

- The long range (2030/2035) v/c ratio along the corridor
- The total number of interchanges along the corridor
- The spacing between freeway on-ramps
- The amount of coverage provided by PennDOT traffic cameras
- The number of reasonable alternate routes
- The approximate length of the freeway on-ramps

Once congested freeway segments are ranked through the high-level screening criteria, specific freeway segments can then be screened against a set of detailed criteria (called warrants in some states) to determine if specific ramp management strategies are applicable. The following types of localized screening criteria can be used for identified freeway segments:

OPERATIONAL SCREENING CRITERIA

- VOLUME CRITERIA
- DESIGN/SYSTEM CRITERIA

Findings - Ranking Candidate Freeways in Pennsylvania for Ramp Management

This initial screening has been applied to the 289 miles of freeway in Pennsylvania previously identified as congested. For future planning and programming purposes the detailed criteria should then be applied to initiate evaluations for the potential success of this congestion management tool. This recommended planning tool should enable Pennsylvania to identify, rank, and evaluate candidate locations for ramp management prior to expending resources for more detailed studies and construction.

Findings - I-376 Case Study for a Freeway Ramp Management Evaluation

A case study was developed for I-376 in Pittsburgh from Downtown Pittsburgh to Monroeville to evaluate the proposed ramp management criteria. Based upon a review of the ramp management criteria, I-376 in Pittsburgh has the appropriate volume and congestion levels to consider ramp management as an alternative solution to reducing congestion. An area-wide simulation model shows that a combination of ramp metering and ramp closure strategies would provide the most effective congestion reduction. With this congestion reduction, several local street routes will experience an increase in traffic; however, with selective traffic mitigation strategies, this congestion will be alleviated. This evaluation has demonstrated that ramp management techniques along the I-376 corridor can provide significant congestion reduction benefits, while having manageable impacts on the local street network. The PennDOT District 11-0 TMC is capable of expanding its current system to incorporate ramp management operations.

Findings – I-376 Benefit Cost Analysis

Based on the calculations and AASHTO “User and Non-User Benefit Analysis for Highways” methodology, all three ramp management options for I-376 were analyzed to determine the benefit/cost ratios. Three main user benefits were examined for each option: value of time, operating and ownership cost, and crash cost. Option 3 shows the highest benefit/cost ratio (58:1). Although Options 1 and 2 show higher annual benefits than Option 3, the capital and operating costs associated with Option 3 were much lower, making the benefit/cost ratio higher. Option 2 shows the second highest ratio (34:1) because although it has the highest capital cost, this option also shows the highest delay reduction per vehicle on I-376. This delay reduction directly relates to value of time savings, as well as ownership and operating cost savings. Option 1 shows a benefit/cost ratio of 12:1. Although this is not as high as the other options, it still shows the large benefits seen from delay reduction on I-376.

Research Recommendations

The results of this research have determined that Pennsylvania has a need to address freeway congestion. The locations and degree of congestion have been identified and a screening tool developed to identify candidate locations for ramp management strategies. It recommended that PennDOT explore the implementation of ramp management strategies through the programming process at the MPO level and then implement high value projects through the design and construction process. The pilot study of the I-376 congestion had identified a high benefit to cost ration for the investment of a ramp management project.

VIII. Future Research Needs

Based upon the results of this research additional studies are needed to further enhance the benefits of ramp management in the state of Pennsylvania. Specifically in the planning and design phases of implementation of projects additional research is needed in the following areas:

1. What is the optimum planning tools (software) to be used for the travel demand and simulation analysis?

2. What are the best communication and operation systems to jointly control a ramp management and local traffic signal network?

3. Develop a methodology to optimize the operation of both the freeway and the local roadway network for an algorithm that evaluates overall system performance and provides metering rates and traffic signal timing plans that can be varied based upon real time traffic conditions in the network.

Chapter 1
Research of Current Ramp Management Practices

Overview of Ramp Management

The Federal Highway Administration (FHWA) publication *The Freeway Management & Operations Handbook* September 2003 (updated June 2006) defines ramp management as "the application of control devices, such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives". This handbook has a chapter devoted entirely to ramp management and control, discussing ramp metering, ramp closures, special use treatments, and ramp terminal treatments. This reference generally describes how ramp management fits into the larger umbrella of overall freeway management, describes the current state of the practice regarding ramp management, and lists some implementation and operational considerations. Two case studies are also discussed.

Due to the increasing demand for information on ramp management strategies, the FHWA published the *Ramp Management and Control Handbook* in January 2006. The ramp management handbook expands on the ramp management material found in the *Freeway Management and Operations Handbook*, and is more comprehensive in scope. The handbook defines clearly what ramp management is, why it is important, and the basic goals and objectives of ramp management strategies.

According to the ramp management handbook, ramp management strategies balance freeway demand and capacity, improve safety, and optimize freeway performance by reducing incidents. Ramp management strategies can also be employed to give special treatment to a specific class of vehicles. The ramp management handbook stresses that these strategies are often integrated with the larger freeway management program in order to improve the efficiency and effectiveness of the system.

Many of today's freeway ramps do not operate under the conditions for which they were originally designed. According to the handbook, "Ramps are often too closely spaced, do not offer adequate acceleration distances for posted speeds, or are simply overwhelmed by the increasing number of motorists that use them on a daily basis." In many cases, these problems can be mitigated without major re-construction, through the implementation of ramp management strategies. This requires effective communication and collaboration between the many different agencies involved and the process of implementing these strategies can help break down the existing barriers between these agencies.

The main goals and objectives of ramp management, according to the *Ramp Management and Control Handbook*, involve the improvements of safety, mobility, quality of life, environmental effects, and motorist perceptions and satisfaction. The ramp management strategy must be justified by a set of needs relating to one of the preceding. The ramp management handbook stresses the importance of making sure that the objectives of the ramp management strategy are consistent with the regional transportation objectives, and that these objectives should fit in with the broader freeway management program.

Ramp Management Strategies

The publications issued by the FHWA discuss four ramp management strategies: ramp metering, ramp closure, special use treatments, and ramp terminal treatments. Both the

Freeway Management and Operations Handbook and the *Ramp Management and Control Handbook* devote sections to describing what each of these strategies entail and the related aspects that need to be considered.

Ramp metering “is the use of a traffic signal(s) deployed on a ramp to control the rate at which vehicles enter a facility.” If deployed correctly, ramp metering can improve the flow of traffic on the mainline, thereby addressing congestion. Safety concerns at specific points along the freeway can also be addressed. The related considerations for ramp metering include: metering strategy, geographic extent, metering approaches, metering algorithms, queue management, flow control, and signing.

Ramp closure “is the application of gates, barriers, or other physical means to temporarily or permanently restrict vehicle access to and from the entrance or exit ramp.” Ramp closure requires traffic to find alternate routes, which can have the greatest potential impact on the existing traffic patterns. This is usually not desirable, and is implemented only as a last resort for severe safety problems.

Special use treatments for ramp management “give special considerations to a vehicle class or classes to improve safety, improve traffic conditions, and/or encourage specific types of driving behavior.” These strategies can include an HOV bypass lane, exclusive HOV ramps, and ramps dedicated to construction, delivery, or emergency vehicles. It should be clarified that ramps dedicated for construction vehicles or emergency vehicles would only pertain to temporary conditions during construction, and existing and new ramps are not intended for this purpose. These types of ramp management strategies work best when coordinated with other supportive transportation programs.

Ramp terminal treatments “are solutions to specific problems that occur at the ramp/arterial intersection or have the potential to affect operations on the ramp, adjacent arterial, or freeway.” Some examples of these strategies include signal timing, ramp widening, turn lanes, additional storage on arterials, signing, and pavement markings. Typically, ramp terminal treatments deal with managing the queue that forms on the ramp, and reduce the spill back onto adjacent arterial or freeway facilities.

Benefits of Ramp Management

According to the FHWA’s publications on ramp management, the main issues that these strategies address are safety, mobility, environmental effects, traveler perception, and traveler satisfaction. The purpose of employing ramp management strategies is to improve one or more of these conditions.

The safety benefits observed for ramp management strategies include the reduction of sideswipe collisions (due to merging problems), rear end collisions (due to stop-and-go driving behavior), and lane change collisions. The *Ramp Management and Control Handbook* provides a summary of these observed benefits (on page 1-7), specific to ramp metering, and is provided below:

Table 1-1: Summary of Ramp Metering Safety Benefits[2]

Location	Benefit
Portland, OR	43% reduction in peak period collisions.
Minneapolis, MN	24% reduction in peak period collisions.
Seattle, WA	39% reduction in collision rate.
Denver, CO	50% reduction in rear-end and side-swipe collisions.
Detroit, MI	50% reduction in total collisions and 71% reduction in injury collisions.
Long Island, NY	15% reduction in collision rate.

The mobility benefits observed for ramp management strategies include increased travel speed, decreased average travel time, and decreased average delay. Under the right circumstances, these benefits can be achieved by managing the rate at which vehicles enter the freeway, based on the downstream capacity. On page 1-8, the *Ramp Management and Control Handbook* summarizes some of these benefits in the table provided below:

Table 1-2: Summary of Ramp Metering Mobility and Productivity Benefits[2]

Location	Benefit
Portland, OR	A 173% increase in average travel speed.
Minneapolis, MN	A 16% increase in average peak hour travel speed and a 25% increase in peak period volume.
Seattle, WA	A 52% reduction in average travel time and a 74% increase in traffic volume.
Denver, CO	A 57% increase in average peak period travel speed and a 37% decrease in average travel time.
Detroit, MI	An 8% increase in average travel speed and a 14% increase in traffic volume.
Long Island, NY	A 9% increase in average travel speed.

The environmental benefits observed for ramp management include the reduction in the amount of emissions released into the environment, increased fuel efficiency, and the reduction of noise levels and neighborhood impacts. The *Ramp Management and Control Handbook* describes a specific case study of the evaluation of ramp meters in Minneapolis that identified "a net annual saving of 1,160 tons of emissions."

The travel perception and satisfaction benefits observed for ramp management include qualitative measurements such as easing motorists' concerns, easing motorists' frustrations, and improving motorists' perception of regional transportation officials and agencies. The *Ramp Management and Control Handbook* states that "the results of the evaluation conducted in Minneapolis indicated that motorists generally thought conditions got worse after meters were turned off compared to when they were operational."

Potential Impacts of Ramp Management

Although ramp management strategies can impact the overall freeway transportation program positively, there are also some potential impacts that can hinder the success of the overall system. According to the FHWA publications, these potential impacts include diversion, queue spillback, equity, emissions on ramps, and public opposition.

Diversion occurs when a portion of the traffic finds alternate routes instead of waiting in the queues that form at ramp meters. This can cause increased traffic on arterials. Queue spillback can also cause congestion on adjacent arterials when the storage capacity of the ramp cannot accommodate the queues at the ramp meter.

The argument of equity arises because ramp management strategies are often seen to favor one group over another, i.e. although the mainline traffic sees less delay, the ramp traffic sees much more delay. This can also lead to public opposition.

Finally, although the emissions on the mainline may be reduced by ramp management strategies, this can also be partially offset by an increase in emissions from the queued ramp traffic.

Guidelines for Selecting Ramp Control

In 1981, the National Cooperative Highway Research Program published a report called *Guidelines for Selection of Ramp Control Systems*. That report describes the approach, methods, and the findings of their research. Appendix E of that report details the guidelines for the selection of ramp control systems, as determined by the research. Generally, these guidelines follow the process of defining an acceptable freeway level of service, then checking if the freeway under study fails this criterion. If so, the guidelines suggest considering the different alternatives, from demand-oriented to capacity-oriented. If ramp metering is desirable, the next step is to determine feasibility. If the strategy is determined to be feasible, the final step is to determine a specific control mode (pretimed, local actuated, or system control).

The pertinent information found in this 1981 report is also contained within the FHWA's 2006 *Ramp Management and Control Handbook*. The handbook expands on the guidelines of the National Cooperative Highway Research Program, and provides a series of flow-charts (page 6-4, 6-11, and 6-12) to aid in the selection process. These charts are provided on the following pages:

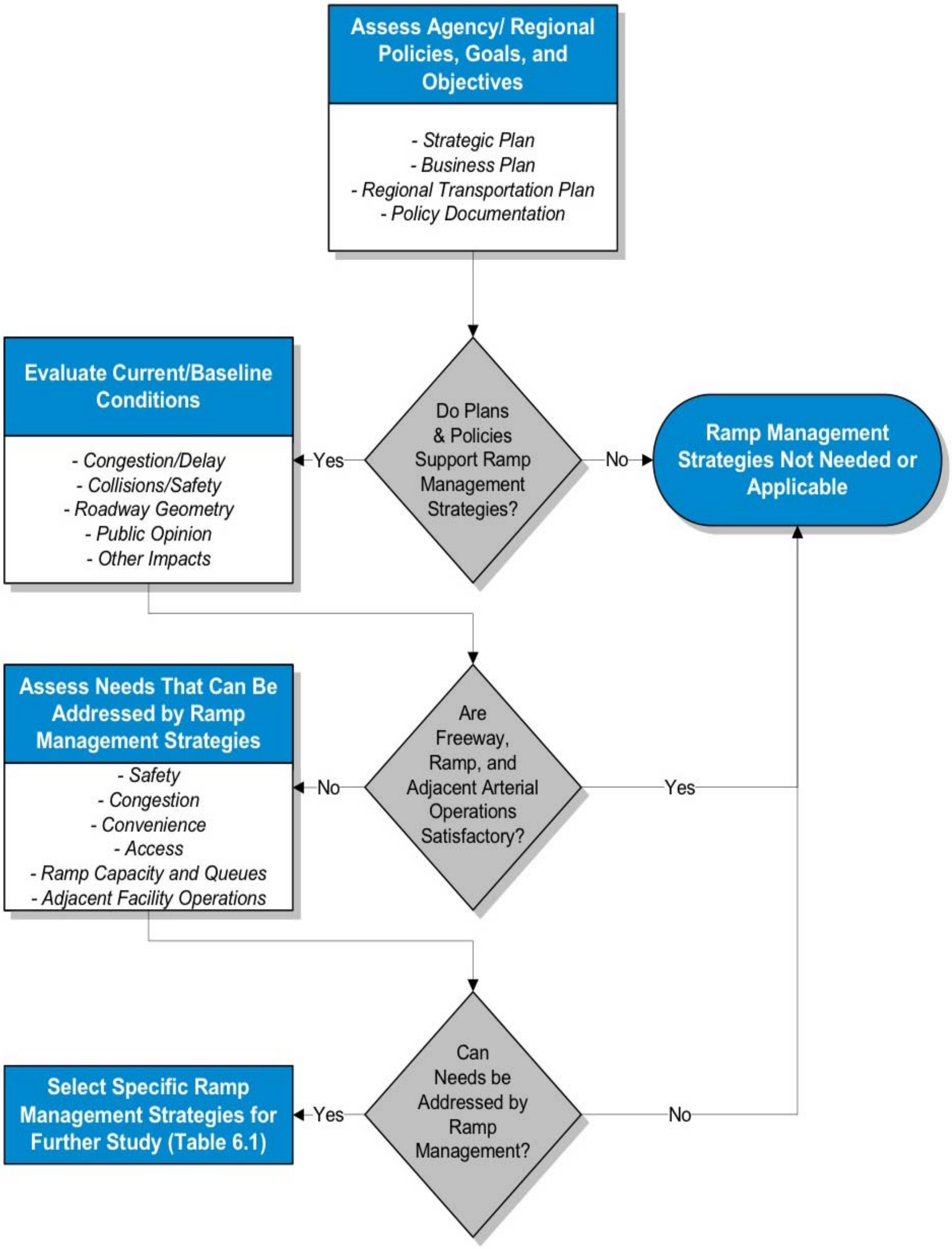


Figure 6-1: High-Level Screening for Ramp Management Strategies

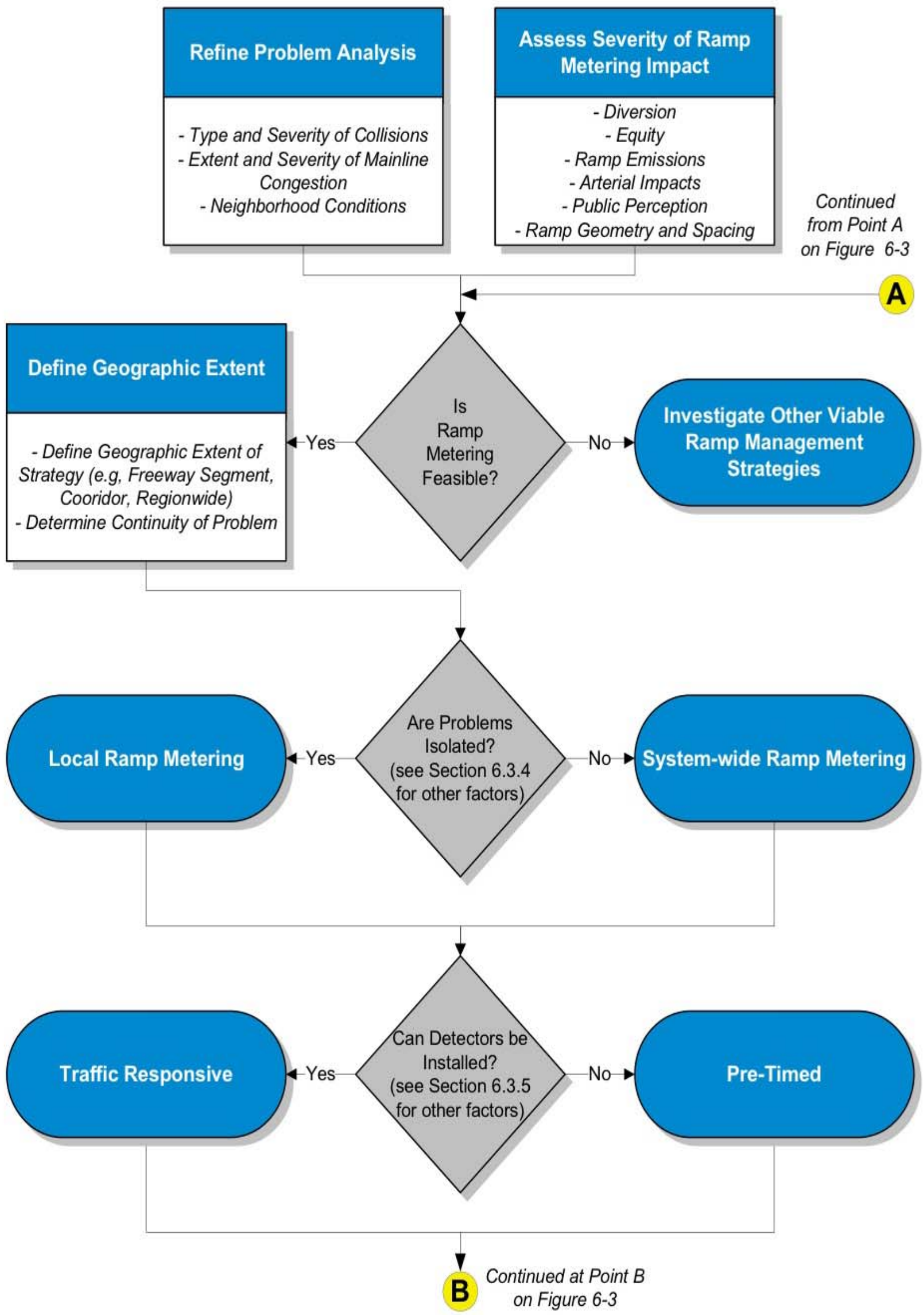


Figure 6-2: Ramp Meter Selection Decision Tree (1 of 2)

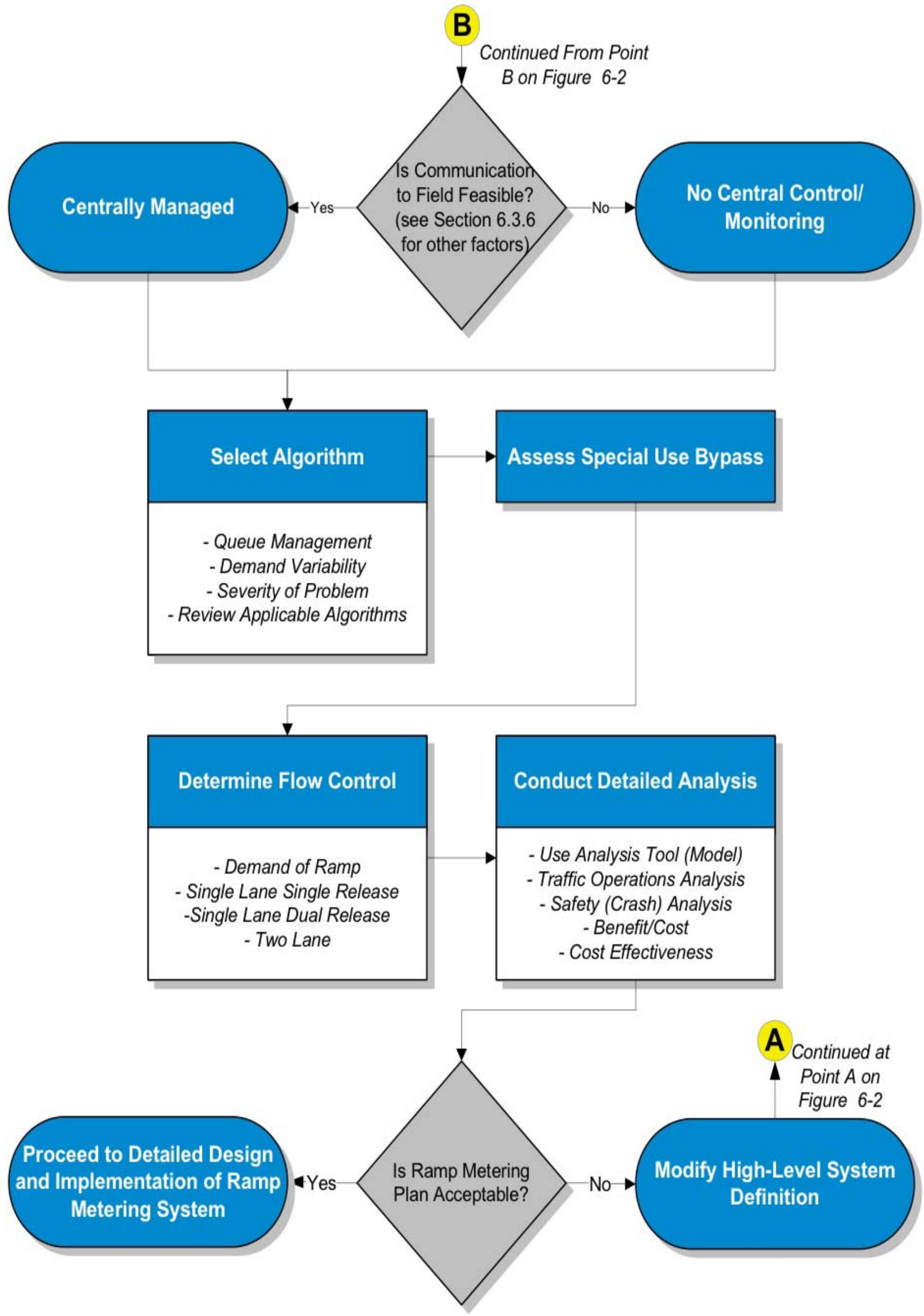


Figure 6-3: Ramp Meter Selection Decision Tree (2 of 2)

Integration of Traffic Management Centers and Arterial Signals

The topic of integrating ramp management with arterial signals and traffic management centers is briefly mentioned in the FHWA publications; however it is not discussed at length in any of the handbooks. The handbooks stress the importance of integrating the strategies into the overall traffic management program, but little detail is given on traffic management centers or arterial signals.

According to the FHWA's *Highway Traffic Operations and Freeway Management State-of-the-Practice Final Report* (March 2003), the current state-of-the-practice at that time was to "manage the freeway and arterial systems separately and to coordinate the operation through the operators of the two separate systems." Since then, there seems to have been a shift towards integrating the systems in some states. According to a contact at WSDOT, Seattle is set to launch an integrated corridor management project within the next year. WSDOT considers the ramp terminal signal a part of the freeway management system. This allows the state to maintain control of this signal, and provide interconnect between the ramp meter cabinet and the ramp terminal signal cabinet.

According to a contact at the Georgia Department of Transportation (GDOT), the ramp meters within the state are not coordinated with the arterial traffic signals. The local jurisdictions operate and maintain the signals at the entrance and exit ramp intersections. However, when problems arise due to the ramp meter, GDOT assists the local jurisdiction with traffic signal timing around the ramp meter area. The Atlanta traffic management center (TMC) is primarily a freeway management system with less emphasis on the arterial streets.

Recent Research (2006-2008)

The *Ramp Management and Control Handbook* is the most comprehensive source on all ramp management information up until 2006. After 2006, the *Transportation Research Record Journal* published two editions relating to ramp management. Edition 2012, "Freeway Operations and High Occupancy Vehicle Systems" was published in 2007, and edition 2047, "Freeway Operations" was published in 2008.

Transportation Research Record Journal Number 2012 contains papers that cover the following ramp management topics: traffic diversion effects of ramp metering, the benefits of system wide adaptive ramp metering strategies in Portland, OR, ramp metering on merging operations, and ramp queue size estimation algorithms.

Transportation Research Record Journal Number 2047 contains papers that cover the following ramp management topics: traffic signal operation policies for ramp metering and methodologies for estimating ramp vehicle queue length.

Kittelson & Associates, Inc. prepared *A Synthesis of Ramp Metering Practices* for the Maryland State Highway Administration in October of 2007. This report documents the benefits and impacts of ramp meters, the development of a ramp metering strategy, the geometric design features, a summary of current practices, and public campaign strategies. Much of the information found in this report is taken from the *Ramp Management and Control Handbook.* This report also references reports from different states DOT's for information on ramp metering studies, current metering algorithms, and current geometric standards. A large focus of this report is technical in nature, and focuses on some of the actual design procedures for ramp management.

There are other recent engineering papers and journals that cover technical aspects of ramp metering, such as specific algorithms and cell transmission models; however those papers were not included in this literature review due to the lack of application to this specific project.

Relevant Case Studies

A. *Minnesota*

According to the case studies found in the *Ramp Management and Control Handbook*, the Minnesota Department of Transportation (Mn/DOT) operates one of the nation's most extensive ramp metering system in the Minneapolis/St. Paul region. This system uses over 430 ramp meters (to be reduced to 350 ramp meters by 2008) to control corridor and regional traffic. The metering algorithms used in this system are some of the nation's most restrictive.

The Minneapolis/St. Paul ramp metering system was turned off for a six-week period in 2000, in order to evaluate the effects of the ramp metering system on the overall transportation system. Certain performance measures were used to compare conditions with the meters turned on versus conditions with the meters turned off. In general, the study revealed that throughput decreased, travel times increased, travel time reliability decreased, and safety decreased when the meters were turned off. A benefit/cost analysis also revealed that the benefits of the ramp metering system outweighed the costs 15 to 1. Finally, survey and focus group efforts revealed that the majority of the Twin Cities' residents supported the use of ramp metering.

B. *Wisconsin*

According to the case studies found in the *Ramp Management and Control Handbook*, the Wisconsin Department of Transportation (WisDOT) deployed ramp meters at three interchange locations in the Madison region. The purpose of these ramp meters was to mitigate safety and congestion problems in a smaller metropolitan area. The system consists of five total on-ramps along a four-mile section of a beltline corridor.

C. *Washington State*

According to the case studies found in the *Ramp Management and Control Handbook*, the Washington State Department of Transportation (WSDOT) operates a mid-sized ramp metering system in the Seattle region. This system focuses on several high-priority corridors, and plans include expansion of metering to additional locations.

WSDOT used an extensive outreach and public information campaign to relay information about the ramp management system to the public.

According to a contact at WSDOT, the Seattle area will be launching an integrated corridor management project within the next year.

D. *California*

According to the case studies found in the *Ramp Management and Control Handbook*, the California Department of Transportation (Caltrans) developed a systematic and integrated deployment strategy for their transportation management system (TMS) in 2002. This plan incorporates ramp metering into a coordinated operational strategy.

California's system includes over 1,000 ramp meters statewide (to be expanded to over 1,400 locations by 2008), along approximately 70% of urban freeway miles. The goal of this ramp metering system is to improve the safety and capacity in the freeway merge areas.

E. *Georgia*

According to a contact at the Georgia Department of Transportation (GDOT), the ramp meters within the state are not coordinated with the arterial traffic signals. The local jurisdictions operate and maintain the signals at the entrance and exit ramp intersections. However, when problems arise due to the ramp meter, GDOT assists the local jurisdiction with traffic signal timing around the ramp meter area. The Atlanta traffic management center (TMC) is primarily a freeway management system with less emphasis on the arterial streets.

F. *Virginia*

According to the case studies found in *A Synthesis of Ramp Metering Practices*, the Virginia Department of Transportation operates 26 meters in the Washington D.C. area, which run from the Smart Traffic Center. It is a centralized, coordinated scheme with meter rates that are updated every one minute.

G. *Arizona*

According to the case studies found in *A Synthesis of Ramp Metering Practices*, the Arizona Department of Transportation (ADOT) operates approximately 121 meters in the Phoenix metropolitan area. The majority of these meters is centrally controlled and operates under fixed timing. However, these meters are capable of adapting to traffic patterns.

H. *Oregon*

According to the case studies found in *A Synthesis of Ramp Metering Practices*, the Oregon Department of Transportation (ODOT) operates more than 140 ramp meters in the Portland area.

I. *Texas*

According to the case studies found in *A Synthesis of Ramp Metering Practices*, the Texas Department of Transportation (TXDOT) installed 106 centralized-computer-controlled ramp meters in Houston in 1996. In 2000, Houston had close to 160 ramp meters.

J. <u>*Other Locations*</u>

According to information found in *A Synthesis of Ramp Metering Practices*, the following locations have known ramp metering systems: Denver, Colorado; Detroit, Michigan; Long Island, New York; Great Britain; and Zoetemeer, Netherlands.

Summary and Conclusion

Based upon this review of the current practice it can be concluded that ramp management has gained acceptance in many states and urban areas in the country. The FHWA and individual state DOTs have developed systems that show major benefit to the urban freeway systems. Their years of operational experience can benefit Pennsylvania's urban freeway system.

Many of the congestion and safety problems exhibited by urban freeways, which can be solved by ramp management, are found in the urban freeway systems of Pennsylvania. These characteristics include insufficient ramp acceleration lane length; close spacing of ramps and deficient mainline capacity during peak periods. The practice review will aid in identify freeways in Pennsylvania that can benefit from ramp management as a strategy to reduce congestion and improve safety.

PennDOT has recently developed the "Smart Transportation" program, in which 10 major themes and objectives are identified. These themes are: money counts, leverage and preserve existing investments, choose projects with high value/price ratio, safety always and maybe safety only, look beyond level-of-service, accommodate all modes of travel, enhance local network, build towns not sprawl, understand the context - plan and design within the context, and develop local governments as strong land use partners.

Ramp metering is a low cost benefit that can help alleviate localized and corridor congestion, improve safety, improve travel perception, and traveler satisfaction. Ramp metering is also a way to improve freeway operations, while preserving the existing infrastructure. Communication among different agencies is a consequential benefit of ramp metering, as communication plays a key role in effectively implementing ramp management strategies. A large part of the decision making process for ramp management strategies depends on the individual project context. Ramp metering strategies are not necessarily right for every situation, therefore a large part of this research will be to identifying the specific contexts in which the strategies might be appropriate in Pennsylvania. These ideals are all consistent with the principles of the PennDOT "Smart Transportation" program.

There appears to be little information on the coordination of freeway and arterial traffic signal management systems. One hypothesis of this research is that if these systems can be integrated ramp management will provide improved operating characteristics on local roadways resulting in greater acceptance by local municipalities.

Chapter 2
Summary of Current Ramp Management State Practices

Five states were selected to evaluation of their ramp management practices. These states were selected because of either their long history with installing or operating management systems or their utilization of the latest technologies and planning systems to implement newer installations. Other states were also contacted for recent cost data for capital and operating costs.

Minneapolis/St. Paul Minnesota

Number of ramp meters	408
Ramp metering types	Arterial-Freeway; Freeway-Freeway
Annual operating/maintenance costs	$2.6 million
Recent capital costs	$100,000 (12 new meters) (2008) does not include communication costs

Ramp meters were initially installed in St. Paul along I-35E in 1970. The meters were initially installed on a fixed time basis, but were quickly upgraded to operate on a traffic responsive basis. Today there are 408 ramp meters operating in the metro area. While most ramp meters are deployed at ramps connecting local/arterial streets to freeways, some ramp meters are employed in freeway to freeway junctions. The ramp meters are just one of many tools used to manage congestion in the Minneapolis/St. Paul area. In addition to ramp meters, the regional traffic management center includes 350 cameras, over 4,000 loop detectors, 95 changeable message signs, a 511 traveler information hotline, freeway incident response patrols, HOV lanes, and a highway advisory radio station. Some ramps that are metered have HOV bypass lanes.

A system-wide ramp metering evaluation study was performed in 2000 at the direction of the state legislature. The ramp meters in the Minneapolis/St. Paul area were turned off for 6 weeks to evaluate traffic flow along the freeway system with and without ramp meters in operation. The results were strongly in favor of ramp metering. Several performance measures were used to evaluate the ramp metering system.

Traffic Volumes – Traffic volumes on the mainline freeway decreased by 9% and there was no appreciable change in the volumes on the parallel arterials when the meters were shut down.

Travel Time – Freeway speeds were reduced by 14% (7.4 mph) when the meters were shut down. There was no appreciable change in travel times on the parallel arterials observed when the meters were shut down.

Travel Time Reliability – Travel times were nearly twice as unpredictable when the meters were shut down.

Safety – Freeway/ramp crashes increased by 26% when the meters were shut down.

Market Research – Marketing research revealed that the majority of residents supported the ramp metering system; however, they also supported changes to the system that would reduce the wait times in ramp queues. Of note, traveler's perceived ramp wait times were twice as long as the actual observed wait times.

Minneapolis uses the Minnesota zone algorithm to meter traffic. This algorithm was developed in 2001 in an attempt to balance traffic volumes entering and exiting predetermined metering zones to maintain a consistent flow of traffic from one zone to another. The new algorithm employs a stratified zone metering concept whereby zones of varying length are layered over one another. Higher-level layers feature larger zones with greater overlap among zones. The maximum wait time is 4 minutes on a local access ramp and 2 minutes on a freeway to freeway ramp. Queues cannot back onto local streets. The meters are traffic responsive and only operate when needed.

The Minnesota ramp meters rely heavily on loop detection. There are over 4,000 loop detectors in the system spaced approximately every ½ mile on the freeway and at every exit and entrance ramp. Data is collected every 30 seconds and ramp metering rates are updated every 30 seconds.

Ramp that warrant metering typically have the following characteristics:

- Peak period speeds less than 30mph
- Vehicle flows between 1,200 and 1,500 vphpl
- High accident rates
- Significant merging problems

Minnesota has just recently added 12 new ramp meters. The cost for this project was approximately $100,000 but the freeway was already instrumented with detection, fiber, and cameras. The DOT estimates that the overall congestion management system saves approximately $40 million annually in terms of reduced congestion. The annual cost to operate regional traffic management center is $7.88 million, of which $2.6 million is attributed to the ramp meters. This corresponds to an overall benefit/cost ratio of 5:1 for the ramp metering portion of the congestion management system.

Overall, Mn/DOT is satisfied with their ramp metering system. Public and political perceptions regarding the effectiveness of ramp metering were positively addressed as part of an overall system-wide study in 2000. The results of the 2000 study prompted an immediate expansion of the system, which continues today.

Wisconsin

Number of ramp meters	130
Ramp metering types	Arterial-Freeway; Freeway-Freeway
Annual maintenance costs	$900 per ramp not including utilities
Recent capital costs	$75,000 for single lane; $100,000 for three lane ramp; ramp meters costs $5,000 per lane mile to implement. (Pre-2004)

WisDOT operates ramp meters during peak travel periods in the urban areas of Milwaukee (126 ramp meters) and Madison (4 ramp meters). One metering location is at the freeway junction of I-94 and US 41, where the 4 ramps of US 41 are metered onto I-94. Most ramp meters are traffic responsive. The metering rates are set based upon the volume, speed, and occupancy of the mainline traffic. Loop detectors are the most common method of detection; however, microwave detectors are becoming more common throughout the system. HOV bypass lanes are incorporated in Wisconsin to encourage carpooling and mass transit use. While very few ramp meters have been installed in the past 5 years, WisDOT remains committed to the ramp metering system and the ramp meters remain an integral part of the freeway management system.

There is no coordination between the ramp meters and the adjacent arterials. The ramp meters include queue override detectors. These loops are placed at the beginning of the on-ramp. If vehicles queue to the queue detector, then the ramp metering rate automatically switches to the fastest metering rate to prevent the queue from spilling back onto the arterial.

WisDOT estimates that the annual maintenance costs are $900 per ramp meter. This cost does not include power. WisDOT does not have any recent installation costs since their system has not undergone a major expansion in the past 5 years. However, previous costs of $75,000 for a one lane ramp meter and $100,000 for a three lane ramp meter were provided by WisDOT. Cost comparisons from early 2000 indicate that a new lane mile of freeway costs $8 million, while ramp metering costs $5,000 per lane mile to implement.

Wisconsin Guide for Ramp Meters

1. Mainline volumes of at least 1200 vehicles per hour per lane

2. Ramp volumes of at least 240 vehicles per hour for a one lane ramp, and 400 vehicles per hour for a two lane ramp

3. Mainline speeds of less than 30 mph in the peak hour

4. Accident rate in the vicinity of the ramp in excess of 80 per hundred million vehicle miles

5. Are two of the four traffic criteria met for at least 50% of the corridor?

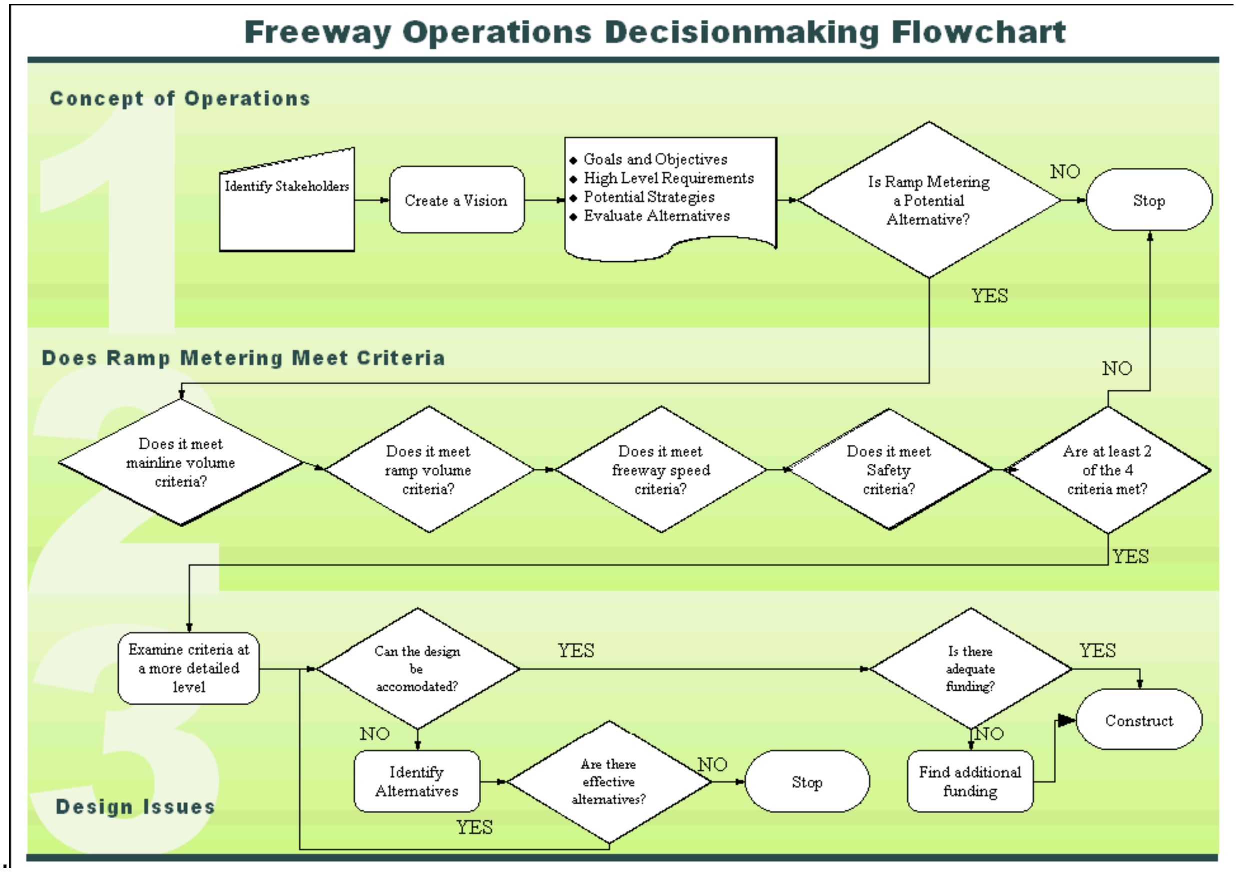
6. Storage length of at least 450 feet (Use formula or graph for individual ramp calculations.) 450 feet is for 240 vehicles per hour on a one lane ramp

7. Acceleration distance of at least 1000 feet (Use formula or graph for individual ramp calculations.)1000 feet is for 55mph merge speed on level grade.

8. Stop bar distance of at least 245 feet (Use formula for individual ramp calculations.) 245 feet is minimum recommended by AASHTO

9. Foot print for ramp metering equipment is minimal (less than 100 square feet)

10. Frontage road/alternate route must be somewhat available in the corridor


Freeway Operations Decisionmaking Flowchart
Concept of Operations
Identify Stakeholders
Create a Vision
Goals and Objectives
High Level Requirements
Potential Strategies
Evaluate Alternatives
Is Ramp Metering a Potential Alternative?
NO
Stop
YES
Does Ramp Metering Meet Criteria
NO
Does it meet mainline volume criteria?
Does it meet ramp volume criteria?
Does it meet freeway speed criteria?
Does it meet Safety criteria?
Are at least 2 of the 4 criteria met?
YES
Examine criteria at a more detailed level
Can the design be accomodated?
YES
Is there adequate funding?
YES
Construct
NO
NO
Identify Alternatives
Are there effective alternatives?
NO
Stop
Find additional funding
YES
Design Issues

Once ramp metering has been approved for installation by WisDOT, the following design procedures are used to implement ramp metering

.

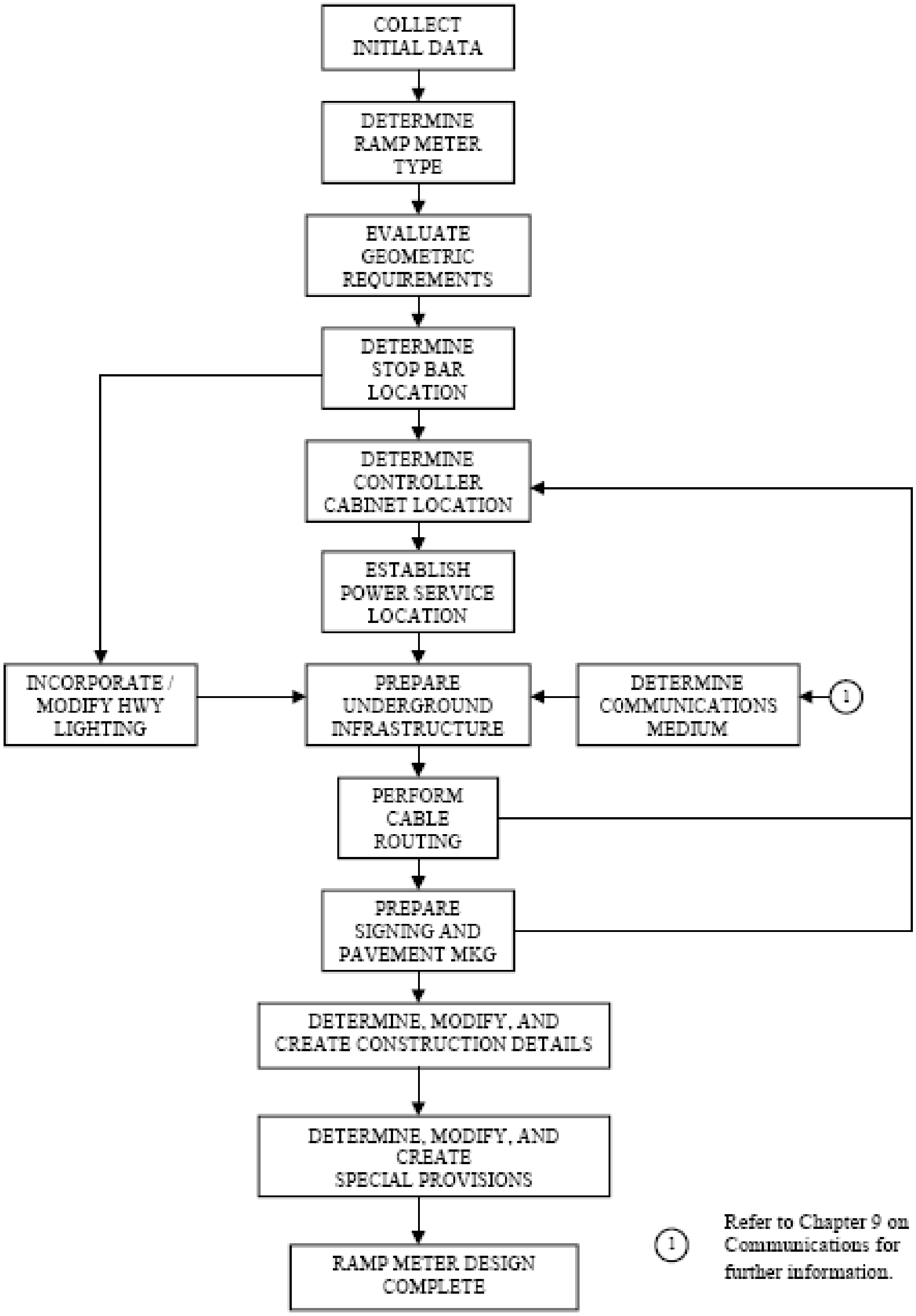


Figure 3-1: Ramp Meter Design Process

Georgia

Number of ramp meters	168 by end of 2009
Ramp metering types	Arterial-Freeway
Recent capital costs	$125,000 per meter (2008) includes design/installation

Georgia began with 4 ramp meters in 1996 as a pilot project. The first four ramps were low-volume ramps that GDOT felt would have a high probably of success and a low probability of ramp spillback onto the arterials. In 2005, 4 additional ramp meters were deployed in downtown Atlanta, which involved ramps with much higher volumes and dual-lane entries. Post-evaluation studies showed a 22% increase in peak hour freeway speeds. In 2006, design began on the installation of 160 ramp meters, of which 101 are currently active. The remaining 59 meters are to be activated in the spring of 2009.

Ramp meters are only used on those freeways experiencing recurring congestion. There are a number of situations that are not considered for ramp metering: freeway to freeway ramps, ramps with very short lengths, slip ramps from frontage roads, and ramps from collector-distributor roads. The ramps meters are installed on a mixture of single lane and dual lane ramps. Stop bar locations are chosen to maintain Green Book acceleration distances, which causes some stop bars to be close to the top of the ramp. There is no coordination between the ramp meters and the arterial traffic signal systems. Most signals are operated by other agencies.

The Atlanta system is currently undergoing a major expansion due to the success of the original 8 installations. Annual operating costs are not available. Costs for the current system expansion average $125,000 per meter, which includes both design and construction of the ramp meters.

New York (INFORM – Long Island)

Number of ramp meters	77
Ramp metering types	Arterial-Freeway
Annual operating/maintenance costs	$2,200 per meter
Recent capital costs	$75,000 per ramp (2002)

The INFORM system on Long Island covers a 60 mile long corridor centered around I-495, the Long Island Expressway (LIE). Also included in the system are the Grand Central Parkway/Northern State Parkway and the Southern State Parkway. Within this system, there are 77 metered entrance ramps, 192 cameras, 3500 vehicle detectors, 185 variable message signs, and 1,080 arterial traffic signals. Most metered ramps are single lanes, with the exception of seven HOV dual lane bypass ramps on the LIE. A traffic management center is in continuous operation monitoring the system.

The original ramp metering system attempted to run a traffic responsive strategy; however, this evolved to be a continually metered time of day system for westbound traffic (towards New York City) in the AM and eastbound traffic (from New York City) in the PM. Due to heavy reverse flow in the afternoon hours, the westbound ramps were eventually added to the PM metering period. The ramp meters run on a time of day schedule that can be changed remotely from the traffic management center or manually at the controller.

Metering rates are set to the maximum 900 vehicles per hour per lane. When long queues occur, queue detectors automatically shut down the meter. If a meter shuts down because of excessive queuing, the meter will remain off for the duration of the metering period. This prevents interference of the ramp metering operation with arterial traffic. Beyond the time of day operation of the ramp meters and the adjacent arterial signals, there is no special coordination between the ramp meters and the arterials.

Maintenance costs for the INFORM ramp meters average $2,200 per location. Capital costs for new installations are becoming dated. The most recent installation occurring in 2002, at which time a new ramp meter cost $75,000. Separate costs for integration into the communication system vary widely by location and were not provided.

INFORM has expanded ramp metering on Long Island to include the majority of the freeway system approaching New York City. NYSDOT is satisfied with the ramp meters and maintains them as an integral part of the overall INFORM traffic management system.

Ohio

Location of ramp meters	Columbus – 25 ramp meters Cincinnati – 4 ramp meters
Ramp metering types	Arterial-Freeway
Annual operating/maintenance costs	not available
Recent capital costs	to be provided as they become available

The ODOT Ramp Meter Design Handbook states that ramp metering usage should strive to improve the conditions on the freeway while minimizing any impact on the ramps and arterial streets. Ramp metering should improve the entire system not just the main intersections. Improving one area of the system to sacrifice another is not acceptable. The objectives of the entire system should be reflected in the ramp metering strategies. One strategy will not satisfy all the goals and objectives of the many systems throughout the state of Ohio.

Ramp meters have been successfully deployed in the Columbus area for a number of years. They are a proven congestion management tool and Ohio has recently expanded its ramp metering system. Columbus added 7 ramp meters in 2005/2006 and ramp meters were introduced in Cincinnati within the past year.

Ohio employs a formal warrant system to evaluate ramp meter installations. These warrants have been adapted from those developed by the Arizona DOT.

Individual Warrants for Ramp Metering

The following are the individual warrants that are used to determine if ramp metering is warranted for a particular ramp. The results of these individual warrants are analyzed by the overall warrant process to determine if ramp metering is warranted at a particular ramp location.

Warrant One – Recurring Congestion Warrant

Does the freeway operate at speeds less than 50 mph for duration of at least 30 minutes for 200 or more calendar days per year?

Warrant Two – Collision History Pattern

Is there a high frequency of crashes (collision rate along the freeway exceeds mean collision rate in the subject metropolitan area) near the freeway entrances because of inadequate merge area and congestion?

Warrant Three – Freeway Level of Service

Will the ramp meter or system of ramp meters contribute to maintaining a specific level of service (LOS) identified in the region's transportation system management (TSM) plan?

Warrant Four – Modal Shift

Not applicable to Ohio, ignore.

Warrant Five – Redistribution of Access

Will the ramp meter or system of ramp meters contribute to balancing demand and capacity at a system of adjacent ramps entering the same facility?

Warrant Six – Sporadic Congestion Warrant

Does the ramp meter or system of ramp meters mitigate predictable sporadic congestion on isolated sections of freeway because of short peak period loads from special events or from severe peak loads of recreational traffic?

Warrant Seven - Total Volume Warrant

Number of Mainline Lanes in One Direction including Auxiliary Lanes that Continue at least 1/3 Mile downstream from Ramp Gore	Criteria Volume Ramp Plus Mainline Volume Downstream of Gore (total vph)
2	2,650
3	4,250
4	5,850
5	7,450
6	9,050

This warrant is met when the criteria in the table is satisfied. Is the ramp plus mainline volume greater than the tabulated criteria for the design hour?

Warrant Eight - Right Lane plus Ramp Volume Warrant

Ramp metering is warranted when the volume of the ramp plus the mainline right lane exceeds 2,100 vph. Is the criteria defined above met, during the design hour?

Warrant Nine - Geometric Warrant

Does the existing or proposed ramp geometry permit safe and effective ramp metering? At some locations, steep inclines on a ramp may warrant against implementing ramp metering at that location. Available lane widths may also be inadequate for metering.

Follow the steps below to determine whether ramp metering is warranted.

1. Are any of Warrants One, Two, Three, Four, Five, or Six satisfied? If yes to any, go to Step 2. If no to all, STOP – ramp metering is not warranted.

2. Are either Warrants Seven or Eight satisfied? If yes to either, go to Step 3. If no to both, STOP – ramp metering is not warranted.

3. An exception to the two previous criteria is that ramp metering may be warranted solely due to current or anticipated high collision rates at a location. Therefore, in some cases at the discretion of ODOT, if Warrant 2 is satisfied, ramp metering can be warranted even if Warrants Seven and Eight are both not satisfied.

4. Is Warrant Nine satisfied? If yes, ramp metering is warranted. If no, STOP – ramp metering is not warranted.

Installation and Maintenance Costs

Funding is a key aspect of implementing a successful ramp metering system. Information provided by the five states contacted for this evaluation indicates that it is difficult to compare installation costs between agencies because each includes different items with their estimates. For example, some costs consider communication infrastructure as a separate ITS entity from the ramp metering.

While the incremental cost of installing metering hardware may be $10,000 per location, the cost jumps to $30,000-$50,000 when communication costs are included. Costs reported for Long Island include communications and are consistent with installation costs in Phoenix which averaged upwards of $90,000 for an isolated installation. Note that these costs are based upon historical data found in referenced reports and some of the data are over 5 years old.

Maintenance costs are consistent between agencies and all did not include utilities in these costs. Average maintenance costs range between $2,000-$3,000 per meter.

Operational costs for the ramp meters are typically included in the overall traffic management center operational costs and are difficult to break out for most agencies since their traffic management centers also include video cameras, VMS, HAR, and incident management patrols. Studies have attempted to determine operating costs for ramp meters in terms of staffing needs. Staffing costs associated with ramp meters typically include some start up cost (approximately $1,250 per meter) and an annual operating cost of approximately $2,800 per meter. Studies report staffing requirements for ramp meters at one staff person for every 72 ramp meters in operation.

Average Installation and Maintenance Cost
(items included in costs vary by agency – some costs reported are over 5 years old)

City	Average Installation	Cost Average Maintenance Cost (yr)
Phoenix	$50,000 to $90,000	$2,000 to $3,000
Caltrans (statewide)	Varies	$3,000
Detroit	N/A	$2,500
Northern Virginia	$10,000 to $15,000	$5,000
Seattle	$30,000 to $50,000	$3,000
Minneapolis	$10,000	$1,000
Milwaukee	$75,000	$900
Atlanta	$125,000 (includes engineering)	N/A
Long Island	$75,000	$2,200

(note some installation costs include communication upgrades while other report such costs separately)

Summary and Conclusions

The information gathered from Minnesota, Wisconsin, Georgia, New York and Ohio was reviewed to determine the latest techniques utilized for ramp management to be used as a viable strategy to address freeway congestion. This information has been utilized to determine what maybe an appropriate methodology for Pennsylvania. In addition, data gathered from these and other states on current capital and operating costs is also being used in this research to estimate project costs.

Chapter 3
Identification of Freeways in Pennsylvania with Recurring Congestion

In order to assess Pennsylvania's current freeway congestion problems, as well as to identify potential candidate locations for ramp management, information was requested from all PennDOT districts and all Pennsylvania MPO's/RPO's. The information requested included current locations/descriptions of freeway congestion, the existing congestion management process (CMP), current ramp management strategies, and future planned projects addressing freeway congestion.

Freeway congestion in Pennsylvania is only one type of congestion that was recently identified as a priority by PennDOT. The Pennsylvania Transportation Advisory Committee recently released the report "Congestion Mitigation and Smart Transportation" in May 2009. This report has quantified the statewide problem of growing congestion and costs to the public that are significant.

The congestion mitigation process recommends a strategy that plans, implements, and monitors congestion in Pennsylvania. Ramp management has been identified in this report as an important strategy to be considered to mitigate congestion. Along with road pricing, corridor management and real time travel information systems, ramp management was determined to be a strategy which brings supply and demand into alignment. The report also recommends that statewide direction on congested corridors be provided by PennDOT. This research provides a first step to providing a statewide measure of freeway congestion. Finally the report identifies ramp management as a congestion mitigation approach that minimizes cost and maximizes benefits.

Summary of Responses from PennDOT Districts and Planning Organizations

PennDOT 1-0 (Erie County Planning Department, Northwest Pennsylvania Regional Planning Commission, & Mercer County Regional Planning Commission)

The PennDOT District 1-0 traffic engineer indicated that there are no congested freeways in District 1-0. Design elements are routinely considered to ensure that ramp traffic does not back onto limited access freeways.

PennDOT 2-0 (North Central Regional Planning Commission, SEDA-COG, Centre Regional Planning Commission)

SEDA-COG identified several ramps that experience sporadic congestion and queuing problems; however, no freeway segments were identified as experiencing recurring congestion. District 2 did not officially respond; however, informal discussions with staff indicate that there is no recurring congestion on any limited access freeways in District 2-0.

PennDOT 3-0 (Northern Tier Regional Planning Commission, Lycoming County Planning Commission, SEDA-COG)

The PennDOT District 3-0 traffic engineer indicated that there are no congested freeways in the district.

PennDOT 4-0 (Northern Tier Regional Planning Commission, Lackawanna/Luzerne MPO, Northeastern Pennsylvania Alliance)

No response was received from PennDOT 4-0 or the MPO. Calculations performed by the PennDOT Bureau of Planning and Research were utilized to identify congested freeway segments (using v/c ratios). There are congested freeway segments along I-81 and PA 309.

PennDOT 5-0 (Northeastern Pennsylvania Alliance, Lehigh Valley Planning Commission, Berks County Planning Commission)

A joint meeting was held with PennDOT 5-0 and the Lehigh Valley Planning Commission. Also, a response was received from the Berks County Planning Commission. Their responses are provided in Section II of this report.

PennDOT 6-0 (Delaware Valley Regional Planning Commission)

A meeting was held with the Delaware Valley Regional Planning Commission. Their response is provided in Section II of this report.

PennDOT 8-0 (Tri-County Regional Planning Commission, Lebanon County Planning Department, Lancaster County Planning Commission, York County Planning Commission, Adams County Planning Department, Franklin County Planning Commission)

A meeting was held with the Tri-County Regional Planning Commission. Their response is provided in Section II of this report. Also, information from the Lancaster County Planning Commission and the York County Planning Commission was obtained from their respective websites.

PennDOT 9-0 (Cambria County Planning Commission, Blair County Planning Commission, Southern Alleghenies Regional Planning Commission)

Cambria County Planning Commission

The Cambria County Planning Commission indicated that they have no limited access freeways with recurring congestion.

Blair County Planning Commission

The Blair County Planning Commission indicated that they have no limited access freeways with recurring congestion.

PennDOT 10-0 (Northwest Pennsylvania Regional Planning Commission, North Central Regional Planning Commission, Southwestern Pennsylvania Commission)

A representative from PennDOT 10-0 Traffic Unit indicated that there were no freeways with recurring congestion in District 10-0. They recommended reviewing the SPC Congestion Management Process (CMP) for more information. No congested limited access interstate/freeway corridors are located in District 10-0. However, the SPC 2035 model does identify a segment of I-79 from the Allegheny County line to Exit 78 (Route 228) that will be congested by 2035. A small portion of this segment of I-79 is in District 10-0.

PennDOT 11-0 (Southwestern Pennsylvania Commission)

PennDOT 11-0 provided a list of congested freeway segments. A meeting was held with the Southwestern Pennsylvania Commission. Their response is provided in Section II of this report.

PennDOT 12-0 (Southwestern Pennsylvania Commission)

PennDOT 12-0 referred us to the SPC CMP for more information. No congested limited access interstate/freeway corridors are located in District 12-0. However, the SPC 2035 model does identify two interstate segments that will be congested by 2035:

- I-79 from Exit 41 (Racetrack Road) to the Allegheny County line
- I-70 Exit 17 to Exit 18 (I-79)

District/MPO Responses Regarding Freeway Congestion

PennDOT 5-0 (Northeastern Pennsylvania Alliance, Lehigh Valley Planning Commission, Berks County Planning Commission)

PennDOT 5-0/Lehigh Valley Planning Commission

The research team attended a joint meeting with PennDOT 5-0 and the Lehigh Valley Planning Commission. District 5-0 has the distinction of installing the first ramp meters in Pennsylvania. Ramp meters were installed on 11 entry ramps along Route 22 during a major reconstruction project in 1997. These ramp meters were used successfully during the construction period and were in operation for approximately two years after the construction. The operation of the ramp meters was discontinued due to the fixed time operation of the devices, their inability to respond to the changing traffic conditions, and queue spillover from the ramps onto local roadways. The signal displays are still located on the ramps.

The current regional long range plan, Lehigh Valley Surface Transportation Plan 2007-2030, incorporates information from the planning commission's Congestion Management System (CMS) and travel demand model. The CMS defines congestion as Level of Service D or worse. Level of Service (LOS) is determined by the volume-to-capacity (v/c) ratio for each freeway segment: LOS D corresponds to a v/c between 0.81 and 0.90, LOS E corresponds to a v/c between 0.91 and 1.0, and LOS F corresponds to a v/c >1.0.

Congested corridors in the CMS are prioritized by a combination of factors including LOS, crash rate versus average rate of similar functional class roadways, and ADT. The CMS utilizes the travel demand model projections through the year 2030, the horizon year of the current long range plan. Route 22 has been identified as the top priority corridor in the CMS and the long range plan. The following freeways were identified as congested corridors by the CMS:

Year 2000 Congested Corridors

- Route 22 Kuhnsville to Schoenersville Road

Year 2030 Congested Corridors

- Route 22 from I-78 to PA 33

- I-78 from Route 22 to PA 100
- I-78 from PA 309 to PA 33

Several projects on the long range plan are intended to address freeway capacity deficiencies. These projects include:

- The American Parkway project in Allentown will improve access to Downtown Allentown and will relieve congestion along Route 22. This project is currently under construction.
- A major Route 22 corridor study was completed in 2001. Seven sections of Route 22 were identified as having insufficient capacity. Three of these seven sections along Route 22 are currently listed on the long range plan to provide major capacity improvements with additional through lanes.
- Both segments of I-78 identified in the CMS are programmed for future study to identify improvements to mitigate congestion.
- The long range plan also addresses freeway congestion through several ITS projects such as additional service patrols, cameras, and variable message signs.
- The current traffic control center operates during daylight hours, 5 days a week. During night hours, the District 6-0 traffic control center has access to the District 5-0 ITS facilities.

Berks County Planning Commission

The Berks County Planning Commission defines the term congestion in their Congestion Management Process (CMP) as “the level of traffic at which transportation system performance is degraded to unacceptable levels of excessive travel times and delays. “ The Berks County CMP goes on to quantify congestion using volume to capacity ratios based on output from the computerized travel demand forecasting model for the 2007 PM peak period (3:00 p.m. to 6:00 p.m.). The Berks County CMP identifies roadways with v/c ratios from 0.8 to 0.89 (moderate congestion), 0.9 to 0.99 (significant congestion), and 1.0 or greater (severe congestion). Future CMP’s will investigate using LOS as a performance measure and will model future years once the regional transportation demand model is updated.

No limited access freeways were identified with a v/c ratio greater than 1.0. However, a representative from Berks County described several freeway ramps with recurring congestion. The majority of these locations are ramps that queue back onto the existing freeway and do not describe freeway congestion:

- SR 222 Northbound at SR 61 Northbound off ramp, Muhlenberg Township
- SR 222 Northbound at SR 183 off ramp, Bern Township
- SR 222 Southbound at merge with SR 422 westbound, Wyomissing Borough
- SR 422 Eastbound and Westbound at interchange with SR 3422 (B-422), West Reading Borough

- SR 422 Eastbound and Westbound at interchange with SR 3222 (B-222), City of Reading

PennDOT 6-0 (Delaware Valley Regional Planning Commission)

PennDOT 6-0 currently operates ramp meters on I-476 in Delaware County. The ramp meters are part of the overall traffic management center which is continually staffed. There are 15 ramp metering stations and 25 mainline loop detector stations located along I-476. The system is currently being updated with a fiber optic communication system. An extensive study was performed in 2005 to evaluate the benefits of ramp metering along I-476. At that time, 4 ramp meters on the southern end of I-476 were activated. The meters operated during the morning and afternoon peak periods with the following results:

	AM Peak Speed Change with Metering	PM Peak Speed Change with Metering	Congestion			
			AM Peak		PM Peak	
			Without Meters	With Meters	Without Meters	With Meters
MacDade NB	+ 31 MPH	+ 35 MPH	2.5 hrs	0 hrs	4 hrs	1.5 hrs
Baltimore Pike NB	+ 14 MPH	+ 3 MPH	2 hrs	45 min	None	None
Baltimore Pike SB	+ 10 MPH	+ 5 MPH	2 hrs	40 min	None	None
US 1 SB	+ 10 MPH	+ 3 MPH	2.5 hrs	1.5 hrs	3.5 hrs	30 min

Source: PennDOT 6 I-476 Ramp Metering, by TransCore, March 2005

As part of the Congestion Management Process (CMP) and regional travel demand model, a congested freeway map based upon 2030 v/c ratios with a constrained network was provided. A significant number of limited access highways are forecasted to operate at a v/c ratio greater than 1.0, with several links operating at a v/c ratio greater than 2.0 due to the high levels of congestion throughout the region. There is no identification as to the source of congestion (basic lane capacity or bottlenecks) in the CMP. The following limited access freeways were identified as congested by the 2030 travel demand model:

- I-95
- I-76 (US 202 to 26th Street)
- I-676
- I-276 (King of Prussia to US 1)
- I-476 (Lansdale to I-95)
- US 1 (Philadelphia)
- US 1 (Bucks County)
- PA 63
- PA 309
- US 422 (Royersford to King of Prussia)
- US 202 (Disjoined segments from West Chester to King of Prussia)
- US 30 (Reeceville Road to US 322 and PA 113 to PA 100)

Along with the typical congestion mitigation strategies presented in most CMP's, Delaware Valley Regional Planning Commission (DVRPC) also considers land use controls as an important component in addressing congestion throughout the region. DVRPC has developed a model interchange area overlay district that local municipalities can incorporate into their zoning ordinance to minimize congestion around highway interchanges.

Incident management and ITS components are recommended on all major corridors throughout the region as part of the CMP. PennDOT 6-0 operates a regional traffic control center with a full time staff that operates 84 variable message signs, 180 traffic cameras, incident detectors, and expressway service patrols within the City of Philadelphia. Future ramp meters are programmed in the current long range plan; however, specific locations have not been identified. In addition, other corridor management features are included in the long range plan such as variable message signs and traffic camera on freeways and arterials. Incident management systems, including gated ramps that would permit closure of freeways during emergencies, are being considered by DVRPC. No specific locations have been identified.

The current TIP and long range plan both have capacity adding projects that may mitigate freeway congestion. The projects include;

- US 202 Section 300 (currently under construction)
- Construction of the I-95/ Turnpike interchange
- Widen I-476 (PA Turnpike Northeast extension) to 6 lanes from Lansdale to Allentown
- Widen I-76 (PA Turnpike) to 6 lanes from Downingtown to Valley Forge
- Route 322/Commodore Barry Bridge/I-95 Interchange

PennDOT 8-0 (Tri-County Regional Planning Commission, Lebanon County Planning Department, Lancaster County Planning Commission, York County Planning Commission, Adams County Planning Department, Franklin County Planning Commission)

Tri-County Regional Planning Commission

Freeway congestion in the Tri-County area is identified by the Congestion Management Process (CMP) which utilizes volume measures (v/c ratios) and Levels of Service (LOS) to evaluate congestion. The LOS calculation is based upon the Highway Capacity Manual (HCM) methodology which estimates vehicle density. The current long range plan projects traffic conditions to the year 2030. CMP corridors with freeway segments experiencing significant congestion include the following:

- I-81 from PA 465 to PA 581 and from US 22/322 to PA 39
- I-83 from PA Turnpike to I-81
- PA 581 from US 11/15 to I-83

Three bottleneck locations are identified on I-83: at 19th street, PA 581 interchange (mainline reduced to one lane), and Eisenhower Interchange (I-283/US 322) (mainline reduced to one lane). Ramp metering has been specifically identified as a potential congestion management strategy in conjunction with future improvements to I-83.

The long range plan includes freeway improvements including incident management and interchange improvements. There appears to be many sub-standard interchanges in the freeway network, which impact freeway capacity conditions especially several freeway to freeway interchanges. These are considered bottlenecks. Another issue that the long range plan addresses is the high volume of truck traffic on the freeway system and the need to provide travel time and best route information for truck traffic.

A review of the long range plan concluded that there are several projects intended to address freeway congestion.

- I-83 East Shore Section 1 (I-81 to Eisenhower Interchange)
- I-81 Widening Exit 57 to 61
- US15/PA 581 Interchange Improvements

Lancaster County Planning Commission

Lancaster County has a Congestion Management System (CMS), which utilizes a Level of Service approach to identify congestion. Future updates to the CMS will utilize travel time to monitor congestion. The CMS includes one limited access freeway, Route 30, which experiences no recurring congestion. The MPO indicated that off-ramp queuing is an issue at several locations. The current TIP has a two interchange projects to improve capacity and safety at ramp-arterial intersections:

- PA 283 at PA 722
- US 30 at Harrisburg Pike

The long range plan has one interchange project identified along US 30 at Centerville Road.

York County Planning Commission

No congested freeways were identified in the 2005 Congestion Management System (CMS) for York County.

PennDOT 10-0 (Southwestern Pennsylvania Commission)

SPC is able to provide v/c ratios from their travel demand model for freeway segments. A review of modeling information shows that the following freeway segments will experience a v/c ratio greater than 1.0 by 2035:

I-79 (from Butler/Allegheny County Line to Route 228 – Exit 78)

PennDOT 11-0 (Southwestern Pennsylvania Commission)

Southwestern Pennsylvania Commission (SPC) measures congestion in their Congestion Management Process (CMP) using actual travel time data. There are no specific criteria to identify a corridor as congested. The CMP uses travel delay as a performance indicator for segments along each CMP corridor. The CMP corridors are categorized by functional classification and the information is summarized by Delay/Vehicle/Mile and by Total Delay in vehicle-hours.

The following summarizes the Interstate Delay in vehicle-hours/mile for Interstates within the SPC region by total peak hour (AM plus PM):

Interstates	
I-376 (Parkway West)	194 peak hour vehicle-hours/mile
I-376 (Parkway East)	153 peak hour vehicle-hours/mile
I-579	72 peak hour vehicle-hours/mile
I-279 (Parkway North)	33 peak hour vehicle-hours/mile
Freeways	
PA 60 (Business 60 – US22/30)	89 peak hour vehicle-hours/mile
SR 28	57 peak hour vehicle-hours/mile
SR 22/30	56 peak hour vehicle-hours/mile

SPC is also able to provide v/c ratios from their travel demand model for freeway segments. A review of modeling information shows that the following freeway segments will experience a v/c ratio greater than 1.0 by 2035:

I-376 (from I-79 – Exit 64 to Business 22 – Exit 80)

I-279 (from I-376 – Exit 1 to Camp Horne Road – Exit 8)

I-579

I-79 (from Washington/Allegheny County Line to Bridgeville – Exit 54)

I-79 (from Kirwan Heights – Exit 55 to Carnegie – Exit 57)

I-79 (from Route 51 – Exit 64 to Route 65 – Exit 66)

I-79 (from I-279 – Exit 72 to Butler/Allegheny County Line)

The 2035 SPC model includes improvements to the Route 28 corridor, US 22/30 – PA 60 corridor, and the Southern Beltway (from US 22/30 to I-79) currently on the long range plan. This information parallels the congestion information provided to us by PennDOT 11-0. In particular, they noted the following:

- I-376 (Parkway East) – AM peak hours - WB builds to Greensburg Pike Interchange (Exit 79A) or Churchill (Exit 79B)
- I-376 (Parkway Central) – PM peak hours – WB Second Ave interchange (Exit 1B) to the Ft Pitt Tunnel and EB Ft Pitt Tunnel to Bates Street Interchange (Exit 73B)
- I-376 (Parkway West) – AM peak hours - NB builds to just before the Green Tree (Exit 67). During PM peak hours – inconsistent day to day – sometimes to Carnegie Interchange and sometimes no congestion at all
- I-279 SB (Parkway North) – AM peak hours - SB and builds to Camp Horne Road (Exit 8). During PM peak hours – some congestion around McKnight Rd Interchange (Exit 4), Perrysville Interchange (Exit 5), and when traffic merges with I-79 at the end of I-279

- SR 0028 – AM peak hours – SB 31st Street Bridge Traffic Signal to Etna Interchange (Exit 5B). During PM peak hours – around Etna/Sharpsburg Interchange (Exit 5A and 5B) and queue due to 31st Street Bridge Signal

Three projects were identified on the TIP to address freeway capacity issues:

- Route 28 – upgrade the existing at-grade freeway to limited access and the completion of a second through lane at the Etna interchange

- I-79 widening project (widening from 4 to 6 lanes) associated with the Meadow Lands auxiliary lanes.

- PA 60/US 22/30 Interchange project – will improve bottleneck on US 22/30 (Future I-376)

PennDOT 12-0 (Southwestern Pennsylvania Commission)

SPC is able to provide v/c ratios from their travel demand model for freeway segments. A review of modeling information shows that the following freeway segments will experience a v/c ratio greater than 1.0 by 2035:

I-79 (from Racetrack Road – Exit 41 to Washington/Allegheny County Line)

I-70 (from Exit 17 to I-79 – Exit 18)

Statewide Freeway Congestion Analysis

PennDOT's Bureau of Planning and Research has developed a statewide congestion database, which utilizes readily available traffic data from the PennDOT Roadway Management System (RMS) to calculate volume to service flow ratios for all state highways. This methodology can be considered a high level planning tool utilizing annual average daily traffic (AADT) volumes from statewide traffic data sources. The AADT's are converted to design hour volumes (DHV's) through peak hour factors, directional factors, and truck factors. The congestion database is not detailed enough to identify sources of congestion (bottlenecks and/or basic lane capacity) in the analysis. A comparison of the information provided by the local agencies and PennDOT districts was made to identify any major corridors that may have been identified at the state level and not the local level.

Since this methodology is determined using a statewide database, it can be a useful tool in identifying areas of congestion statewide; however, a more refined screening of v/c ratios at the MPO level is recommended (if available) since each MPO typically has access to more local traffic data and a more detailed travel demand model. The statewide database can be used as an initial screening tool where local information is lacking. The statewide database can provide v/c ratios for freeways.

Potential Definitions of Recurring Congestion

The availability of uniform data from PennDOT and the MPO's Congestion Management Process/travel demand models are a limitation in selecting a planning level tool to identify recurring congestion. Traffic data are typically collected on a limited, periodic basis providing just a snapshot of the actual conditions over an entire year. Traffic data typically does not reflect the amount of daily variation in traffic volumes due to fluctuating demand, special events, incidents, or weather. Recurring congestion, by definition, would need to be measured by daily and monthly data to confirm the recurring event. However, the data provided can be considered reliable enough for a planning analysis.

Several definitions of congestion could be considered as a planning level test for recurring freeway congestion including:

- V/C ratio greater than 1.0
- Vehicle density based upon the Highway Capacity Manual
- Freeway speeds below a certain threshold on the mainline freeway
- Freeway speeds below a certain threshold for a specific time period
- Travel times
- Congestion duration and extent measures (hours of delay)
- System reliability measures

Most MPO's utilize LOS or v/c ratios from their regional travel demand models as part of their CMP and long range plans. The use of a v/c ratio is an easy to understand method of identifying congestion. V/C ratio is the most basic measure of roadway capacity as compared to traffic demand, vehicle density, or mobility performance. This ratio is well understood by traffic engineers and transportation planners. Using available information, with some adjustments, this uniform measure can be applied statewide. For this reason, a volume based performance measure (v/c ratio greater than 1.0) is recommended as an initial screening tool to identify congested freeways. Once corridors are identified, more reliable mobility performance measures such as travel time, speed, travel time index (TTI) can be obtained as a baseline measure of congestion to compare future improvements.

FHWA's traffic operations program area is specifically targeting recurring congestion. One of the main goals in reducing recurring congestion is to identify bottlenecks that offer point specific, low cost solutions as opposed to "mega" projects that address systemic congestion at the corridor or regional level. The data reviewed as part of this research effort does not distinguish between bottlenecks and system congestion.

Recommended Definition of Recurrent Freeway Congestion for Pennsylvania

Based upon a review of the current literature; the regional CMP/CMS plans; and the most readily available data; the use of a v/c ratio > 1.0 to screen freeway segments for congestion is recommended.

Furthermore, since the purpose of this screening tool is to identify and plan for the implementation of ramp management techniques, model data or growth rates should be used where available to project v/c ratios for freeway segments out to the design year of the local area long range plan. This long range view of freeway congestion will allow local regions to evaluate and program ramp management improvements into their long range plans.

The following source information is available for v/c ratio by freeway segment:

District 4-0	Statewide Database – v/c ratios by segment forecasted to 2030
District 5-0	Local Travel Demand Model – v/c ratios through 2030
District 6-0	Local Travel Demand Model – v/c ratios through 2030
District 8-0	Local Travel Demand Model – v/c ratios through 2030
District 10-0	Local Travel Demand Model – v/c ratios through 2035
District 11-0	Local Travel Demand Model – v/c ratios through 2035
District 12-0	Local Travel Demand Model – v/c ratios through 2035

The other remaining PennDOT districts did not report any freeway congestion.

Identified Congested Freeway Segments in Pennsylvania

PennDOT District 4-0

Utilizing v/c ratios calculated by the PennDOT Bureau of Planning and Research (from 2007 Roadway Management System (RMS) data) and county-wide growth rates by functional class provided by PennDOT BPR, the following freeway segments are forecasted to be congested by 2030 (v/c ratio >1.0):

- I-81 Exit 164 (PA 29) to Exit 180 (US 11)
- I-81 Exit 182 (Montage Mountain Road) to Exit 185 (Scranton Expressway)
- I-81 Exit 191 (Business US 6) to Exit 194 (I-476)
- PA 309 Exit 3 (North River Street) to I-81

Figure 1 (Appendix A) shows the location of this congestion. Approximately 25 miles of congested freeway are identified.

PennDOT District 5-0

Utilizing travel demand modeling information (v/c ratios) from LVRPC, the following freeway segments are forecasted to be congested (v/c >1.0) in 2030:

- US 22 From PA Turnpike to PA 309
- US 22 From 15th Street to 7th Street (PA 145)

Figure 2 (Appendix A) shows the location of this congestion. Approximately 2 miles of congested freeway are identified.

PennDOT District 6-0

Utilizing travel demand modeling information (v/c ratios) from DVRPC, the following freeway segments are forecasted to be congested (v/c >1.0) in 2030:

- I-95 Entire length
- I-76 Exit 326 (King of Prussia) to Exit 347 (PA 291)
- I-676 Entire length
- I-276 Exit 326 (King of Prussia) to Exit 351 (US 1)
- I-476 Exit 0 (I-95) to Exit 31 (Lansdale)
- US 1 Philadelphia County
- US 1 I-276 to I-95 and US 13 to NJ (Bucks County)
- PA 63
- PA 309 Entire length
- US 422 Royersford to King of Prussia
- US 202 Various segments from West Chester to King of Prussia
- US 30 Reeceville Road to US 322
- US 30 PA 113 to PA 100

Figure 3 (Appendix A) shows the location of this congestion. Approximately 183 miles of congested freeway are identified.

PennDOT District 8-0

Utilizing the CMP information (v/c ratios) from the Tri-County Planning Commission, the following freeway segments will be congested (v/c >1.0) in 2030:

- I-81 Exit 52 (US 11) to Exit 59 (PA 581)
- I-81 Exit 72 (Mountain Road) to Exit 80 (Grantville)
- I-83 Exit 44 (19th Street) to Exit 48 (Union Deposit Road)

Figure 4 (Appendix A) shows the location of this congestion. Approximately 19 miles of congested freeway are identified.

PennDOT Districts 10-0

The SPC 2035 travel demand model was utilized to identify congested freeways. The following freeway will be congested (v/c ratio >1.0) in 2035:

- I-79 Allegheny/Butler County Line to Exit 78 (Route 228)

Figure 5 (Appendix A) shows the location of this congestion. Approximately 1 mile of congested freeway is identified.

PennDOT District 11-0

The SPC 2035 travel demand model was utilized to identify congested freeways. The following freeways will be congested (v/c ratio >1.0) in 2035:

- I-279 Exit 1 (I-376) to Exit 8 (Camp Horne Road)
- I-376 Exit 64 (I-79) to Exit 80 (Business 22)
- I-579
- I-79 Washington/Allegheny County Line to Exit 54 (Bridgeville)
- I-79 Exit 55 (Kirwan Heights) to Exit 57 (Carnegie)
- I-79 Exit 64 (Route 51) to Exit 66 (Route 65)
- I-79 Exit 72 (I-279) to Butler/Allegheny County Line

Figure 5 (Appendix A) shows the location of this congestion. Approximately 35 miles of congested freeway are identified.

PennDOT District 12-0

The SPC 2035 travel demand model was utilized to identify congested freeways. The following freeways will be congested (v/c ratio >1.0) in 2035:

- I-79 Exit 41 (Racetrack Road) to Washington/Allegheny County Line
- I-70 Exit 17 to Exit 18 (I-79)

Figure 5 (Appendix A) shows the location of this congestion. Approximately 10 miles of congested freeway are identified.

Statewide Congested Freeway Rankings (2030/2035)

For each District, except District 4, data from the long-range transportation model and the local Congestion Management Program was utilized to summarize the average v/c ratio for each congested freeway segment. For District 4-0, the v/c ratios calculated by the PennDOT Bureau of Planning and Research (using RMS data) and county-wide growth rates by functional class provided by PennDOT BPR were used to forecast 2030 v/c ratios for congested freeways.

Table 1 summarizes 30 freeway segments forecasted to be congested in 2030/2035

TABLE 1
Average V/C Ratios for Congested Freeways
Forecasted to 2030/2035

District	Route	From	To	Average V/C Ratio
6	US 1	I-76	PA 611	2.91
6	I-76	US 1	PA 291	2.23
6	I-76	PA Turnpike	US 1	2.07
11	I-376	I-79	I-279	1.86
6	I-476	I-95	Turnpike	1.78
6	I-95	I-676	Turnpike	1.70
6	I-676	I-76	I-95	1.61
4	PA 309	I-81	Exit 3	1.58
6	I-95	DE Line	I-676	1.57
11	I-376	I-279	Exit 80	1.51
6	US 202	Section 200	Section 400	1.41
6	PA Turnpike	Exit 326	Exit 351	1.35
4	I-81	Exit 191	Exit 194	1.33
6	US 1	PA Turnpike	NJ Line	1.30
6	US 422	Royersford	US 202	1.26
6	PA 309	PA 152	PA 63	1.22
6	I-476	Exit 20	Exit 31	1.22
6	PA 63	Knights Road	I-95	1.20
4	I-81	Exit 182	Exit 185	1.14
6	I-95	PA Turnpike	NJ Line	1.13
11/12	I-79	Exit 41	Exit 57	1.13
8	I-83	Exit 44	Exit 48	1.10
4	I-81	Exit 164	Exit 180	1.10
5	US 22	PA Turnpike	PA 309	1.10
8	I-81	Exit 52	Exit 59	1.08
11	I-279	I-376	Exit 8	1.05
6	US 30	Reeceville Road	PA 100	1.05
10/11	I-79	Exit 65	Exit 78	1.04
8	I-81	Exit 72	Exit 80	1.01
5	US 22	15th Street	PA 145 (7th St)	1.01

Note that this data is compiled from various sources. District 4-0 data were forecasted for 2030 using a statewide v/c database based upon 2007 Roadway Management System data and annual growth rates provided by the Bureau of Planning and Research. Data for all other districts based upon regional MPO model forecasts for 2030 (Districts 5-0, 6-0 and 8-0) or 2035 (Districts 10-0, 11-0 and 12-0). Each MPO long range model is unique. For each segment listed above, a weighted average v/c ratio over the segment length was calculated. Peak localized v/c ratios along a particular segment may vary.

The following is a breakdown of forecasted congestion by PennDOT District

PennDOT District 4-0

- PA 309 — I-81 to Exit 3 — 2030 v/c ratio = 1.58
- I-81 — Exit 191 to Exit 194 — 2030 v/c ratio = 1.33
- I-81 — Exit 182 to Exit 185 — 2030 v/c ratio = 1.14
- I-81 — Exit 164 to Exit 180 — 2030 v/c ratio = 1.10

PennDOT District 5-0

- US 22 — PA Turnpike to PA 309 — 2030 v/c ratio = 1.10
- US 22 — 15th Street to PA 145 (7th St) — 2030 v/c ratio = 1.01

PennDOT District 6-0

- US 1 — I-76 to PA 611 — 2030 v/c ratio = 2.91
- I-76 — US 1 to PA 291 — 2030 v/c ratio = 2.23
- I-76 — PA Turnpike to US 1 — 2030 v/c ratio = 2.07
- I-476 — I-95 to PA Turnpike — 2030 v/c ratio = 1.78
- I-95 — I-676 to PA Turnpike — 2030 v/c ratio = 1.70
- I-676 — I-76 to I-95 — 2030 v/c ratio = 1.61
- I-95 — DE Line to I-676 — 2030 v/c ratio = 1.57
- US 202 — Section 200 to 400 — 2030 v/c ratio = 1.41
- PA Turnpike — Exit 326 to Exit 351 — 2030 v/c ratio = 1.35
- US 1 — PA Turnpike to NJ — 2030 v/c ratio = 1.30
- US 422 — Royersford to US 202 — 2030 v/c ratio = 1.26
- PA 309 — PA 152 to PA 63 — 2030 v/c ratio = 1.22
- I-476 — Exit 20 to Exit 31 — 2030 v/c ratio = 1.22
- PA 63 — Knights Road to I-95 — 2030 v/c ratio = 1.20
- I-95 — PA Turnpike to NJ — 2030 v/c ratio = 1.13
- US 30 — Reeceville Rd to PA 100 — 2030 v/c ratio = 1.05

PennDOT District 8-0

- I-83 — Exit 44 to Exit 48 — 2030 v/c ratio = 1.10
- I-81 — Exit 52 to Exit 59 — 2030 v/c ratio = 1.08
- I-81 — Exit 72 to Exit 80 — 2030 v/c ratio = 1.01

PennDOT District 10-0

- I-79 — Butler/Allegheny County Line to Exit 78 — 2035 v/c ratio = 1.04

PennDOT District 11-0

- I-376 — Exit 64 to Exit 70 — 2035 v/c ratio = 1.86
- I-376 — Exit 70 to Exit 80 — 2035 v/c ratio = 1.51
- I-79 — Washington/Allegheny County Line to Exit 57 — 2035 v/c ratio = 1.13
- I-279 — Exit 1 to Exit 8 — 2035 v/c ratio = 1.05
- I-79 — Butler/Allegheny County Line Exit 78 — 2035 v/c ratio = 1.04

PennDOT District 12-0

• I-79	Exit 41 to Washington/ Allegheny County Line	2035 v/c ratio = 1.13

Summary of Projects and Costs Identified to Address Freeway Congestion

For each region with congested freeways, the local Transportation Improvement Program (TIP) and Long Range Transportation Plan were reviewed to identify freeway capacity projects.

District 4-0/Lackawanna-Luzerne MPO

I-81 Widening (Exit 182 to Exit 185)	$8 million

The Lackawanna-Luzerne long range plan is currently being updated, and as such, long range freeway congestion projects are not included at this time. A total of 6 additional lane miles (3 miles in each direction) are programmed on the TIP totaling $8 million.

District 5-0/Lehigh Valley MPO

US 22 (Airport Road to 15th Street)	$137 million
US 22 (15th Street to Cedar Crest Blvd)	$161 million
US 22 (Airport Road to PA 512)	$306 million
I-78 (project undefined – study programmed)	$1.7 million

The Lehigh Valley has approximately $605.7 million programmed on their long range plan to add capacity to the regional freeway system. The $605.7 million includes new lane miles, reconstruction, and planning. Of the $605.7 million, $604 million is programmed to provide 18 additional lane miles (9 miles in each direction) along US 22. The Lehigh Valley MPO also has $363 million programmed on the long range program to implement recommendations from the CMP, which will include recommendations from the I-78 planning studies.

District 6-0/DVRPC

I-95/ Turnpike interchange	$145.6 million (costs do not include Pa Tpk funds)
I-76 Downingtown to Valley Forge	(no Federal funds - Pa Tpk funds only)
I-476 Lansdale to Allentown	(no Federal funds - Pa Tpk funds only)
US 1 I-276 to N.J. State Line (12 mi)	$22.5 million (spot widening where needed)
US 202 Section 300 (Chester Co. – 7 mi)	$50.0 million
I-95/Route 322 Interchange (1 mi)	$22.4 million

DVRPC currently has approximately $240.5 million programmed on their long range plan to add capacity to the regional freeway system, not including non-federal funds for projects exclusive to the PA Turnpike,. Of the $240.5 million, $72.4 million is programmed to provide 16 additional lane miles (8 miles in each direction) to the freeway system.

District 8-0/Tri-County Planning Commission

I-83 East Shore Sec. 1 (Exit 46 to I-81)	$159 million
I-81 Widening Exit 57 to 61	$84 million
US15/PA 581 Interchange Improvements	$91 million
I-81 Exits 48/49 Interchanges (1 mi.)	$92 million

The Tri-County MPO has approximately $426 million programmed on their long range plan to add capacity to the regional freeway system. The $426 million programmed will provide 22 additional lane miles (11 miles in each direction) to the freeway system.

District 11-0

Route 28 Etna Interchange	$20.3 million
PA 60/US 22/30 Interchange	$17.4 million

District 12-0

I-79 Meadowlands auxiliary lanes	$21.0 million

SPC has approximately $58.7 million programmed on their long range plan to add capacity to the regional freeway system. However, none of these projects will add significant lane miles to the existing freeway system. A number of new freeways are proposed by the PA Turnpike; however, they are not included in this summary.

Conclusion

Based upon the information gathered from PennDOT Districts, RPO's and MPO's, a uniform definition of recurring congestion is recommended. While congestion can be defined various ways (such as travel times, level of service and v/c ratios), the use of v/c ratio is recommended. V/C ratio is the most basic measure of roadway capacity as compared to the traffic demand. This ratio is well understood by traffic engineers and transportation planners. Using available information, with some adjustments, this uniform measure can be applied statewide.

The application of the recommended congestion criteria results in the identification of 275 miles of congested freeways in Pennsylvania. The breakdown of congestion by region is as follows:

- Wilkes-Barre/Scranton Region – 25 miles
- Allentown/Bethlehem Region – 2 miles
- Philadelphia Region – 183 miles
- Harrisburg Region – 19 miles
- Pittsburgh Region – 46 miles

This significant amount of recurrent freeway congestion cannot be solved by capacity-adding projects alone. As per the current MPO's long-range plans, approximately 62 lane-miles of the freeway are anticipated to be added (31 miles in each direction) by freeway capacity adding projects costing a total of $1.11 billion. This represents only 11% of the total freeway mileage identified as congested. Using the estimated costs of the currently programmed congestion projects, this approximates the capacity-adding cost to solve recurrent congestion as $17.9 million per lane mile (or $35.8 million per mile in both directions). Applying these costs to the remaining 244 miles of congested freeway segments would result in a total cost to the highway network of $8.74 billion to solve recurring congestion problems in Pennsylvania.

Not all freeway segments identified as congested are candidates for ramp management. However, this strategy could play a significant role in addressing many of these locations. The next chapter explores the specific criteria for determining whether or not a freeway segment is a candidate for ramp management.

Chapter 4
Criteria for the Implementation of Ramp Management as a Congestion Relief Strategy in Pennsylvania

Ramp Management Criteria Used in Similar States

A review of the five states previously discussed in the state of the art (New York, Minnesota, Wisconsin, Ohio, and Georgia) revealed that most ramp management systems seem to grow organically over time. While some states have very detailed criteria to review ramp management implementation, some states have no formal criteria.

Minnesota
Ramp metering has been in place for over 10 years; however, Minnesota lacks formal criteria for ramp metering. Prior to 2000, Minnesota's ramp management policy was to add ramp meters system-wide in the Twin Cities area where freeway management (ITS) systems were being installed. In recent years, MinnDOT has held back on the installation of ramp meters as part of the initial freeway management deployment to allow for a few years of traffic flow data/observation to be collected before making a final decision on ramp metering.

Georgia
Georgia is relatively new to ramp management, and similar to Minnesota, lacks formal criteria for installing ramp meters. Most freeways in the Atlanta area are congested on a daily basis and implementation of ramp metering on congested freeways is a policy decision that is being implemented system-wide in Atlanta. GaDOT officials are utilizing an unofficial rule that ramp metering is being implemented on a corridor-wide basis. Once a corridor is selected for ramp management, all ramps along that corridor are to be metered.

Wisconsin
While some states use "warrants" for ramp metering, little information was found on a comprehensive statewide planning tool used to evaluate all congested freeways statewide for ramp management treatments. One exception to this was in Wisconsin.

In 2006, a report (Wisconsin Statewide Ramp Control Plan: WisDOT Ramp Metering and Control Plan) was issued, which outlined criteria for ramp control strategies and a methodology to incorporate ramp control into the statewide planning and programming process. By 2006, Wisconsin already had ramp meters in the Milwaukee area. The purpose of the study was to incorporate ramp management of future corridors on a statewide basis. The study cautioned that it is not appropriate to make final implementation decisions based on a high level scan and that ramp metering success is highly dependent on local conditions. The report pointed out that the literature indicates that freeway sections with ramp metering have the following characteristics:

- Peak period speeds less than 30 mph;
- Vehicle flows between 1,200 to 1,500 vphpl;
- High accident rates;
- Significant merging problems.

Wisconsin Guide for Ramp Meters

Traffic Criteria

1. Mainline volumes of at least 1200 vehicles per hour per lane
2. Ramp volumes of at least 240 vehicles per hour for a one lane ramp, and 400 vehicles per hour for a two lane ramp
3. Mainline speeds of less than 30 mph in the peak hour
4. Accident rate in the vicinity of the ramp in excess of 80 per hundred million vehicle miles

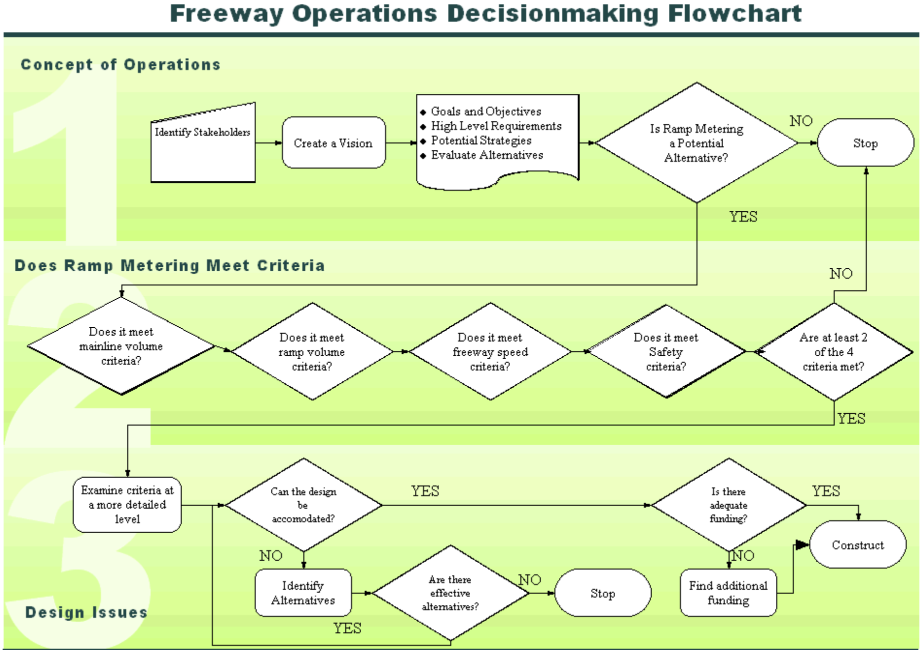
Corridor Criteria

1. Are two of the four traffic criteria met for at least 50% of the corridor?

Minimal Design Requirements

1. Storage length of at least 450 feet behind ramp meter signal (450 feet is for 240 vehicles per hour on a one lane ramp)
2. Acceleration distance of at least 1000 feet beyond ramp meter signal (1000 feet is for 55 mph merge speed on level grade).
3. Distance from ramp meter stop bar to centerline of adjacent arterial of at least 245 feet (245 feet is minimum recommended by AASHTO).
4. Foot print for ramp metering equipment is minimal (less than 100 square feet)
5. Frontage road/alternate route must be somewhat available in the corridor

Freeway Operations Decisionmaking Flowchart



Ohio

ODOT uses a detailed 'warrant' process adapted from AzDOT to evaluate ramp metering. The following are the individual criteria that are used to determine if ramp metering is warranted for a particular ramp.

Warrant Summary (Ohio/Arizona)
Warrant One – Recurring Congestion Warrant – Does the freeway operate at speeds less than 50 mph for duration of at least 30 minutes for 200 or more calendar days per year?

Warrant Two – Collision History Pattern – Is there a high frequency of crashes (collision rate along the freeway exceeds mean collision rate in the subject metropolitan area) near the freeway entrances because of inadequate merge area and congestion?

Warrant Three – Freeway Level of Service Will the ramp meter or system of ramp meters contribute to maintaining a specific level of service (LOS) identified in the region's transportation system management (TSM) plan?

Warrant Four – Modal Shift – Will the ramp meter or system of ramp meters contribute to maintaining a higher level of vehicle occupancy through the use of HOV preferential treatments as identified in the region's transportation system management (TSM) plan? (NOT USED IN OHIO – USED IN ARIZONA)

Warrant Five – Redistribution of Access – Will the ramp meter or system of ramp meters contribute to balancing demand and capacity at a system of adjacent ramps entering the same facility?

Warrant Six – Sporadic Congestion Warrant – Does the ramp meter or system of ramp meters mitigate predictable sporadic congestion on isolated sections of freeway because of short peak period loads from special events or from severe peak loads of recreational traffic?

Warrant Seven - Total Volume Warrant Criteria

Number of Mainline Lanes in One Direction including Auxiliary Lanes that Continue at least 1/3 Mile downstream from Ramp Gore	Criteria Volume Ramp Plus Mainline Volume Downstream of Gore (total vph)
2	2,650
3	4,250
4	5,850
5	7,450
6	9,050

Warrant Eight - Right Lane plus Ramp Volume Warrant – Ramp metering is warranted when the volume of the ramp plus the mainline right lane exceeds 2,100 vph. Is the criteria defined above met, during the design hour?

Warrant Nine - Geometric Warrant – Do the existing or proposed ramp geometry permit safe and effective ramp metering? At some locations, steep inclines on a ramp may warrant against implementing ramp metering at that location. Available lane widths may also be inadequate for metering.

Follow the steps below to determine whether ramp metering is warranted.

STEP 1 – Are any of Warrants One, Two, Three, Four, Five, or Six satisfied? If yes to any, go to Step 2. If no to all, STOP – ramp metering is not warranted.

STEP 2 – Are either Warrants Seven or Eight satisfied? If yes to either, go to Step 3. If no to both, STOP – ramp metering is not warranted. An exception to the two previous criteria is that ramp metering may be warranted solely due to current or anticipated high collision rates at a location. Therefore, in some cases at the discretion of the DOT, if Warrant 2 is satisfied, ramp metering can be warranted even if Warrants Seven and Eight are both not satisfied.

STEP 3 – Is Warrant Nine satisfied? If yes, ramp metering is warranted. If no, STOP – ramp metering is not warranted.

High Level Planning Tool for Ramp Management

Approximately 275 miles of Pennsylvania's freeways are congested (v/c ratio greater than 1.0) or will be congested within the next 20-25 years. In an effort to screen "congested corridors" as candidate ramp management locations, a rating system was developed and applied to each congested corridor in Pennsylvania. A high level planning tool was developed based upon basic volume and geometry information for each congested freeway in Pennsylvania. The high level planning tool utilizes a rating system using readily available information from PennDOT and the local MPO's.

The following data (and what that information tells us about ramp management possibilities) was used in the process:

- The long range (2030/2035) v/c ratio along the corridor – Using v/c ratios calculated from long range planning data will assist in determining where to deploy ramp management systems.

- The total number of interchanges along the corridor – The literature suggests that ramp management is more effective when implemented on a corridor-wide basis.

- The spacing between freeway on-ramps – If the freeway on-ramps are spaced too closely, the corridor might not be suitable to ramp metering; however, they might be candidates for ramp closure or a combination of ramp metering and ramp closure.

- The amount of coverage provided by PennDOT traffic cameras – This was used to determine if ITS infrastructure exists along the congested corridor.

- The number of reasonable alternate routes – If closing or metering a ramp leaves motorists without a reasonable route, it is less desirable.

- The approximate length of the freeway on-ramps – To determine if there will be adequate storage on the ramps to hold the queues caused by metering.

High Level Screening of PA Congested Freeways

Available Pennsylvania freeway data was utilized to develop criteria to evaluate the congested freeways, with each criteria given a rating from one to three (one being the least desirable and three being the most desirable condition for ramp management). Each criterion was also weighted differently to reflect the significance of each piece of data.

7 Forecasted v/c ratio of the corridor	weighting factor 3
Amount of existing ITS coverage within the corridor	weighting factor 3
Approximate length of the freeway on-ramps	weighting factor 3
Number of reasonable alternate routes	weighting factor 2
Total number of interchange ramps along the corridor	weighting factor 1
Spacing between freeway on-ramps	weighting factor 1

Forecasted v/c ratios (2030/2035), existing ITS corridor coverage, and the length of the freeway on-ramps were weighted the heaviest. Freeway segments with greater congestion will benefit more from ramp management than those segments will less congestion. Ramp management can be viewed as a low-cost alternative to improve freeway operations and as such, it is important to utilize existing ITS infrastructure where possible in order to keep costs low. Similarly, if adequate storage does not exist on the freeway on-ramps, queues from metering will spill onto the arterial network. This problem could be fixed with reconstruction of the ramps or arterial streets; however this increases the cost of the ramp management project.

The existence of reasonable alternate routes was weighted the next heaviest. When metering freeway on-ramps, it is expected that some of the traffic will divert to other routes. When closing freeway on-ramps, traffic must be able to reach their destination via another route. Therefore, if other routes do not exist or are unreasonable in travel time/distance, ramp management might not be desirable.

Finally, the criteria with the least weight were the number of interchange on-ramps and the spacing of on-ramps within a corridor. Ramp management works most efficiently within a system. These criteria were weighted the lowest because although they give some insight to the corridor's potential for ramp management, they are not definitive. Some on-ramps that are spaced closely together might actually be good candidates for ramp management.

Tables 1 through 5 show the preliminary ratings for each Pennsylvania congested corridor by MPO: Scranton-Wilkes Barre; Allentown; Philadelphia; Harrisburg; and Pittsburgh. In some instances, adjacent congested segments were combined for the purposes of this screening.

Table 1
Wilkes-Barre/Scranton Ratings

Corridor ID	Description	Weighted Rating
1 A	I-81, exit 164 to 185	26
1 B	I-81, exit 191 to 194	23
1 C	PA-309, I-81 to exit 3	21

Table 2
Allentown Ratings

Corridor ID	Description	Weighted Rating
2 A	US22, PA Turnpike to PA 309	25
2 B	US22, 15th Street to PA 145	23

Table 3
Philadelphia Ratings

Corridor ID	Description	Weighted Rating
3 K	I-76, Turnpike to US-1	33
3 F	I-95, DE to I-676	32
3 D	I-476, I-95 to Turnpike (Blue Route)	31
3 I	I-676, I-76 to I-95	30
3 J	US-1, I-76 to PA 611	30
3 L	I-76, US-1 to PA 291	30
3 G	I-95, I-676 to Turnpike	29
3 B	Rt 202, Section 200 to Section 400	26
3 C	Rt 422, Royersford to US 202	25
3 A	Rt 30, Reeceville Road to PA 100	24
3 M	PA 309, PA 152 to PA 63	24
3 E	I-476, Exit 20 to Exit 31 (PA Turnpike)	23
3 P	PA Turnpike, Exit 326 to Exit 351	22
3 H	I-95, Turnpike to NJ	19
3 N	PA 63, Knights Road to I-95	19
3 O	US-1, Turnpike to NJ	19

Table 4
Harrisburg Ratings

Corridor ID	Description	Weighted Rating
4 C	I-83, exit 44 to exit 48	25
4 B	I-81, exit 72 to exit 80	23
4 A	I-81, exit 52 to exit 59	22

Table 5
Pittsburgh Ratings

Corridor ID	Description	Weighted Rating
5 A	I-376, exit 70 to exit 80	32
5 C	I-376, exit 64 to exit 70	29
5 B	I-279, exit 1 to exit 8	27
5 E	I-79, exit 65 to exit 78	27
5 D	I-79, exit 41 to exit 57	25

Figures detailing the limits of each congested corridor on PennDOT mapping are also included in **Appendix B**. A detailed summary of the ratings calculations are in **Appendix C**. It is important to note that this screening criteria and rating system is only a preliminary guide to help quantify which freeway segments are the best ramp management candidates. However, if certain corridors do not rank high through this system and PennDOT deems there to be a special circumstance, more detailed criteria by interchange should be evaluated. While this preliminary planning tool can screen candidate locations statewide to consider ramp management, more specific criteria is required once a candidate corridor is identified.

Detailed Criteria to Consider Ramp Management of Freeway Segment

Based upon a review of existing criteria for ramp management, the most readily available criteria in use is the Ohio/Arizona “warrants” along with additional design related criteria taken from Wisconsin. The following is a blending of both Ohio/Arizona “warrants” and the Wisconsin design criteria.

OPERATIONAL SCREENING CRITERIA – Must meet at least one out of five operational criteria

1. Does the freeway operate at speeds less than 50 mph for duration of at least 30 minutes for 200 or more calendar days per year?

2. Is there a high frequency of crashes (collision rate along the freeway exceeds mean collision rate in the subject metropolitan area) near the freeway entrances because of inadequate merge area and congestion?

3. Will the ramp meter or system of ramp meters contribute to maintaining a specific level of service (LOS) identified in the region’s transportation system management (TSM) plan?

4. Will the ramp meter or system of ramp meters contribute to balancing demand and capacity at a system of adjacent ramps entering the same facility?

5. Does the ramp meter or system of ramp meters mitigate predictable sporadic congestion on isolated sections of freeway because of short peak period loads from special events or from severe peak loads of recreational traffic?

VOLUME CRITERIA – If one of the operational screening criteria is met, then the location must meet at least one out of three volume criteria

6. Total Volume Criteria

Total Volume Criteria

Number of Mainline Lanes in One Direction including Auxiliary Lanes that Continue at least 1/3 Mile downstream from Ramp Gore	Criteria Volume Ramp Plus Mainline Volume Downstream of Gore (total vph)
2	2,650
3	4,250
4	5,850
5	7,450
6	9,050

Is the ramp plus mainline volume greater than the tabulated criteria for the design hour?

7. Ramp metering is warranted when the volume of the ramp plus the mainline right lane exceeds 2,100 vph. Is the criteria defined above met, during the design hour?

8. Exception to volume criteria can be made if crash data is overwhelming in the opinion of the local district engineer.

DESIGN/SYSTEM CRITERIA – If operational and traffic criteria are met, then criteria 9 and 10 must be met to consider ramp management.

9. Does the existing or proposed ramp geometry permit safe and effective ramp metering and are adequate alternative routes available? The ramp should provide 450' of storage for ramp queues, a downstream acceleration lane at least 1000', and adequate sight distance from the arterial to the back of queue. Adequate alternative route must exist.

10. Do the measures of effectiveness for an area-wide simulation model indicate a benefit to the freeway system while at the same time minimizing impacts on adjacent arterials?

Summary

In summary it is recommended that a two step approach be used for Pennsylvania to screen and identify potential freeway segments as candidates for ramp management. The research of other state's practices indicates that a detailed warrant analysis is the tool typically used. However, because of the large number of congested freeway miles in Pennsylvania, an initial screening based upon freeway characteristics is recommended that measures the potential for ramp management implementation. This initial screening has been applied to the 289 miles of freeway in Pennsylvania previously identified as congested. For future planning and programming purposes the detailed criteria should then be applied to initiate evaluations for the potential success of this congestion management tool. This recommended planning tool should enable Pennsylvania to identify, rank and evaluate candidate locations for ramp management prior to expending resources for more detailed studies and construction.

Chapter 5
Evaluation of Ramp Management for I-376

I-376 in Pittsburgh (from Downtown Pittsburgh to Monroeville) was selected by the research team as a demonstration corridor to test the ramp management screening criteria previously described in Chapter 4. The I-376 corridor was as a highly ranked candidate corridor using the high level screening criteria previously described. The corridor specific criteria were then applied to this freeway section. The primary congestion on I-376 is due to a bottleneck at the Squirrel Hill Tunnel. This bottleneck creates excessive delays and queues during the AM and PM peak hours.

The purpose of this evaluation is to demonstrate how the criteria can be applied to a specific freeway section and to conduct a detailed planning study of the potential impacts of applying a ramp management solution to reduction of the freeway congestion problem. The more detailed evaluation required the creation and utilization of an area wide travel demand model and simulation model to predict the impacts of a ramp management system. The following sections of the report provide the application of the evaluation criteria and the more detailed analysis of the potential ramp management implementation plan for I-376.

Evaluation of Ramp Metering Criteria for I-376

The following summarizes the application of the recommended ramp metering criteria to I-376 from Exit 70 to Exit 80.

OPERATIONAL SCREENING CRITERIA – Must meet at least one of the five criteria listed below relating to operations

1. **Does the freeway operate at speeds less than 50 mph for duration of at least 30 minutes for 200 or more calendar days per year?** *I-376 from Bates Street to Churchill meets this criterion based upon observed rush hour queues during typical commuter weekdays.*

2. **Is there a high frequency of crashes (collision rate along the freeway exceeds mean collision rate in the subject metropolitan area) near the freeway entrances because of inadequate merge area and congestion?** *This criterion was not verified as only one of the first five criteria is required to be met for ramp metering.*

3. **Will the ramp meter or system of ramp meters contribute to maintaining a specific level of service (LOS) identified in the region's transportation system management (TSM) plan?** *I-376 currently operates at LOS F with excessive mainline queues during the peak hours. Ramp management would be implemented to improve the LOS and queue impacts as much as possible during some peak hours but will not improve the LOS during the highest peaks.*

4. **Will the ramp meter or system of ramp meters contribute to balancing demand and capacity at a system of adjacent ramps entering the same facility?** *This criterion is not applicable along I-376 as there are no frontage roads or adjacent on-ramps to balance.*

5. **Does the ramp meter or system of ramp meters mitigate predictable sporadic congestion on isolated sections of freeway because of short peak period loads from special events or from severe peak loads of recreational traffic?** *I-376 is not subject to predictable, sporadic congestion on isolated sections. This system would be used primarily to mitigate recurring commuter congestion along a 10-mile segment of I-376 due to the tunnel bottleneck. However it can also be used to mitigate congestion due to incidents.*

VOLUME CRITERIA – If one of the operational screening criteria is met, then the location must meet at least one of the three criteria listed below relating to volume

6. **Total Volume Criteria**

Number of Mainline Lanes in One Direction including Auxiliary Lanes that Continue at least 1/3 Mile downstream from Ramp Gore	Criteria Volume Ramp Plus Mainline Volume Downstream of Gore (total vph)
2	2,650
3	4,250
4	5,850
5	7,450
6	9,050

Is the ramp plus mainline volume greater than the tabulated criteria for the design hour?

The following summarizes the data from I-376 for criterion 6:

On-Ramps to I-376 Eastbound

Ramp	Number of Mainline Lanes	AM Peak Hour		PM Peak Hour	
		Volume	Criteria Met?	Volume	Criteria Met?
Bates Street (Oakland)	3	2,466	No	4,349	Yes
Beechwood Boulevard (Squirrel Hill)	2	2,841	Yes	4,306	Yes
Braddock Avenue SB (Edgewood/Swissvale)	2	2,392	No	3,748	Yes
Braddock Avenue NB (Edgewood/Swissvale)	2	2,707	Yes	4,274	Yes
Ardmore Boulevard (Forest Hills)	3	2,421	No	4,141	No
Beulah Road (Churchill)	3	2,525	No	4,503	Yes
Churchill Road (Churchill)	3	2,630	No	4,662	Yes

On-Ramps to I-376 Westbound

Ramp	Number of Mainline Lanes	AM Peak Hour		PM Peak Hour	
		Volume	Criteria Met?	Volume	Criteria Met?
William Penn Highway (Churchill)	2	4,096	Yes	4,349	Yes
Ardmore Boulevard NB (Forest Hills)	2	3,454	Yes	3,336	Yes
Ardmore Boulevard SB (Forest Hills)	2	3,901	Yes	3,556	Yes
Braddock Avenue (Edgewood/Swissvale)	2	4,316	Yes	3,594	Yes
Beechwood Boulevard (Squirrel Hills)	3	5,991	Yes	4,646	Yes

7. **Ramp metering is warranted when the volume of the ramp plus the mainline right lane exceeds 2,100 vph. Is the criteria defined above met, during the design hour?**

The following summarizes the data from I-376 for criterion 7:

On-Ramps to I-376 Eastbound

Ramp	AM Peak Hour		PM Peak Hour	
	Volume	Criteria Met?	Volume	Criteria Met?
Bates Street (Oakland)	822	No	1,450	No
Beechwood Boulevard (Squirrel Hill)	1,421	No	2,153	Yes
Braddock Avenue SB (Edgewood/Swissvale)	1,196	No	1,874	No
Braddock Avenue NB (Edgewood/Swissvale)	1,354	No	2,137	Yes
Ardmore Boulevard (Forest Hills)	807	No	1,380	No
Beulah Road (Churchill)	842	No	1,501	No
Churchill Road (Churchill)	877	No	1,554	No

On-Ramps to I-376 Westbound

Ramp	AM Peak Hour		PM Peak Hour	
	Volume	Criteria Met?	Volume	Criteria Met?
William Penn Highway (Churchill)	2,048	No	1,579	No
Ardmore Boulevard NB (Forest Hills)	1,727	No	1,668	No
Ardmore Boulevard SB (Forest Hills)	1,951	No	1,778	No
Braddock Avenue (Edgewood/Swissvale)	2,158	Yes	1,797	No
Beechwood Boulevard (Squirrel Hills)	1,997	No	1,549	No

8. **Exception to volume criteria can be made if crash data is overwhelming in the opinion of the local district engineer.** *This criterion was not applied as criteria 6 and 7 we both met.*

DESIGN/SYSTEM CRITERIA – If operational and traffic criteria are met, then the location must meet both criteria 9 and 10 to be considered for ramp management.

9. **Does the existing or proposed ramp geometry permit safe and effective ramp metering and are adequate alternative routes available? The ramp should provide 450' of storage for ramp queues, a downstream acceleration lane at least 1000', and adequate sight distance from the arterial to the back of queue. Adequate alternative route must exist.**

The following summarizes the data from I-376 for criterion 9:

On-Ramps to I-376 Eastbound

Ramp	Queue Storage	Acceleration Length	Criteria Met?
Bates Street (Oakland)	1,140'	190'	No
Beechwood Boulevard (Squirrel Hill)	675'	120'	No
Braddock Avenue SB (Edgewood/Swissvale)	475'	95'	No
Braddock Avenue NB (Edgewood/Swissvale)	850'	310'	No
Ardmore Boulevard (Forest Hills)	3,375'	370'	No
Beulah Road (Churchill)	1,370'	Land Add	Yes
Churchill Road (Churchill)	590'	195'	No

On-Ramps to I-376 Westbound

Ramp	Queue Storage	Acceleration Length	Criteria Met?
William Penn Highway (Churchill)	910'	265'	No
Ardmore Boulevard NB (Forest Hills)	2,610'	190'	No
Ardmore Boulevard SB (Forest Hills)	1,840'	385'	No
Braddock Avenue (Edgewood/Swissvale)	1,560'	250'	Yes
Beechwood Boulevard (Squirrel Hills)	2,230'	Lane Add	No

This criterion will be difficult to meet on most 1950/1960 era urban interstates. During design, placement of the metering signals could be set back into the storage area to provide more acceleration length. This will need to be done on a case by case basis.

10. **Do the measures of effectiveness for an area-wide simulation model indicate a benefit to the freeway system while at the same time minimizing impacts on adjacent arterials?** *A review of the data supports implementation of ramp management along the I-376 corridor. More details on the area-wide simulation model are presented in the next section.*

Area-wide Simulation Model of Ramp Management Techniques on I-376
One of the recommended ramp metering criteria is a review of an area-wide simulation model and the forecasted impacts of ramp management over a wide-area of potential impact. For this task, a model of the east end of Pittsburgh was developed. **Appendix D** delineates the model area used in the analysis. A travel demand forecasting model was developed for the study area to define roadway operational conditions and identify existing origin-destination traffic patterns during the morning and evening peak travel hours. Selected options for ramp management were subsequently evaluated in the travel demand model to identify changes in route choice in response to the ramp management strategies. The routing patterns identified by the travel demand model for each zonal origin-destination pairing within the study area was incorporated into a parallel traffic simulation model to identify measures of effectiveness for ramp management.

Travel demand forecasting can be described as the process of developing traffic volume projections for a set of transportation features within a given analysis area from mathematical models of actual travel behavior. Such models typically include four major components; trip generation, trip distribution, mode choice, and traffic assignment. By implementing these four components, travel demand models can be calibrated to evaluate a multitude of scenarios such as alternative land development patterns, alternative demographic forecasts, major highway and transit initiatives such as the construction of new roadways, or even minor transportation improvements such as the addition of new travel lanes. The models are typically calibrated to match travel activity from an observed baseline (existing) condition. This ensures the validity of future travel estimates when evaluating alternative scenarios.

The travel demand model developed for the ramp management study area was implemented in the software package VISUM, Version 10 by PTV America. VISUM provides several unique features that make it well suited for urban roadway networks. These features include:

- Explicit consideration of intersection traffic control based on Highway Capacity Manual methods within the traffic assignment process;
- Origin-destination tracking capabilities from traffic assignment results at segment, intersection, and turn movement levels-of-detail;
- Origin-destination travel pattern estimating capabilities from segment traffic counts, intersection turn counts, and zonal origin-destination totals by trip type; and
- Data importing/exporting capabilities with other related software packages including Microsoft Excel, Synchro 7 by Trafficware, Inc, and VISSIM 5.1 by PTV America.

<u>Model Calibration</u>
The following steps provide an overview of the travel demand model calibration process for the ramp management study area:

- Establish baseline roadway network;
- Establish transportation analysis zones (TAZ) to allow aggregation of land-use information for individual parcels into common points of origin and destination;
- Document origin-destination patterns within the local study area from the large-scale regional travel demand model maintained by the Southwestern Pennsylvania Commission (SPC);

- Estimate existing zonal trip generation totals within the local study area from the large-scale model maintained by SPC;
- Adjust the origin-destination patterns implemented in the SPC model to better replicate existing traffic counts taken within the study area and existing trip generation estimates by TAZ;
- Initiate existing year traffic assignment through the model;
- Validate the existing year model with observed traffic counts; and
- Export origin-destination routing patterns to the traffic simulation model to identify measures of effectiveness.

A hybrid static/dynamic traffic assignment algorithm known as the Blocking-Back method was incorporated into the travel demand model for the ramp management study area. Rather than assigning a volume that exceeds link capacity like traditional static assignment procedures, the blocking-back method will estimate the queue lengths and queue waiting times that form at a bottleneck and spill back onto upstream links. Together with incremental traffic assignment to simulate the build-up of queues over time, the blocking back method provided the most efficient procedure to incorporate the impact of the Squirrel Hill tunnel on route choice behavior.

Appendix E provides scatter plots of observed versus modeled traffic flow conditions from the calibrated travel demand model. The plot illustrates a high degree of correlation between the actual counts and the model results, well exceeding calibration thresholds suggested by the US Department of Transportation, Travel Model Improvement Program.

<u>Area-Wide Traffic Simulation Model</u>

Traffic simulation models were prepared for the ramp management study area to provide visualization of traffic conditions and identify measures of effectiveness for various ramp management options. These types of models are based upon driver behavior at an individual vehicle level-of-detail. Driver behavior is defined stochastically based upon vehicle type/performance, car-following behavior, gap acceptance, lane-change behavior, and motorist reaction to traffic control devices.

The area-wide simulation models for the ramp management study area were developed within the software package VISSIM 5.1, published by PTV America. VISSIM is a microscopic, time step and behavior based simulation program that provides modeling functionality for both motor vehicle and public transit operations. The program can analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals, transit stop, and tolling operations. The program provides a multitude of measures of effectiveness for evaluation of transportation engineering/planning alternatives including number of stops, travel speeds, travel times, queue time, queue length, lane change maneuvers, and traffic control delay.

Calibration for the baseline VISSIM models was aimed primarily at replicating the morning and afternoon queue lengths on I-376 Parkway East as the Squirrel Hill Tunnel. The model was review by an expert panel of local transportation officials and adjusted, as necessary, based upon panel comments. Default values suggested by PTV America were generally incorporated into the model for driving conditions on the local street network. Merging behavior for traffic on I-376 was adjusted to provide a more aggressive distribution of acceleration and gap acceptance. Car following characteristics for traffic within the Squirrel Hill Tunnel were adjusted to replicate the increased headway spacing/variations within the narrow tunnel cross-section.

Origin-destination traffic patterns established in the VISUM travel demand model were imported directly into the corresponding VISSIM simulation model. The simulation model was executed a total of 5 times, each with a unique random number seed, to incorporate the statistical variability inherit to traffic simulation modeling. Measures of effectiveness were reported based on the average and standard deviation of the 5 traffic simulation runs. Comparison of ramp management alternatives to baseline conditions followed a one-sided paired Student's t-Test at a 95 percent confidence interval.

Simulation Model Measures of Effectiveness

Several measures of effectiveness (MOE's) were selected in collaboration with PennDOT 11-0, the City of Pittsburgh, and FHWA to review potential ramp management solutions along I-376.

Tunnel Queue – The Squirrel Hill Tunnel has been identified as a major bottleneck along I-376 and the length of queue is a significant indicator of congestion in this area.

I-376 Throughput – One of the reported benefits of ramp metering is an increase in mainline throughput due to decreased turbulence at upstream ramp junctions.

I-376 Travel Time – A primary benefit of ramp metering is to reduce congestion and thereby improve travel time.

I-376 Delay Time – Delay time is highly correlated with travel time as a measure of effectiveness.

Total System Travel Time – System-wide travel time is an overall measure of effectiveness that can determine if ramp management is moving congestion from the freeway onto the local street system.

Total System-wide Stops – System-wide number of stops can also be used as a surrogate statistic to determine if ramp management is moving congestion from the freeway onto the local street system.

Spot Queues at Critical Intersection – While system-wide travel time and system-wide number of stop can provide a global view of congestion within the system, a review of queues at critical intersections can identify the impacts on the local street network caused by ramp management. Queue increases over 200' were considered significant enough to summarize.

Internal Study Area Travel Times – One concern for the City of Pittsburgh is that local residents within the East End will be significantly impacted by ramp management. Travel time summaries by TAZ are provided for review. Travel time changes greater than one minute are reported.

Model Options

Two ramp management options were analyzed for the study area. The analysis was conducted for both the AM and the PM peak hour. **Appendix F** illustrates ramp management option 1 and ramp management option 2.

Option 1 – ramp management options

- Meter Braddock Avenue on-ramps to WB I-376 in the AM
- Meter Ardmore Boulevard on-ramp to WB I-376 in the AM
- Meter Greensburg Pike on-ramp to WB I-376 in the AM
- Meter Bates Street on-ramp to EB I-376 in the PM
- Meter Beechwood Boulevard on-ramp to EB I-376 in the PM
- Meter Braddock Avenue on-ramps to EB I-376 in the PM

Option 2 – ramp management options

- Close SB Braddock Avenue on-ramps to WB I-376 in the AM
- Close SB Ardmore Boulevard on-ramp to WB I-376 in the AM
- Meter NB Ardmore Boulevard on-ramp to WB I-376 in the AM
- Meter WB Greensburg Pike on-ramp to WB I-376 in the AM
- Meter Bates Street on-ramp to EB I-376 in the PM
- Close Beechwood Boulevard ramp to EB I-376 in the PM
- Close SB Braddock Avenue on-ramp to EB I-376 in the PM

During the development and review of these preliminary model results it was suggested that another option (Option 3) be evaluated, which was a phased approach option 2. Option 3 would analyze closing the Beechwood Boulevard eastbound on ramp in the PM peak hour.

Option 3 – ramp management options

- Close Beechwood Boulevard ramp to EB I-376 in the PM

After the model was run, local network congestion due to diverted traffic was identified. To mitigate localized congestion within the local street network, several intersection mitigation improvements have been recommended in conjunction with the ramp management options. These assumptions include the following improvements:

Option 1 – required local network mitigation

1. Beechwood/Hazelwood – Revise pavement markings to provide one EB thru lane and one EB right-turn lane on Hazelwood Ave.

2. Ardmore/Swissvale – Revise pavement markings to provide WB thru lane and WB thru-right-lane on Ardmore.

Option 2 – required local network mitigation

1. Hazelwood/Murray – Revise pavement markings to provide a SB right-turn lane on Murray.
2. Greenfield/Saline – Remove NB left-turn phase. Construct WB left-turn lane.
3. Greenfield/Hazelwood – Construct traffic signal.
4. Beechwood/Hazelwood – Revise pavement markings to provide one EB thru lane and one EB right-turn lane on Hazelwood Ave.
5. Swissvale/Race – Revise pavement markings to provide EB right-turn lane on Race St. Construct traffic signal.
6. Swissvale/Ross – Construct NB right-turn lane on Swissvale.
7. Ardmore/Brinton – Construct NB right-turn lane on Brinton.
8. Hobart/Shady – Construct traffic signal.
9. Ardmore/Swissvale – Revise pavement markings to provide WB thru lane and WB thru-right-lane on Ardmore.
10. Boulevard of the Allies/Dawson – Revise pavement markings to provide NB right-turn lane on Dawson.
11. Brashear/Braddock – Construct traffic signal.
12. Fifth/Bellefield – Revise pavement markings to provide three WB lanes and one egress lane on Fifth Avenue.
13. Ardmore/South – sign for right-in/right-out on South with YIELD sign.

Option 3 – required local network mitigation

1. Hazelwood/Murray – Revise pavement markings to provide a SB right-turn lane on Murray.
2. Greenfield/Saline – Remove NB left-turn phase. Construct WB left-turn lane.
3. Greenfield/Hazelwood – Construct traffic signal.
4. Beechwood/Hazelwood – Revise pavement markings to provide one EB thru lane and one EB right-turn lane on Hazelwood Ave.
5. Swissvale/Race – Revise pavement markings to provide EB right-turn lane on Race St. Construct traffic signal.
6. Swissvale/Ross – Construct NB right-turn lane on Swissvale.
7. Ardmore/Brinton – Construct NB right-turn lane on Brinton.

8. Hobart/Shady – Construct traffic signal.

9. Ardmore/Swissvale – Revise pavement markings to provide WB thru lane and WB thru-right-lane on Ardmore.

10. Boulevard of the Allies/Dawson – Revise pavement markings to provide NB right-turn lane on Dawson.

11. Brashear/Braddock – Construct traffic signal.

12. Fifth/Bellefield – Revise pavement markings to provide three WB lanes and one egress lane on Fifth Avenue.

13. Ardmore/South – sign for right-in/right-out on South with YIELD sign.

Model Results

Appendix G summarizes the AM and PM peak hour simulation measure of effectiveness for two ramp management options. **Appendix H** summarizes the results of the queuing comparisons between options. **Appendix I** summarizes routes within the study where traffic is forecasted to divert based upon the ramp management option selected. **Appendix J** summarizes the network-wide travel times by TAZ for each option.

A. Option 1 Results Summary

For Option 1, the following MOE's were identified by a statistically significant change:

<u>Option 1 – AM Peak Hour</u>
Tunnel Queue – Westbound decrease (2,480')
I-376 Travel Time – Westbound decrease (77 seconds)
I-376 Delay Time – Eastbound increase (9 seconds)
I-376 Delay Time – Westbound decrease (77 seconds)
Network Stops – decrease (16%)
Queue Hot Spots
- Penn Avenue at Hay Street (increase)
- Panther Hollow at Schenley Drive (decrease)
- Old Gate Road at William Penn Highway (increase)
- Murray Avenue at Pocusset Street (decrease)
- Greenfield Bridge at Pocusset Street (increase)
- Forward Avenue at Tilbury Avenue (increase)
- Edgewood at Maple (decrease)
- East Swissvale Avenue at Race Street (decrease)
- Brasher Street at S. Braddock Avenue (increase)
- Boulevard of the Allies at Parkview Avenue (increase)
- Bartlett Street at Panther Hollow Road (increase)

Internal Study Area Travel Times
- Zone 18 (City of Pittsburgh) (-2.0 minutes)
- Zone 19 (City of Pittsburgh) (-3.1 minutes)
- Zone 20 (City of Pittsburgh) (-3.7 minutes)
- Zone 21 (City of Pittsburgh) (+2.8 minutes)
- Zone 23 (City of Pittsburgh) (+1.8 minutes)
- Zone 30 (City of Pittsburgh) (-1.3 minutes)
- Zone 1028 (City of Pittsburgh) (-1.8 minutes)

Zone 1033 (City of Pittsburgh) (-1.2 minutes)
All internal zones (-0.2 minutes)

Option 1 – PM Peak Hour
Network Stops – increase (9%)
Queue Hot Spots
Monongahela Avenue at Whipple Street (increase)
Frazier St/Swinburne Bridge at Greenfield Avenue (increase)
Forbes Avenue at Schenley Drive (increase)
Forbes Avenue at Morewood Avenue (decrease)
Bigelow Boulevard at Schenley Drive (increase)
Beulah Rd at William Penn Hwy (decrease)
Beechwood Boulevard at Monitor Street (decrease)
Beechwood Boulevard at Hazelwood Avenue (increase)
Bates Street Ramp from I-376 WB (increase)
Bates Street at McKee Place (increase)
Alger Street at Greenfield Bridge (increase)
2^{nd} Avenue at Bates Street (decrease)
Internal Study Area Travel Times
No local zones >1.0 minutes
All internal zones (-0.1 minutes)

B. Option 2 Results Summary
For Option 2, the following MOE's were identified by a statistically significant change:

Option 2 – AM Peak Hour
Tunnel Queue – Westbound decrease (10,800')
I-376 Throughput – Westbound increase (16%)
I-376 Travel Time – Eastbound increase (10 seconds)
I-376 Travel Time – Westbound decrease (334 seconds)
I-376 Delay Time – Eastbound increase (10 seconds)
I-376 Delay Time – Westbound decrease (334 seconds)
Network Travel Time – Increase (6%)
Network Stops – Decrease (32%)
Queue Hot Spots
Panther Hollow at Schenley Drive (decrease)
Old Gate Road at William Penn Highway (increase)
Greenfield Avenue at Saline Street (increase)
Frazier St/Swinburne Bridge at Greenfield Avenue (increase)
Forward Avenue at Tilbury Avenue (increase)
Forbes Avenue at Dallas Avenue (increase)
Forbes Avenue at S. Braddock Avenue (decrease)
Edgewood at Maple (decrease)
East Swissvale Avenue at Race Street (decrease)
Brasher Street at S. Braddock Avenue (decrease)
Beulah Rd at Churchill Road (increase)
Ardmore Avenue at Ross Avenue (increase)
2^{nd} Avenue at Irvine Street (increase)
Internal Study Area Travel Times
Zone 7 (City of Pittsburgh) (+1.2 minutes)

- Zone 18 (City of Pittsburgh) (-1.6 minutes)
- Zone 19 (City of Pittsburgh) (-1.7 minutes)
- Zone 20 (City of Pittsburgh) (-3.6 minutes)
- Zone 21 (City of Pittsburgh) (+1.7 minutes)
- Zone 23 (City of Pittsburgh) (+1.6 minutes)
- Zone 26 (Wilkinsburg) (+1.2 minutes)
- Zone 30 (City of Pittsburgh) (-1.7 minutes)
- Zone 1028 (City of Pittsburgh) (-1.9 minutes)
- Zone 1032 (City of Pittsburgh) (+2.0 minutes)
- All internal zones (-0.2 minutes)

<u>Option 2 – PM Peak Hour</u>

Tunnel Queue – Eastbound decrease (3,306')
I-376 Throughput – Eastbound increase (14%)
I-376 Travel Time – Eastbound decrease (253 seconds)
I-376 Travel Time – Westbound increase (54 seconds)
I-376 Delay Time – Eastbound decrease (253 seconds)
Network Stops – Decrease (13%)
Queue Hot Spots

- South Avenue at Swissvale Avenue (increase)
- Pennwood Avenue at Race Street (increase)
- Penn Avenue at N. Braddock Avenue (increase)
- Panther Hollow at Schenley Drive (decrease)
- Monongahela Avenue at Whipple Street (increase)
- Frazier St/Swinburne Bridge at Greenfield Avenue (increase)
- Forbes Avenue at Schenley Drive (increase)
- Forbes Avenue at Morewood Avenue (decrease)
- 5th Avenue at Darragh Street (increase)
- Edgewood at Maple (increase)
- Commercial Street at Whipple Street (increase)
- Brasher Street at S. Braddock Avenue (increase)
- Beulah Rd at William Penn Hwy (decrease)
- Beechwood Boulevard at Hazelwood Avenue (increase)
- Bates Street Ramp from I-376 WB (decrease)
- Ardmore Boulevard at South Avenue (increase)
- 5th Avenue at Halket Street (increase)
- 5th Avenue at Craft Avenue (increase)
- 2nd Avenue at Bates Street (increase)

Internal Study Area Travel Times

- Zone 6 (City of Pittsburgh) (+2.8 minutes)
- Zone 9 (City of Pittsburgh) (+1.1 minutes)
- Zone 10 (City of Pittsburgh) (+1.8 minutes)
- Zone 25 (City of Pittsburgh) (+1.7 minutes)
- Zone 25 (Wilkinsburg) (+1.7 minutes)
- Zone 26 (Wilkinsburg) (+1.0 minutes)
- Zone 32 (Wilkinsburg) (+1.2 minutes)
- Zone 57 (Wilkinsburg) (+1.5 minutes)
- Zone 1028 (City of Pittsburgh) (+1.3 minutes)
- Zone 1035 (City of Pittsburgh) (+3.7 minutes)
- All internal zones (-0.2 minutes)

C. Option 3 Results Summary
For Option 3, only a PM peak hour analysis was performed. The following MOE's were identified by a statistically significant change:

Option 3 – PM Peak Hour
Tunnel Queue – Eastbound decrease (1,218')
I-376 Throughput – Eastbound increase (7%)
I-376 Travel Time – Eastbound decrease (112 seconds)
I-376 Delay Time – Eastbound decrease (112 seconds)
Network Stops – Decrease (8%)
Queue Hot Spots
- Pennwood Avenue at Race Street (decrease)
- Panther Hollow at Schenley Drive (decrease)
- Monongahela Avenue at Whipple Street (increase)
- Frazier St/Swinburne Bridge at Greenfield Avenue (increase)
- Forbes Avenue at Morewood Avenue (decrease)
- Brasher Street at S. Braddock Avenue (increase)
- Boulevard of the Allies at Dawson Street (decrease)
- Beulah Rd at William Penn Hwy (decrease)
- Beechwood Boulevard at Monitor Street (decrease)
- Beechwood Boulevard at Hazelwood Avenue (increase)
- Bates Street Ramp from I-376 WB (decrease)
- 2nd Avenue at Hot Metal Street (increase)
- 2nd Avenue at Bates Street (increase)

Internal Study Area Travel Times
- Zone 11 (City of Pittsburgh) (-1.1 minutes)
- Zone 1033 (City of Pittsburgh (-1.3 minutes)
- All internal zones (-0.2 minutes)

An issue of concern is ramp queuing beyond the amount of available storage. For options 1 and 2, ramp metering queues were confined to the existing ramp storage area. No ramp queues extended back onto the arterial street system.

A comparison of the two options indicates that option 2 provides a more statistically significant reduction in commuter congestion in both the AM and PM peak hour. Option 3 was analyzed for the PM peak hour only as an interim phase to fully implementing Option 2.

Preliminary Review of TMC Capabilities to Incorporate Ramp Management on I-376
TA has met with PennDOT District 11-0 Traffic Management Center Personnel to determine the ability of the current ITS system along I-376 Parkway East to accommodate the proposed ramp management strategies.

PennDOT current operates Highway Advisory Radios (HAR), Dynamic Message Signs (DMS) and closed circuit surveillance cameras along I-376 in the project corridor. All of these features are controlled by the PennDOT Traffic Management Center located in the District Office in Bridgeville Pennsylvania. Information is sent and gathered from the devices by fiber optic communication lines. PennDOT personnel stated that the current fiber optic lines could accommodate the additional proposed ramp metering devices.

In constructing the PennDOT Traffic Management Center architecture, ramp metering was not anticipated. However, PennDOT personnel have indicated that the existing Center architecture was capable to accept this type of expansion.

The City of Pittsburgh operates a traffic responsive signal system in the central business district (CBD) of the city. This system is referred to as the Computerized Traffic Responsive Traffic Control System (CTRTCS). Communication from the traffic signal controllers in the field to a central computer in the City-County Building is accomplished by use of fiber-optic cable. The CTRTCS system gathers traffic volume information on the roadway network by use of in-pavement detectors. This information is then sent back to the central computer, which in turn selects traffic plans for the field intersections to operate under. Other information such as various alarms and failures can be relayed from the field controllers to the central computer.

TA has been informed by City personnel that the existing CTRTCS communication system is currently operating at its maximum capacity. The capability of adding additional intersections or information to this current system is limited. The CTRTCS system does not currently include, nor are there plans to expand the system to the signalized intersections, included in the study area of this report. However, The City of Pittsburgh is currently in the design stages to expand the CTRTCS system to the following sections of the City:

- North Shore
- Penn Circle
- South Side
- South Hills
- Oakland

In addition to these expansions, there are plans to connect the CTRTCS system to the PennDOT Traffic Management Center for shared use of information. These expansions are in the early stage of design and no definite information on there operation or construction schedule could be obtained.

Conclusion

Based upon a review of the ramp metering criteria, I-376 has the appropriate volume and congestion levels to consider ramp management as an alternative solution to reducing congestion. The simulation model shows that Option 2, which is a combination of ramp metering and ramp closure strategies, would provide the most effective congestion reduction. However it is also noted that option 1 does also have a positive impact in the reduction of overall system performance. Option 3 (PM ramp closure only from Beechwood Boulevard EB) was analyzed as an interim phase to full implementation of Option 2. The results show that implementing Option 3 would also have positive congestion reducing benefits as an interim step to implementing Option 2.

With this congestion reduction, several local street routes will experience an increase in traffic; however, with the proposed mitigation strategies, this congestion will be alleviated. This evaluation has demonstrated that ramp management techniques along the I-376 corridor can provide significant congestion reduction benefits, while having manageable impacts on the local street network. The PennDOT TMC is capable of expanding its current system to incorporate ramp management operations. It is recommended that Option 2 be evaluated for the next task which is development of an operating plan, capital costs and operating cost estimates.

Chapter 6
Designing a Ramp Management Conceptual Plan and Cost Estimate for I-376 in the Squirrel Hill Area

The results of the traffic analysis/simulation for the I-376 corridor concluded that there are substantial benefits to be derived from the installation of a ramp management system which includes arterial traffic signal improvements. This Chapter does into further detail to describe a conceptual ramp management project to reduce congestion on I-376. This description includes an operational plan, a summary of capital and operating costs, and a timeline for implementation. This task also identifies a possible intergovernmental cooperation agreement for operation of the system.

A ramp management system for I-376 would be an integral component of the existing freeway management system operated by PennDOT District 11-0 from their traffic management center (TMC) in Bridgeville, PA. Existing elements of the freeway management system can be expanded to provide for the operation of the ramp management system, specifically the communication and surveillance systems currently in use on I-376. In addition, recommended upgrades to the existing local roadway traffic signal system could be operated by the TMC. Operation and maintenance issues related to the ramp management system have been identified along with an opinion of probable cost for the implementation of a ramp management system. Assumptions related to the operations and maintenance of the ramp management system will influence the overall cost of the system. In addition to the costs associated with the ramp management system, offline improvements to the local street system have been incorporated in the costs.

The following provides the results of these findings relative to the ramp management operational plan, a ramp management maintenance plan, local roadway network improvements, estimated capital and operating costs, timeline for implementation and intergovernmental cooperation agreements.

Ramp Management Operational Plan

The recommended ramp management operational analyses have examined the potential strategies that may be utilized to operate the meters, a recommended operational plan for the meters, and a description of the recommended types of meter installations, and a ramp closure operational plan with a recommended installation type.

The development of a preferred ramp metering strategy is essential in determining the needs and the design of the ramp management system.

<u>Restrictive vs. Non-Restrictive Ramp Metering</u>

Restrictive ramp metering – sets the metering rate below the non-metered ramp volume. A restrictive ramp metering strategy leads to longer queues and increased traffic diversions by reducing the ramp capacity and increasing the upstream flow rate on the mainline freeway. Restrictive ramp metering typically leads to improved mainline operations as the entering ramp traffic is restricted below a theoretical operational capacity.

Non-restrictive ramp metering – sets the metering rate equal to the average ramp arrival volume. With metering, improved mainline flow is achieved primarily through smoothing the merging traffic onto the mainline. Non-restrictive metering typically results in shorter queues and less traffic diversion; however, operational improvements to mainline freeway operations are typically less when compared to restrictive metering.

Ramp Metering Coordination

Local metering – refers to operation of individual ramp meters by measuring conditions local to the specific ramp being metered.

System-wide metering –utilizes data from the entire freeway system to coordinated system-wide operations and metering rates.

Selection of Metering Rates

Operator selected rates – operator inputted metering rates used to address special conditions. This can be done at the controller site or remotely via the TMC.

Fixed metering rates – A fixed time metering rate can be programmed into the controller. Freeway detection systems are not required for establishing fixed metering rates. This method requires frequent observation and adjustment of metering rates depending upon traffic conditions.

Traffic responsive metering rates – computer algorithms are used to calculate or select metering rates for local or system-wide ramp meters using real-time data from the freeway detector system. Local traffic responsive metering typically uses open loop occupancy control based upon mainline occupancy or closed loop occupancy control based upon downstream occupancy. System-wide traffic responsive metering is achieved through analysis of real time data using specific algorithms. Examples of such system-wide algorithms are the Minnesota Algorithm, the Washington State Algorithm, Fuzzy Logic, and the SWARM Algorithm.

Metering Schedule

Pretimed (time of day/day of week scheduling) – ramp meters will only operate at certain times of the day regardless of the traffic conditions. Pretimed programs can be overridden for weekends, holidays, special events, and freeway incidents. When operating on a pretimed schedule, the local controller can set the metering rate using pre-programmed fixed rates or variable traffic responsive rates.

Traffic responsive scheduling – in this mode, the ramp metering system can become active at any time based upon real-time traffic conditions. Local meters can turn on individually or system-wide depending upon the type of coordination being used.

Recommended Metering Strategy

For the I-376 corridor evaluation, the travel demand model/simulation utilized a restrictive ramp metering strategy. For the initial installation, the research team recommends that the I-376 ramp management system utilize traffic responsive ramp metering with local control operating on a pretimed schedule. Each ramp should have a queue over-ride which will prevent the queues from spilling back onto the local street network. This type of operation will provide a restrictive operation when queues can be stored on the ramps and a non-restrictive operation when queue pre-emption is put into operation.

For the initial ramp metering operation, a defined pretimed time of day/day of week schedule will help drivers become acclimated to the new system. Eventually, the system can be operated in the traffic responsive scheduling mode which will allow the system to activate during periods of non-recurring congestion (incidents, holidays, or special events). It is recommended that additional analysis using the simulation model be performed once the ramps queue areas are better defined, and then develop an initial pretimed rate for each timing period.

Future upgrades to the system could include system-wide traffic responsive operation. There are a number of system-wide traffic responsive ramp metering algorithms including the Minnesota Algorithm, the Washington State Algorithm, Fuzzy Logic, and the SWARM algorithm.

It is also noted that the simulation modeling shows that additional traffic will be attracted to I-376 when travel times are reduced. These additional trips originate from beyond the areas of restrictive metering. It maybe necessary to evaluate the need to extend the metering further to the east or west to maintain the performance improvement forecasted.

Ramp Meter Operation
Each ramp meter location will require the following field components:

Signal Displays – A two-section red-green display shall be post mounted at the stop bar of the ramp being metered. Two post mountings will be required for each ramp, one on each side of the ramp, to provide the necessary two signal indications per approach. Special wall mountings may be required where adequate area is not provided for post mounted signals. Chapter 4H of the MUTCD addresses the display requirements in more detail.

Advance metering beacons - Advance ramp metering signs with flashing yellow beacons shall be provided on each ramp being metered and along the adjacent local street within ¼ mile of the ramp being metered.

Local Controller – A local controller is required to operate the signal, process detector data, and control the ramp meter timing. Type 170 controllers have a history of providing ramp metering control. The local controller will operate the signal indications, store pretimed metering schedules, implement local traffic responsive control algorithms using mainline detector data, communicate with the central control system, operate with the queue detection system, and control the advance metering beacons.

Vehicle Detectors – Various detectors are required to measure traffic conditions along the mainline freeway and ramps. To minimize construction costs, maintenance costs, and lane closures, video detection is recommended for the freeway system. Video detection allows flexibility in the location of detection zones and the type of detection being use. For ramp management, the following detection types are required:

Demand detector – located at the stop bar to signal the controller of a vehicle waiting for a green indication.

Passage detector – located just beyond the stop bar. The passage detector will immediately terminate the green indication as soon as the vehicle leaves the stop bar.

Queue detector – located at the top of the entry ramp to prevent vehicles from spilling back onto the local street system. Detection of a vehicle queue can trigger an increased metering rate or a termination of metering.

Merge detector - used in some installations to sense if a vehicle is stopped in the merge area. If a vehicle stops in the merge area, the red indication for the next vehicle can be extended if necessary to prevent merging congestion.

Mainline detectors – used to obtain vehicle flow, speed, and occupancy rates for traffic responsive metering.

Flow control at the ramp meter – Initially, the I-376 system will be operated with single entry metering, which will permit only one vehicle to enter the freeway per green interval. The signal will operate in red rest until actuated by the calling detector. Metering rates up to 900 vph can be achieved with single entry metering.

Sample metering rates

Ramp volume	*Metering rate*
900 vph	*4 seconds*
800 vph	*4.5 seconds*
700 vph	*5.1 seconds*
600 vph	*6 seconds*

Queue management – A queue detector will be used to limit the impacts of the ramp metering system on the local street network. Different queue control strategies could be utilized for the I-376 system. Typical strategies involve either increasing the meter rate as a function of the queue detector occupancy or terminating ramp metering for a specific period of time until the queue clears. A more sophisticated queue management strategy involves limiting motorist waiting time in the queue by decreasing the metering rate as vehicle wait times on the ramp increase.

Communication with TMC – communication between the local controllers and the TMC will be via the existing fiber optic ITS communication cable along I-376.

Ramp Closure Operations and Installation

Various types of ramp closure operations can be implemented. For I-376, it is recommended to limit the ramp closures to a specific time of day/day of week schedule corresponding to the times of recurring congestion on I-376. At locations where ramp closures are planned, ramp meters will also be installed. The ramp meters at these locations would only operate in the event that the ramp closure system malfunctions or if the system is allowed to run in traffic responsive scheduling mode, whereby the meters activate outside the typical commuter congestion periods.

Automated barriers would be installed at the top of each ramp to provide local or remote operation of the ramp closure system. The gates can be controlled by type 170 controllers. Advance ramp closure signs with flashing yellow beacons shall be provided on each ramp being closed and along the adjacent local street within ¼ mile of the ramp being metered. For the ramps to be closed, the advanced warning signs would likely need to contain a variable message indicating if the ramp is closed or being metered.

Ramp Management System Maintenance

The Department will need to evaluate if in-house personnel have the capability to maintain the ramp management system. Qualified electricians will be required to perform scheduled maintenance and respond to emergency service calls for the system. Qualified traffic engineers will be required to evaluate system performance and to perform timing adjustments. Qualified

TMC operators will be required to monitor the surveillance equipment and to activate/deactivate the ramp metering system under special conditions.

A schedule of quarterly and annual preventive maintenance activities should be developed to minimize the number of emergency service calls related to the system. The costs associated with these activities, based upon other state's experience have been included in this report.

Local Roadway Network Improvements to Implement Ramp Management on I-376
A unique aspect of this research is to document the forecasted offline impacts of operating a ramp management system on I-376. Traffic volumes on the local street system are forecasted to increase due to ramp management of I-376. The forecasted volume changes are based upon the restrictive metering rates assumed in the simulation. Prior to proceeding with implementation of these improvements metering rates should be studied in more detail. Offline improvements such as lane restriping and traffic signal upgrades will be needed to efficiently manage the local street network.

One of the offline improvements necessary to manage the local street traffic is an upgrade of the existing traffic signal system. An expansion of the City of Pittsburgh's central traffic signal system into Oakland and the East End is recommended. To make the system truly regional, interconnection of several traffic signals in Edgewood, Wilkinsburg, Forest Hills, and Churchill is also recommended. To accomplish this effort, approximately 20 miles of fiber optic interconnect cable will be required along with upgrades/replacement of 72 traffic signals. **Appendix L Figure 1** identifies the assumed fiber optic connections and traffic signal locations to be improved.

In addition to the traffic signal upgrades, twelve intersection improvements have been identified to accommodate projected traffic diversions.

1. Hazelwood/Murray – Revise pavement markings and remove parking to provide a SB right-turn lane on Murray.

2. Greenfield/Saline – Remove NB left-turn phase and construct WB left-turn lane.

3. Greenfield/Hazelwood – Construct traffic signal.

4. Swissvale/Race – Construct traffic signal

5. Swissvale/Ross – Stripe a NB right-turn lane on Swissvale.

6. Ardmore/Brinton – Stripe shoulder to provide a NB right-turn lane on Brinton.

7. Hobart/Shady – Construct traffic signal.

8. Penn/Swissvale – Revise pavement markings to provide WB thru lane and WB thru-right-lane on Penn. Parking may have to be restricted along Penn Avenue westbound.

9. Boulevard of the Allies/Dawson – Revise pavement markings to provide NB right-turn lane on Dawson. Some parking may have to be removed.

10. Brashear/Braddock – Construct traffic signal.

11. Fifth/Bellefield – Revise pavement markings to provide four WB lanes and one egress lane on Fifth Avenue.

12. Ardmore/South – sign for right-in/right-out on South with YIELD sign.

The above improvements are shown graphically in the **Appendix K**.

Ramp Management Capital and Operating System Costs
A preliminary opinion of probable cost for the implementation of the ramp metering and closures has been developed. In task 5 there were two options presented. Option 1 included metering only on all ramps studied. Option 2 included closure of specific ramps in addition to metering of other ramps. As described in the operational plan, those ramps recommended for closure during high traffic volume periods are also recommended for metering when volume permit this type of operation. The difference in capital costs between the two options is not significant. However, these differences are noted in this section of the report. Also the differences between the two options relative to operating costs are not significant if it is assumed that all ramp closure equipment is operated by the TMC and does not require manual operation. This difference is also noted in this section.

This probable option of cost is based upon price data provided by FHWA for recent ramp metering systems and a review of historic price data for similar work documented in previous tasks of this research from the other states contacted. Elements to be considered in the opinion of probable cost include the instillation of the ramp management equipment, the cost to upgrade the PennDOT TMC, costs associated with the local roadway network improvements, and engineering costs associated with the design. The following is a summary of the capital and operating costs.

Preliminary Opinion of Probable Capital Costs
The preliminary opinion of probable capital costs and the assumptions used to formulate the costs are summarized below. A detailed breakdown of assumption is included in the **Appendix L**.

Interchange Ramp Meters and Closures Costs
The following summarizes the anticipated costs for installing the ramp management system along I-376, this cost assumes both metering and closure equipment for option 2, and the ramps were both are assumed are noted:

Bates Street Interchange	$115,000
Squirrel Hill Interchange (metering and closure)	$155,000
Swissvale/Edgewood Interchange (metering and closure)	$385,000
Forest Hills Interchange (metering and closure)	$255,000
Churchill Interchange	$110,000
20% contingency	$209,000
Subtotal for ramps	**$1,224,000**

Appendix L Figures 2 to 6 depict conceptual equipment requirements at each interchange to implement the ramp management system.

A total of 8 ramps will be managed, at an average construction cost of approximately $153,000 per ramp. This cost is somewhat higher than the averages found in other locations; however, none of the historical cost data included a combined ramp meter/ramp closure system.

PennDOT TMC Upgrades Costs

TMC Software and system integration	$200,000
Traffic signal control software and system integration	$140,000
20% contingency	$68,000
Subtotal for TMC Upgrades	**$408,000**

Local Roadway Network Upgrade Costs

It is assumed that all traffic signals along roadways with an increase in diverted traffic volumes must be in communication with the PennDOT TMC so that the timings can be changed by the operator at TMC or by a traffic responsive system monitored by the TMC. Also it assumed that on the local roadway network, 72 signalized intersections will need to be upgraded or at a minimum retimed for optimal efficiency. The signal system upgrade would also include a surveillance system for monitoring major arterials. Intersection improvements involving 4 new traffic signals and lane restriping at various locations have been assumed.

Fiber optic installation	$416,000
Traffic signalized upgrades	$558,000
Surveillance system	$75,000
New traffic signal/intersection restriping	$650,000
20% contingency	$339,800
Subtotal for local network improvements	**$2,038,800**

Summary of Preliminary Estimate of Probable Costs

Assume engineering will be 25% of the estimated construction cost.

Subtotal for ramps (including closure equipment)	$1,224,000
Subtotal for TMC Upgrades	$408,000
Subtotal for offline improvements	$2,038,800
Construction Subtotal	**$3,670,800**
Engineering (25%)	**$917,700**
TOTAL OPINION OF CAPITAL COST	**$4,588,500**

The total capital cost of **$4,588,500** is for the **option 2** plan. If **option 1** were implemented, without ramp closure equipment, the estimated capital cost is **$3,253,500**. The cost for option 1 is reduced due to the elimination of the ramp gates and software, and the new traffic signal/intersection stripping. Only the intersection of Ardmore Boulevard and Swissvale Boulevard will need to be stripped in this option.

Operational/Maintenance Costs

Other state agencies have reported annual maintenance costs vary between $900 and $5,000 per ramp installation. Assuming 8 ramps, the annual operational and maintenance costs can be anticipated to range from $7,200 to $40,000. It is recommended that due to PennDOT's inexperience with these types of installation an annual budget of $40,000 for maintenance be programmed. This would not include the additional operational costs for the TMC. It is assumed that the costs for operators and maintenance of software and systems would not increase from present costs. These would be estimated costs for option 1. For option 2 if the ramp closures were operating remotely by the TMC the costs would be similar. However if manual operation of the ramp closures were implemented costs would be higher.

Timeline for Implementation

The implementation of the ramp management system will require several project development steps achieve construction and operation of the ramp metering system. The following is a brief summary of each step and the estimated time for completions.

Conceptual Design Completion and Intergovernmental Cooperation Agreements

The work completed to date will require additional conceptual level engineering to define in more detail the operational plan and installation requirements. This task is recommended to ensure that the full benefits of the project can be measured by examining the measures of effectiveness developed for a full year of operation. This will require the analysis of peak and off peak traffic data and the further analysis of benefits using the model developed. This analysis will better refine the proposed days and times of operation and benefits achieved.

This task would also develop a similar operational plan for the local traffic signal roadway network. A conceptual intergovernmental agreement is also recommended to be developed during this task. Also during this task a more refined design plan and cost estimates are recommended to be developed for programming purposes. A particular issue that should be investigated in more detail during this task would be feasibility of widening existing ramps for two lanes of storage which could greatly improve the operating efficiency of the system.

This agreement or, memorandum of understanding, would be developed between Penn DOT, the City of Pittsburgh and the other 4 municipalities that currently have ramp and traffic signals impacted by the plan. It is estimated that this task will require 6 months for completion. Such an agreement is recommended prior to proceeding with detailed design plans. A sample agreement is included in the **Appendix M**.

Design Development and Completion of Plans, Specifications and Cost Estimates

This task will perform the PennDOT project development process of creating a plans, specifications and estimate (PS&E) package needed for bidding of the project. These tasks assume separate design, bid, and build processes and not a design/build project delivery method.

While design/build is current being used by PennDOT for many ITS projects, this project is unique to PennDOT and may not be desirable for that type of delivery system. The aspects of the project that maybe the most concern would be the integration of the ramp systems and traffic signal operations into the TMC. The use of a design/build contract for this integration may not provide specific enough information to the bidders and could result in an undesirable operating system.

Using the traditional design development process the required steps of development of a design field view submission and final PS&E submission would be followed. The estimated time for completion of this portion of the project is estimated to be 12 months. Because there is currently a project being developed for work on I-376 it maybe possible to add this work to a PS&E contract that is currently in development, which would require the acceleration of the design. Under these conditions the design process maybe shortened to 6 months.

Construction and Testing
The actual construction of the system would be similar to other ITS construction projects completed by Penn DOT. Equipment procurement would be the first portion of the construction schedule to be followed by installation. Total time period for the construction is estimated to be 12 months. It is recommended that due to the unique aspects of the project relative to the operating system and integration into the TMC that a 6 month testing period be specified in the contract to ensure that all systems are operating properly for a significant time period. Total time for the construction and testing is estimated to be 18 months.

In summary the total project implementation period for the ramp management system is estimated to be 36 months or 3 years. Using an accelerated schedule for design or perhaps a design/build delivery method could reduce the schedule to 30 months.

Potential Phasing Options for Implementation
A third option (Option 3) was analyzed as an interim phase before full implementation of Option 2. Option 3 would provide for a PM peak hour ramp closure at the Beechwood Boulevard on-ramp to I-376 eastbound. This option could be implemented as a stand-alone project with its own measurable operational improvements along I-376. The cost to implement Option 3 as an interim phase is estimated to be **$632,750**.

Intergovernmental Cooperation Agreement
The implementation of the ramp management system could be achieved by two basic scenarios of operation. The first scenario would involve using the current requirements for operating and maintenance of traffic control devices per the motor vehicle code in Pennsylvania.

This would scenario require PennDOT to operate the ramp meters and closure devices along with future maintenance costs and also require each of the 5 local municipalities to operate and maintain the local traffic signal networks to be installed as part of the project. This option may not desirable because the local municipalities do not currently have capability to operate the type of demand responsive traffic signal system that maybe implemented along with the traffic surveillance equipment.

For the system to operate and respond to changing traffic conditions one operator of the system, PennDOT, is recommended to be given the responsibility. The precedent for this type of operation has been achieved in the Philadelphia area by district 6-0 which operates traveler information systems on local roadways. The anticipated type of operating agreement would be similar but would be unprecedented in the state of Pennsylvania. The agreement would relinquish the operating responsibility of the local traffic signal system installed by PennDOT to PennDOT on the local roadway networks impacted to PennDOT and operated remotely by the TMC. The local municipalities would still be required to maintain the system. Attached to this report is the agreement that was utilized in PennDOT District 6-0 that maybe similar to that which would be needed for this project.

Conclusion and Summary
For the I-376 corridor evaluation, the travel demand model/simulation utilized a restrictive ramp metering strategy. For the initial installation, we recommend that the I-376 ramp management system utilize traffic responsive ramp metering with local control operating on a pretimed schedule. Each ramp should have a queue over-ride which will prevent the queues from spilling back onto the local street network.

For the initial ramp metering operation, a defined pretimed time of day/day of week schedule will help drivers become acclimated to the new system. Eventually, the system can be operated in the traffic responsive scheduling mode which will allow the system to activate during periods of non-recurring congestion (incidents, holidays, or special events).

Future upgrades to the system could include system-wide traffic responsive operation. There are a number of system-wide traffic responsive ramp metering algorithms including the Minnesota Algorithm, the Washington State Algorithm, Fuzzy Logic, and the SWARM algorithm.

Improvements will be necessary to manage the local street traffic. An expansion of the City of Pittsburgh's central traffic signal system into Oakland and the East End is recommended. To make the system truly regional, interconnection of several traffic signals in Edgewood, Wilkinsburg, Forest Hills, and Churchill is also recommended. To accomplish this effort, approximately 20 miles of fiber optic interconnect cable will be required along with upgrades/replacement of 72 traffic signals.

To operate and maintain the system, personnel will be required that are qualified in both ramp systems and traffic signal systems. A schedule of preventive maintenance activities should be developed. The costs associated with these activities, based upon other state's experience have been included in this report.

The total estimated capital cost of the system is $4,588,500 is for the option 2 plan. If option 1 was implemented, without ramp closure equipment and associated local intersection improvements, the estimated capital cost is $3,253,500.

Option 3 was analyzed as an interim phase before full implementation of Option 2. Option 3 would provide for a PM peak hour ramp closure at the Beechwood Boulevard on-ramp to I-376 eastbound. The cost to implement Option 3 as an interim phase is estimated to be $632,750.

The annual operational and maintenance costs can be anticipated to be $40,000 for Options 1 and 2, and $5,000 for Option 3.

The total project implementation period for the ramp management system is estimated to be 36 months or 3 years. Using an accelerated schedule for design or perhaps a design/build delivery method could reduce the schedule to 30 months.

For the system to operate and respond to changing traffic conditions one operator of the system, PennDOT, should be given the responsibility. This would include both operation of the ramp meters, ramp closure equipment, and the local traffic signal systems to be installed by the project. An intergovernmental agreement would be required for this type of responsibility to be transferred from the local municipalities to PennDOT.

Chapter 7
Benefit/Cost Analysis of Implementing Ramp Management on I-376

To perform the benefit/cost analysis for each ramp management option, the September 2010 (3rd edition) AASHTO publication "User and Non-User Benefit Analysis for Highways" methodology was followed. Three main user benefits were examined for each option: Value of Time, Operating and Ownership Cost, and Crash Cost. Once these benefits were determined for both the AM peak and the PM peak hour for each option, the benefits were then extrapolated to a yearly value based on assumed ramp meter/closure operating hours. Yearly capital and operating costs were estimated in Chapter 6. Both the user benefits and the capital and operating costs for each year of the expected ramp management project were entered into a basic present value formula (using a riskless real discount rate and a risk premia) to bring values back to present day dollars. A real rate was used (vs. a nominal rate) because the net benefit calculations were in real terms (i.e. uniflated). A risk premia was used to obtain a risk-adjusted discount rate. The total present value benefit to present value cost ratio was then calculated for each ramp management option.

User Benefit Costs

Value of Time

Value of time calculations followed the methodology presented in the September 2010 AASHTO publication "User and Non-User Benefit Analysis for Highways." Due to the type of data from the simulation model, the "value of time saved due to change in delay" equation was used to determine the costs savings for both the AM and the PM peak hours. The benefits were then extrapolated to a yearly value based on assumed ramp meter/closure operating hours.

Operating and Ownership Costs

Operating and ownership cost calculations followed the methodology presented in the September 2010 AASHTO publication "User and Non-User Benefit Analysis for Highways." Three main elements were evaluated: fuel cost savings, truck inventory savings, and capital cost savings. Due to the type of data from the simulation model, the "change in fuel costs due to delay" equation was used to determine the fuel cost savings for both the AM and the PM peak hours. Similarly, the "change in inventory costs due to delay" equation was used to determine the inventory cost savings for both the AM and the PM peak hours. Finally, the "change in capital costs due to delay" equation was used to determine the capital cost savings for both the AM and the PM peak hours. The benefits were then extrapolated to a yearly value based on assumed ramp meter/closure operating hours.

Crash Costs

Crash cost calculations followed the methodology presented in the September 2010 AASHTO publication "User and Non-User Benefit Analysis for Highways."

Crash data was obtained from PennDOT for 2006, 2007, and 2008. This data was used to determine the average number of fatal, injury, and property-damage only crashes per year within the study area on I-376. Only crashes occurring on the eastbound lanes from the Bates Street Interchange to the Squirrel Hill Tunnel and on the westbound lanes from the Squirrel Hill Tunnel to the Greensburg Pike Interchange were considered relevant crashes for Options 1 and 2. The relevant crashes for Option 3 included those on the eastbound lanes from The Beechwood Boulevard Onramp to the Squirrel Hill Tunnel. The total number and type of relevant crashes are presented in the following table:

Number and Type of Relevant Crashes

	Prop Damage Only	Injury	Fatal
Option 1	178	146	2
Option 2	178	146	2
Option 3	66	52	0

The national average of crash reduction percentage due to ramp metering from the "Intelligent Transportation Systems Benefits: 2001 Report" by AASHTO was determined to be 33% and was used for expected crash reduction in all options. Net perceived user cost information per crash was taken from "User and Non-User Benefit Analysis for Highways." The values provided in the handbook were given in year 2000 dollars, so an inflation rate was applied to the data to bring these costs to today's value. Detailed calculations can be found in **Appendix M**.

A summary of yearly user benefits for each option is presented in the following table:

Yearly User Benefits

	Option 1	Option 2	Option 3
Value of Time Savings	$515,675.73	$5,733,075.56	$1,357,006.49
Operating and Ownership Cost Savings	$840,170.72	$9,790,094.65	$2,252,690.43
Crash Cost Savings	$3,349,229.13	$3,349,229.13	$812,301.36
Total Yearly Savings	$4,705,075.58	$18,872,399.34	$4,421,998.29

Capital and Operating Costs

Capital costs for each option were estimated in Chapter 6. The operating and maintenance cost for Option 1 was estimated to be $40,000 per year in Chapter 6. Assuming that the ramp closures would be operating remotely by the TMC, the operating and maintenance cost of Option 2 was estimated to be $40,000 per year. Option 3 consists of dealing with one ramp closure, and was assumed to carry an annual operating and maintenance cost of $5,000. These numbers are all based on reported cost ranges from other state agencies, with the recommendation that due to PennDOT's inexperience with these types of installations, values on the higher end of the range should be assumed.

A summary of the total capital and yearly operating and maintenance costs is presented in the following table:

Capital and Operating Costs

	Option 1	Option 2	Option 3
Capital Cost	$3,253,500	$4,588,500	$632,750
Yearly Operational and Maintenance Cost	$40,000	$40,000	$5,000

Benefit/Cost Ratio

To determine the benefit/cost ratio for each option, the user benefit cost, capital cost, and operating cost for each year of the expected ramp management project life were entered into a basic present value formula to bring values back to present day dollars. The total present value benefit to total present value cost ratio was then calculated. A riskless real discount rate of 3.5% was used, as was an assumed risk premia of 3%. A real rate was used (vs. a nominal rate) because the net benefit calculations were in real terms (i.e. uniflated). A risk premia was used to obtain a risk-adjusted discount rate. It was also assumed that the service life of the project would be 15 years, and that the terminal asset value would be $0. The valuation year of the calculation was assumed to be 2011, while the implementation date was assumed to be 2014.

A summary of the net present value (as defined by the September 2010 AASHTO publication "User and Non-User Benefit Analysis for Highways") as well as the benefit/cost ratios for each option are presented in the following table:

Net Present Value (valuation year 2011) and Benefit/Cost Ratios

	Option 1	Option 2	Option 3
Net Present Value:	$35,614,275	$151,805,506	$36,021,779
Benefit-Cost Ratio:	12:1	34:1	58:1

Assumptions

For the benefit/cost ratio calculation, some assumptions were made. These include:

- The focus of this evaluation is on the cost savings to users on I-376. Based on the outputs of the model, average change in delay on I-376 only was used in the calculations. It is assumed that the average delay on some surface streets may increase, however these calculations are not a reflection of those potential increases. It is also noted tat mitigation strategies to reduce delay on the local streets are part of the capital costs.

- If the average change in delay from the model was found to be "not statistically significant," the average delay used in the calculations was the same as the base value.

- The driver type for this study is assumed to be "drive alone commuter." According to 2005-2009 census data, the average vehicle occupancy was determined to be 1.12.

- In determining user benefits for hours of congested condition in the AM and PM peaks other than the two single hours studied, it was assumed that the percentage of savings was the same as the percentage of volume of the hour in question compared to the peak hour.

- It was assumed that the ramp meters/closure devices would be in operation 4 hours during the AM peak and 4 hours during the PM peak during congested hours.
- It was assumed that the meters would typically run for an additional 50 hours per year during off peak times during incidents or events. These hours were assumed to save users the equivalent of 25 AM peak hour benefits and 25 PM peak hour benefits.
- It was assumed that there are 10 federal holidays per year, and that on these days, the meters would not be running because conditions would be less congested.
- Two user types were used – passenger cars and trucks.
- To calculate truck inventory savings, an interest rate of 5% was assumed, and the average value of cargo was assumed to be $200,000.
- To calculate capital cost savings, the average capital value of vehicle was assumed to be $20,000. The average interest rate was assumed to be 5%. The average expected life of the vehicle was assumed to be 10 years. And the average salvage value of the vehicle was assumed to be $0.
- To calculate Crash cost savings, the delay cost of a crash was assumed to be included in the "Net Perceived User Cost" value.
- To calculate the present value of the benefits and costs, a risk-free real discount rate of 3.5% was assumed. A risk premia rate of 3% was assumed. The terminal value of the project was assumed to be $0, and the life of the project was assumed to be 15 years. It was also assumed that the design and construction period of the project would be 3 years.

Conclusion and Summary

Based on the calculations and AASHTO "User and Non-User Benefit Analysis for Highways" methodology, all three ramp management options show high benefit/cost ratios. Option 3 shows the highest benefit/cost ratio (58:1). Although Options 1 and 2 show higher annual benefits than Option 3, the capital and operating costs associated with Option 3 were much lower, making the benefit/cost ratio higher. Option 2 shows the second highest ratio (34:1) because although it has the highest capital cost, this option also shows the highest delay reduction per vehicle on I-376. This delay reduction directly relates to value of time savings, as well as ownership and operating cost savings. Option 1 shows a benefit/cost ratio of 12:1. Although this is not as high as the other options, it still shows the large benefits seen from delay reduction on I-376.

Chapter 8
Research Findings and Recommendations

Benefits of Ramp Management for Pennsylvania Research Findings
Ramp Management can be used in Pennsylvania as a method to help reduce congestion along freeways, without the high costs of capacity improvements. Congested Pennsylvania freeways that are eligible for ramp metering or ramp closure are likely to see not only a decrease in mainline congestion, but also a decrease in emissions and crash rates.

Multiple case studies of ramp management systems around the country show a reduction of sideswipe collisions (due to merging problems), rear end collisions (due to stop-and-go driving behavior), and lane change collisions, with the installation of ramp meters. According to the FHWA's *Ramp Management and Control Handbook*, Detroit's ramp metering system showed a 50% reduction in total collisions and 71% reduction in injury collisions. Collision rates were also reduced in Portland, Minneapolis, Seattle, Denver, and Long Island after the installation of ramp meters. Although each case study showed a different amount of collision reduction, it can be assumed that similar safety benefits would be experienced in Pennsylvania with the use of ramp management strategies.

Case studies also show mobility benefits of ramp management in the form of increased travel speeds and peak period volume. Portland saw as much as a 173% increase in average travel speed with the installation of ramp meters. This research's own case study of I-376 simulated a ramp management system that increased the throughput of the freeway, decreased the tunnel queues, and decreased delay times.

The environmental benefits observed for ramp management include the reduction in the amount of emissions released into the environment, increased fuel efficiency, and the reduction of noise levels and neighborhood impacts. The *Ramp Management and Control Handbook* describes a specific case study of the evaluation of ramp meters in Minneapolis that identified "a net annual saving of 1,160 tons of emissions."

Recommended Screening Criteria for Planning and Programming Research Findings
A basic, high level planning tool was developed based upon readily available volume and geometry information from PennDOT and the local MPO's. Based upon a review of the current literature; the regional CMP/CMS plans; and the most readily available data; the use of a v/c ratio > 1.0 to screen freeway segments for congestion is recommended. Using long range planning data from the local MPO's, approximately 275 miles of freeways are forecasted to operate with a v/c ratio greater than 1.0 by 2030/2035. Those freeway segments forecasted with v/c ratios >1.0 were further analyzed to determine a project ranking score.

The following data (and what that information tells us about ramp management possibilities) was used in the ranking process:

- The long range (2030/2035) v/c ratio along the corridor – Using v/c ratios calculated from long range planning data will assist in determining where to deploy ramp management systems.

- The total number of interchanges along the corridor – The literature suggests that ramp management is more effective when implemented on a corridor-wide basis.

- The spacing between freeway on-ramps – If the freeway on-ramps are spaced too closely, the corridor might not be suitable to ramp metering; however, they might be candidates for ramp closure or a combination of ramp metering and ramp closure.

- The amount of coverage provided by PennDOT traffic cameras – This was used to determine if ITS infrastructure exists along the congested corridor.

- The number of reasonable alternate routes – If closing or metering a ramp leaves motorists without a reasonable route, it is less desirable.

- The approximate length of the freeway on-ramps – To determine if there will be adequate storage on the ramps to hold the queues caused by metering.

Available data were utilized to develop criteria to evaluate the congested freeways, with each criteria given a rating from one to three (one being the least desirable and three being the most desirable condition for ramp management). Each criterion was also weighted differently to reflect the significance of each piece of data.

Forecasted v/c ratio of the corridor	weighting factor 3
Amount of existing ITS coverage within the corridor	weighting factor 3
Approximate length of the freeway on-ramps	weighting factor 3
Number of reasonable alternate routes	weighting factor 2
Total number of interchange ramps along the corridor	weighting factor 1
Spacing between freeway on-ramps	weighting factor 1

It is important to note that this screening criteria and rating system is only a preliminary guide to help quantify which freeway segments are the best ramp management candidates. However, if certain corridors do not rank high through this system and PennDOT deems there to be a special circumstance, more detailed criteria by interchange should be evaluated. While this preliminary planning tool can screen candidate locations statewide to consider ramp management, more specific criteria is required once a candidate corridor is identified. It recommended that MPOs in Pennsylvania adopt this evaluation methodology to be used for long range planning purposes to evaluate potential locations for ramp management.

Recommended Evaluation Study Methodology for Corridor Evaluations Research Findings

Once a congested freeway has passed the initial high level screening, a more detailed set of criteria involving operational, volume, and design/system considerations can be applied. This detailed criteria was developed based upon review of other state DOT's existing criteria, primarily the Ohio/Arizona warrants. Additional design-related criteria were taken from Wisconsin.

OPERATIONAL SCREENING CRITERIA – Must meet at least one out of five operational criteria

1. Does the freeway operate at speeds less than 50 mph for duration of at least 30 minutes for 200 or more calendar days per year?

2. Is there a high frequency of crashes (collision rate along the freeway exceeds mean collision rate in the subject metropolitan area) near the freeway entrances because of inadequate merge area and congestion?

3. Will the ramp meter or system of ramp meters contribute to maintaining a specific level of service (LOS) identified in the region's transportation system management (TSM) plan?

4. Will the ramp meter or system of ramp meters contribute to balancing demand and capacity at a system of adjacent ramps entering the same facility?

5. Does the ramp meter or system of ramp meters mitigate predictable sporadic congestion on isolated sections of freeway because of short peak period loads from special events or from severe peak loads of recreational traffic?

VOLUME CRITERIA – If one of the operational screening criteria is met, then the location must meet at least one out of three volume criteria

6. Total Volume Criteria

Total Volume Criteria

Number of Mainline Lanes in One Direction including Auxiliary Lanes that Continue at least 1/3 Mile downstream from Ramp Gore	Criteria Volume Ramp Plus Mainline Volume Downstream of Gore (total vph)
2	2,650
3	4,250
4	5,850
5	7,450
6	9,050

Is the ramp plus mainline volume greater than the tabulated criteria for the design hour?

7. Ramp metering is warranted when the volume of the ramp plus the mainline right lane exceeds 2,100 vph. Is the criteria defined above met, during the design hour?

8. Exception to volume criteria can be made if crash data is overwhelming in the opinion of the local district engineer.

DESIGN/SYSTEM CRITERIA – If operational and traffic criteria are met, then criteria 9 and 10 must be met to consider ramp management.

9. Does the existing or proposed ramp geometry permit safe and effective ramp metering and are adequate alternative routes available? The ramp should provide 450' of storage for ramp queues, a downstream acceleration lane at least 1000', and adequate sight distance from the arterial to the back of queue. Adequate alternative route must exist.

10. Do the measures of effectiveness for an area-wide simulation model indicate a benefit to the freeway system while at the same time minimizing impacts on adjacent arterials?

It recommended these criteria, 1 thorough 9, be used by the MPO or PennDOT districts to further study the feasibility of implementing ramp management, if the MPO long range plan has identified the corridor as a candidate. These criteria can be analyzed on the basis of data that may be collected or existing data. It is important to note these when applying these criteria they should be used as an initial screening criteria and not the final evaluation tool to proceed with design and construction.

Criteria 10, which requires an analysis of the benefits of a ramp management plan, involves the use of both a travel demand and traffic simulation models. This level of evaluation will be a much more involved relative to data collection and analysis but is necessary to determine the feasibility and benefit of the potential project. The use of a travel demand model is unique when comparing this methodology to other states and involves evaluating impacts of the project off of the freeway.

In addition this analysis will set the framework for discussion with local municipalities about how the ramp management project may impact the local roadway network and plan for these impacts. The research has set forth a recommended intergovernmental cooperation framework so that local municipalities and PennDOT can work together to both evaluate and implement a ramp management system. One of the challenges of this effort is to create an integrated operations system that responds to both changes to the freeway and local roadway network conditions. Operation of local traffic signal systems in conjunction with the ramp meters or closures is critical to the success of a ramp management system because of the changes in both daily travel patterns and incident induced patterns.

Recommendations for the MPO/RPO Programming and PennDOT Design Processes

It is recommended that the MPOs of Pennsylvania consider adoption of a policy that the initial screening criteria of a forecasted V/C>1.0 as a basis for the analysis of freeways as candidates for ramp management. In addition the MPOs and PennDOT are recommended to jointly adopt a policy to screen candidate corridors identified by an MPO long range plan using the criteria developed as part of this research. The appropriate policies or manuals should be identified for this change of policy. In addition the use of the travel demand and simulation models as a tool of further evaluation should also be adopted by PennDOT in the appropriate manuals or policies.

Benefits/Costs to Implement Ramp Management Research Findings

Each ramp management option reviewed for I-376 for this study shows positive net benefits. Option 3 has the highest benefit/cost ratio of 58:1. Option 2 has the second highest benefit/cost ratio of 34:1. The lowest benefit/cost ratio is seen with Option 1 and is 12:1. Although the lowest of the three options, this ratio still shows a significant amount of user benefits when compared to the capital and operating costs. In summary, the relatively low cost of each ramp management option, combined with the relatively large expected user benefits, results in high benefit/cost ratios for each option.

Future Research Recommendations

Based upon the results of this research additional studies are needed to further enhance the benefits of ramp management in the state of Pennsylvania. Specifically in the planning and design phases of implementation of projects additional research is needed in the following areas:

1. What is the optimum planning tools (software) to be used for the travel demand and simulation analysis?

2. What are the best communication and operation systems to jointly control a ramp management and local traffic signal network?

3. Develop a methodology to optimize the operation of both the freeway and the local roadway network for an algorithm that evaluates overall system performance and provides metering rates and traffic signal timing plans that can be varied based upon real time traffic conditions in the network.

Appendices

A. Pennsylvania Freeway Congested Corridor Maps
B. Candidate Ramp Management Freeway Corridor maps
C. Candidate Ramp Management Freeway ranking calculations
D. I-376 Model Zone and Link Network
E. I-376 Model Calibration Results
F. I-376 Ramp Management Option 1 and 2 Map
G. I-376 Measures of Effectiveness Summary for AM and PM peak hours
H. I-376 Modeling Peak Hour Queue Length Summaries
I. I-376 Maps of Traffic Diversions for Options 1 and 2
J. I-376 Internal and External Zone Travel Time Comparisons
K. Suggested Intersection Improvements for Ramp Management Option 2
L. Cost Assumptions for Ramp Management System
M. Benefit Cost Analysis Worksheets
N. Intergovernmental Agreement Sample

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APPENDIX A

Pennsylvania Freeway Congested Corridor Maps

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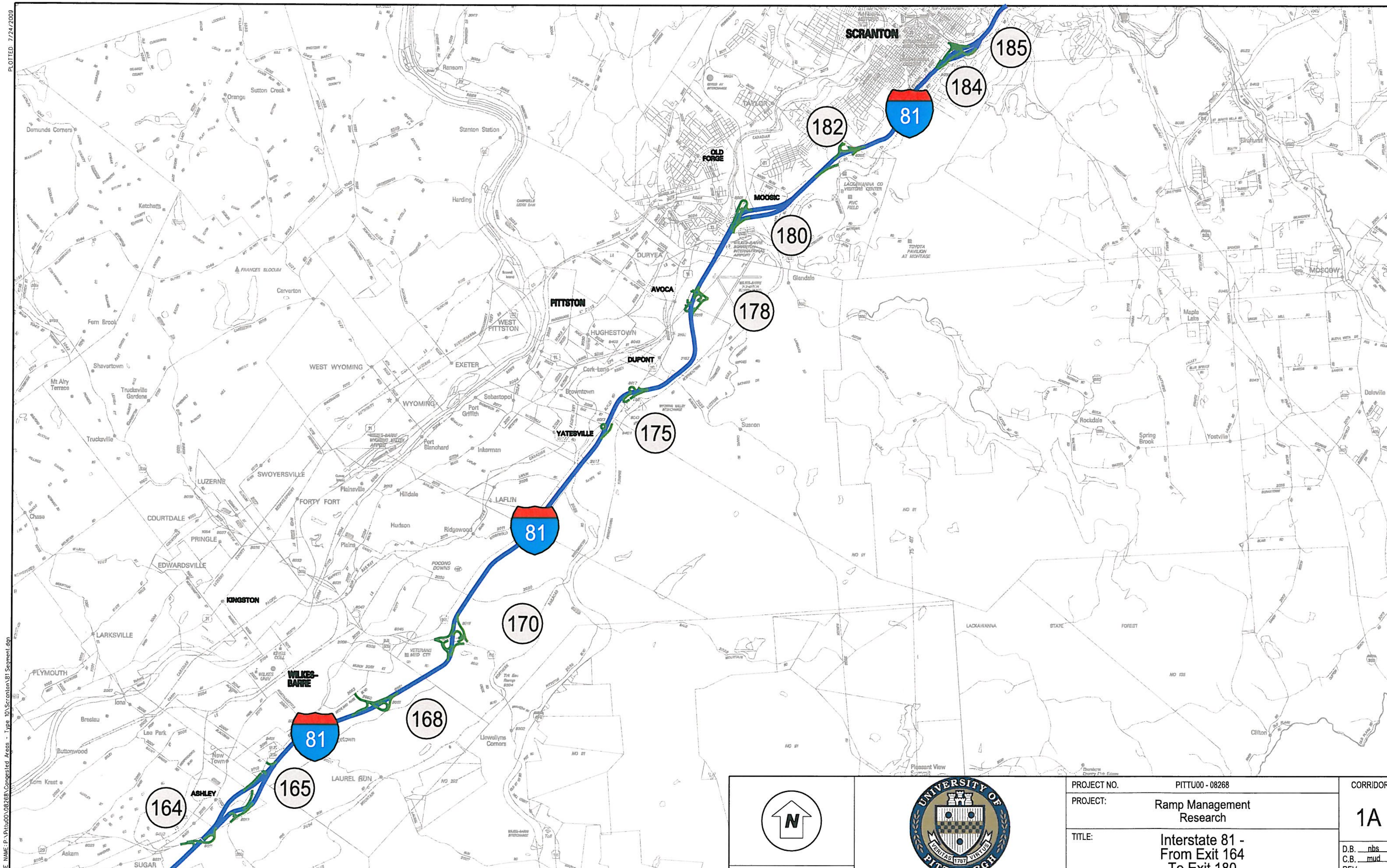

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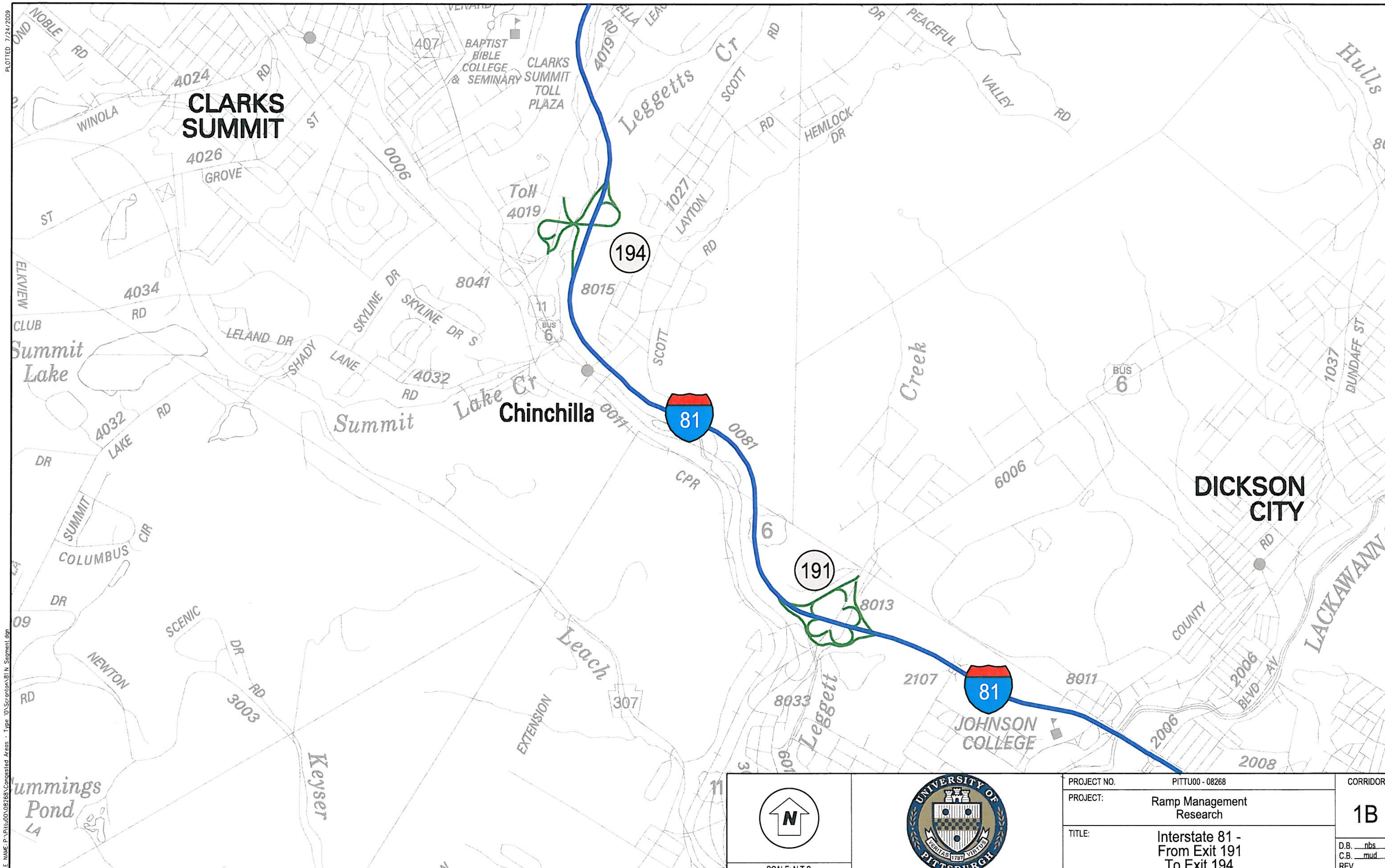

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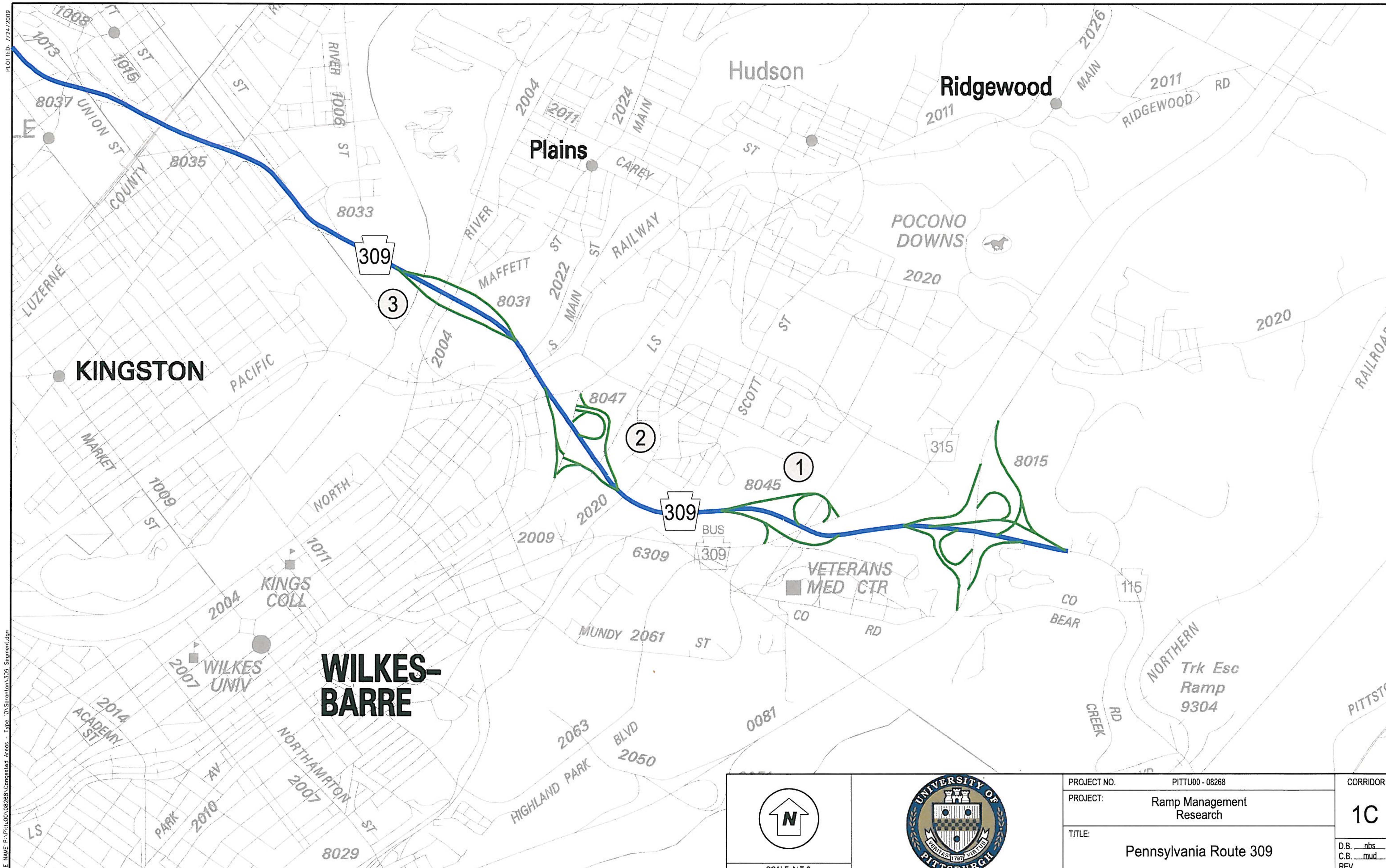

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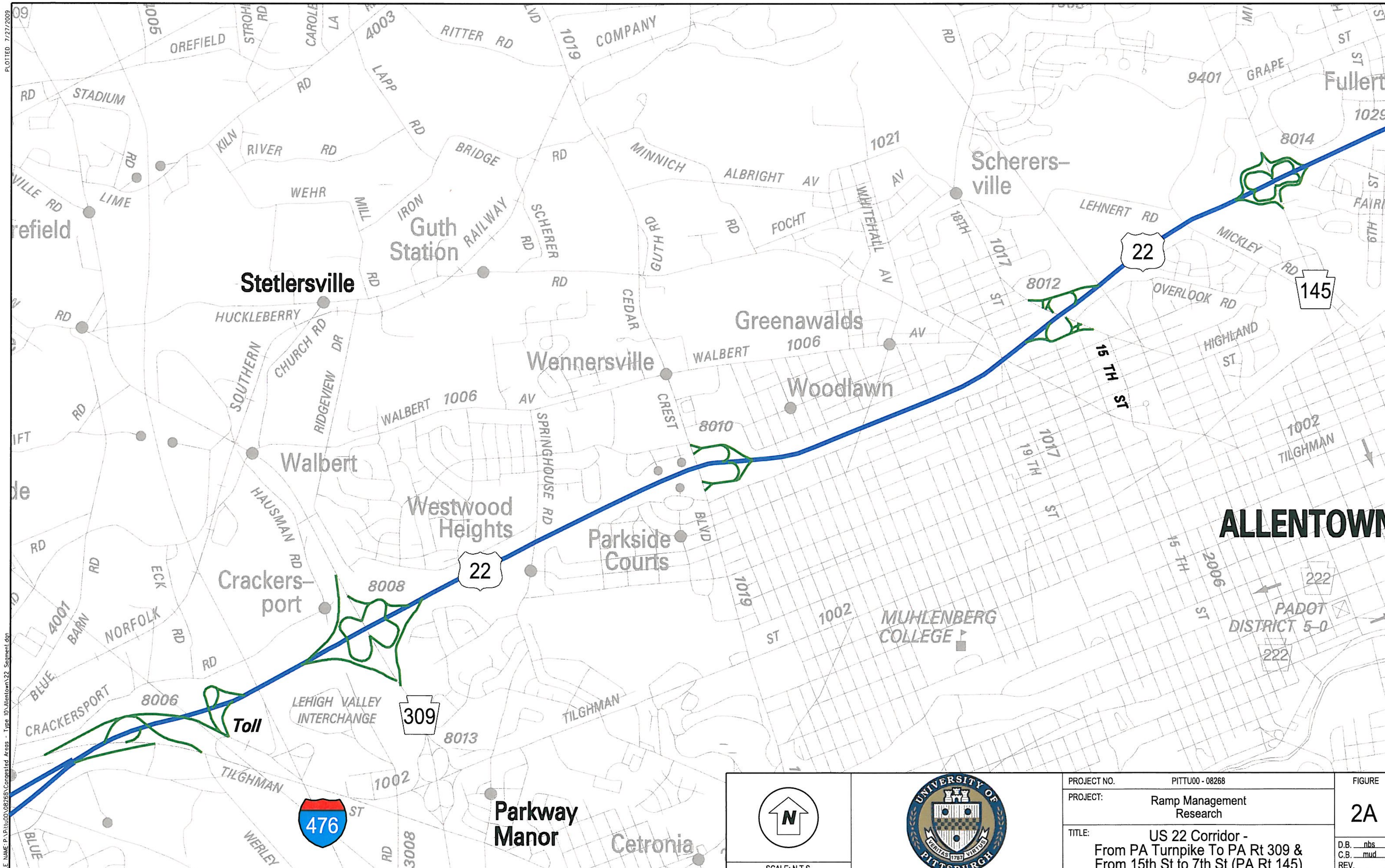

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FIGURE 2A

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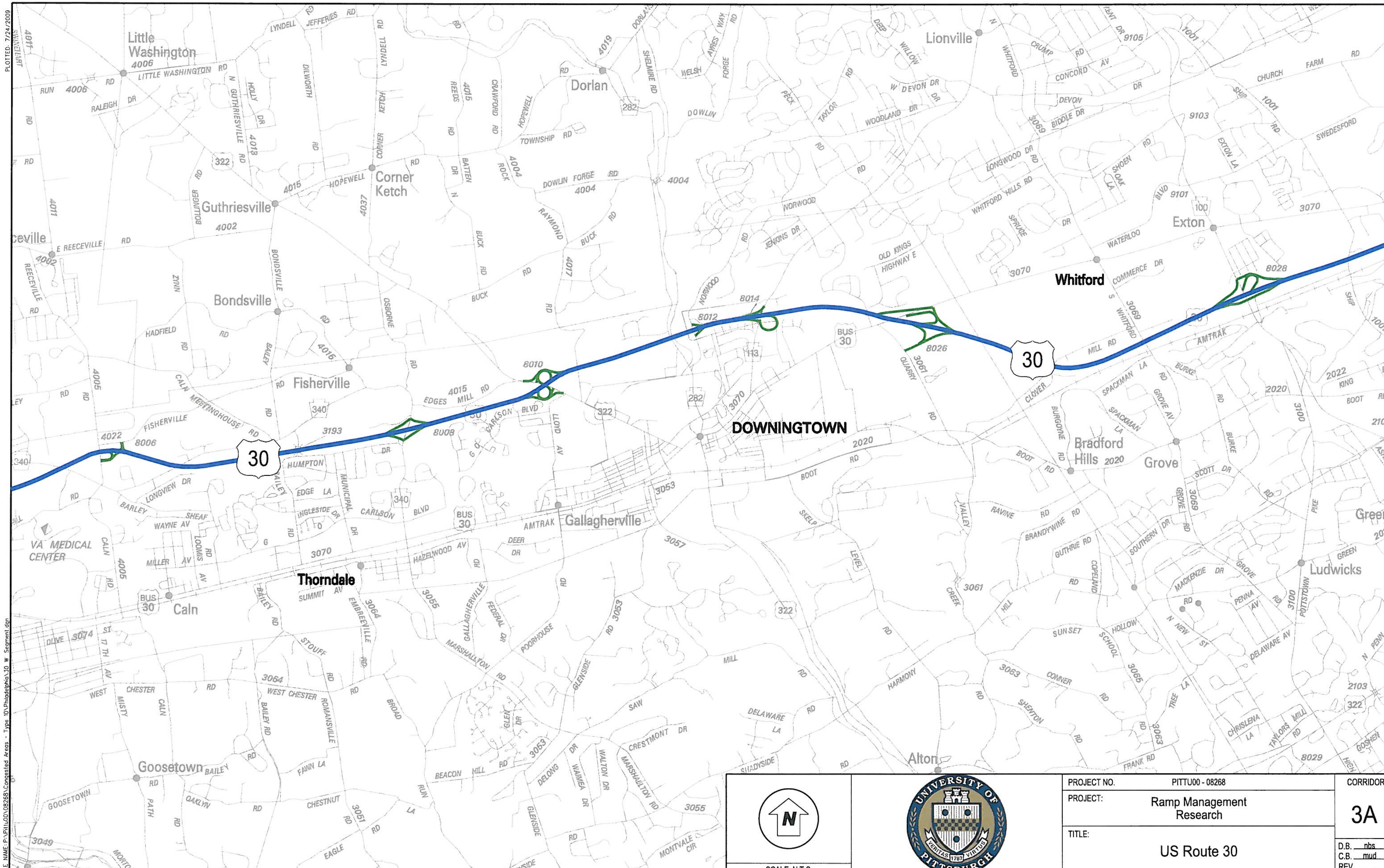

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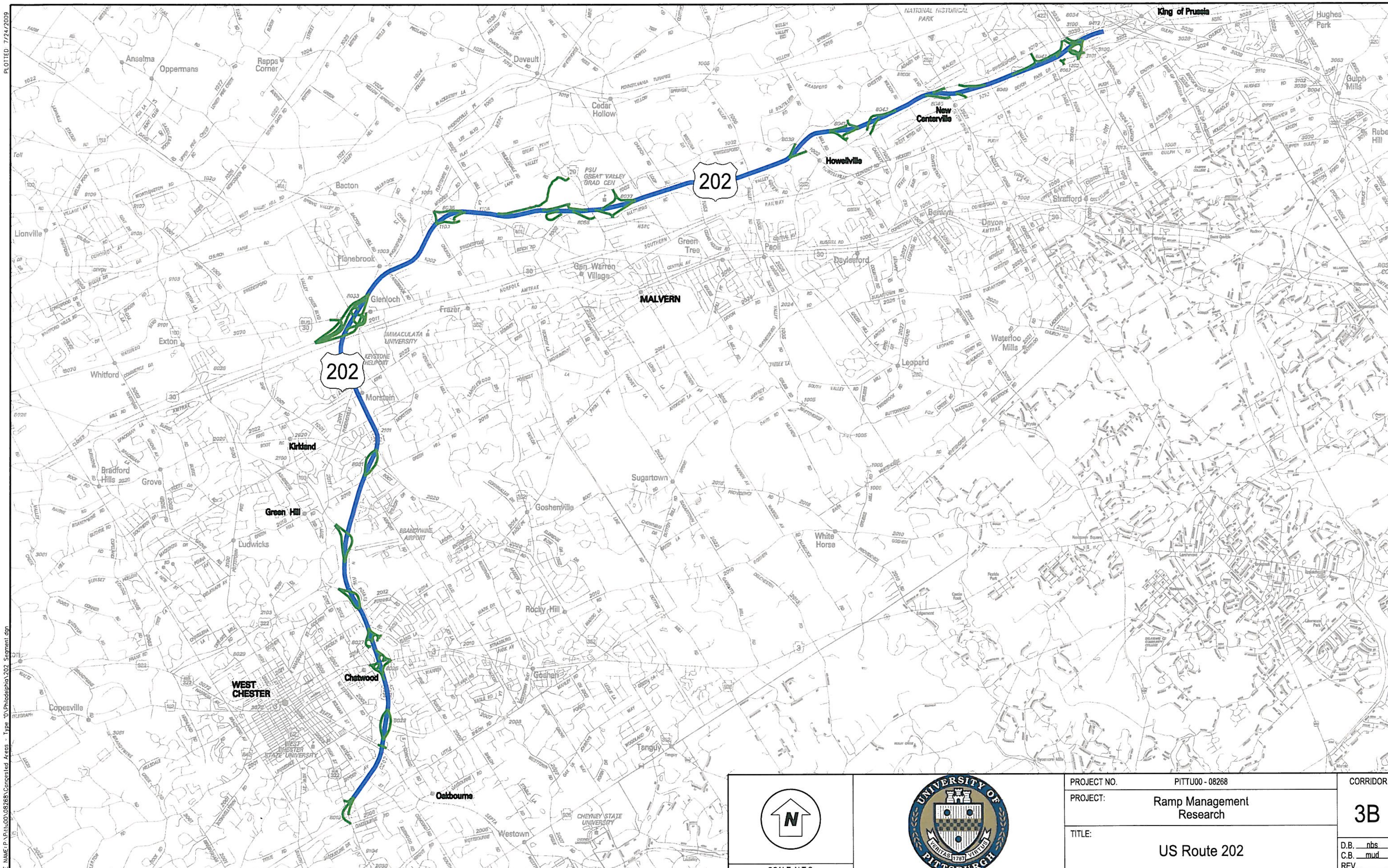

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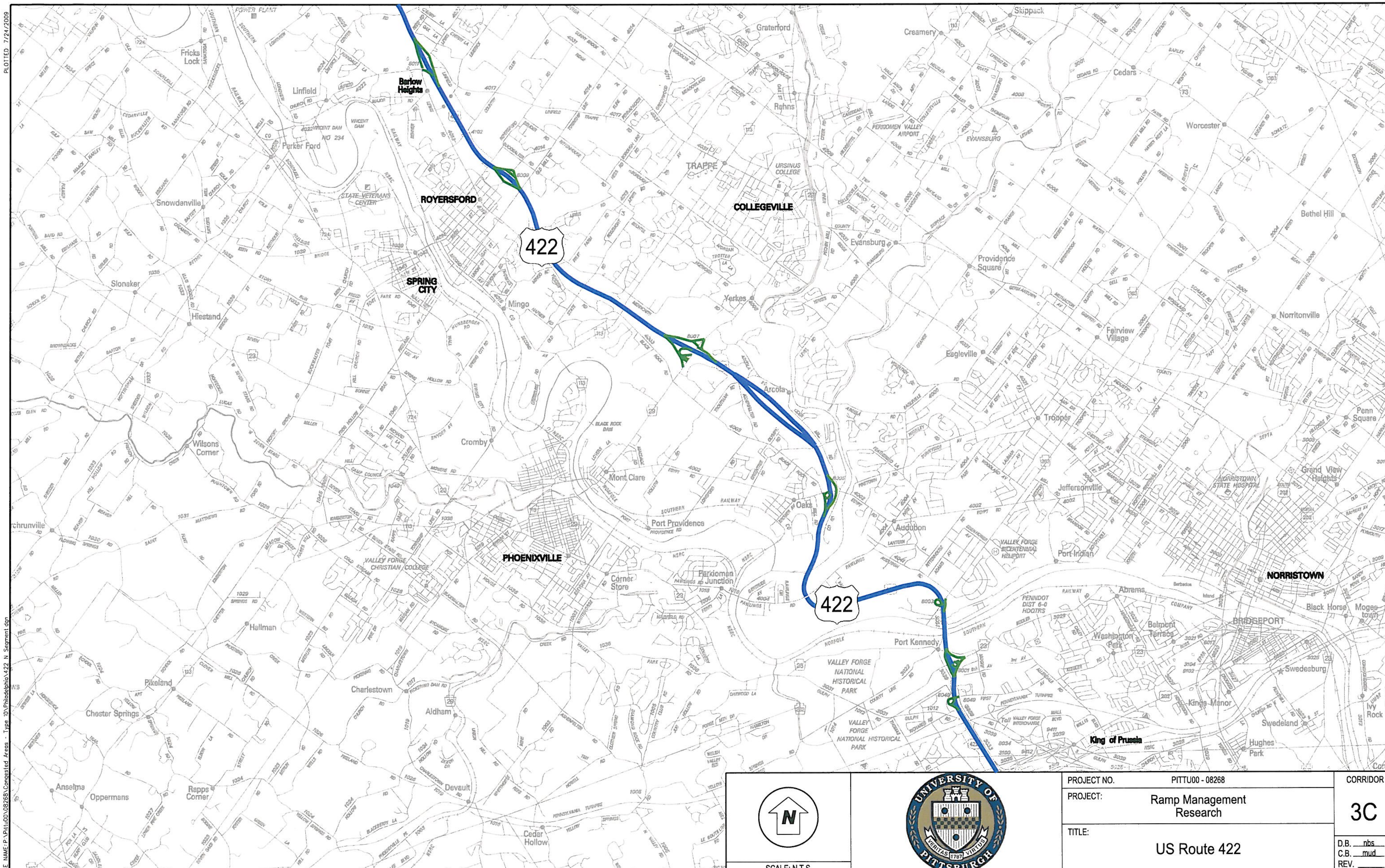

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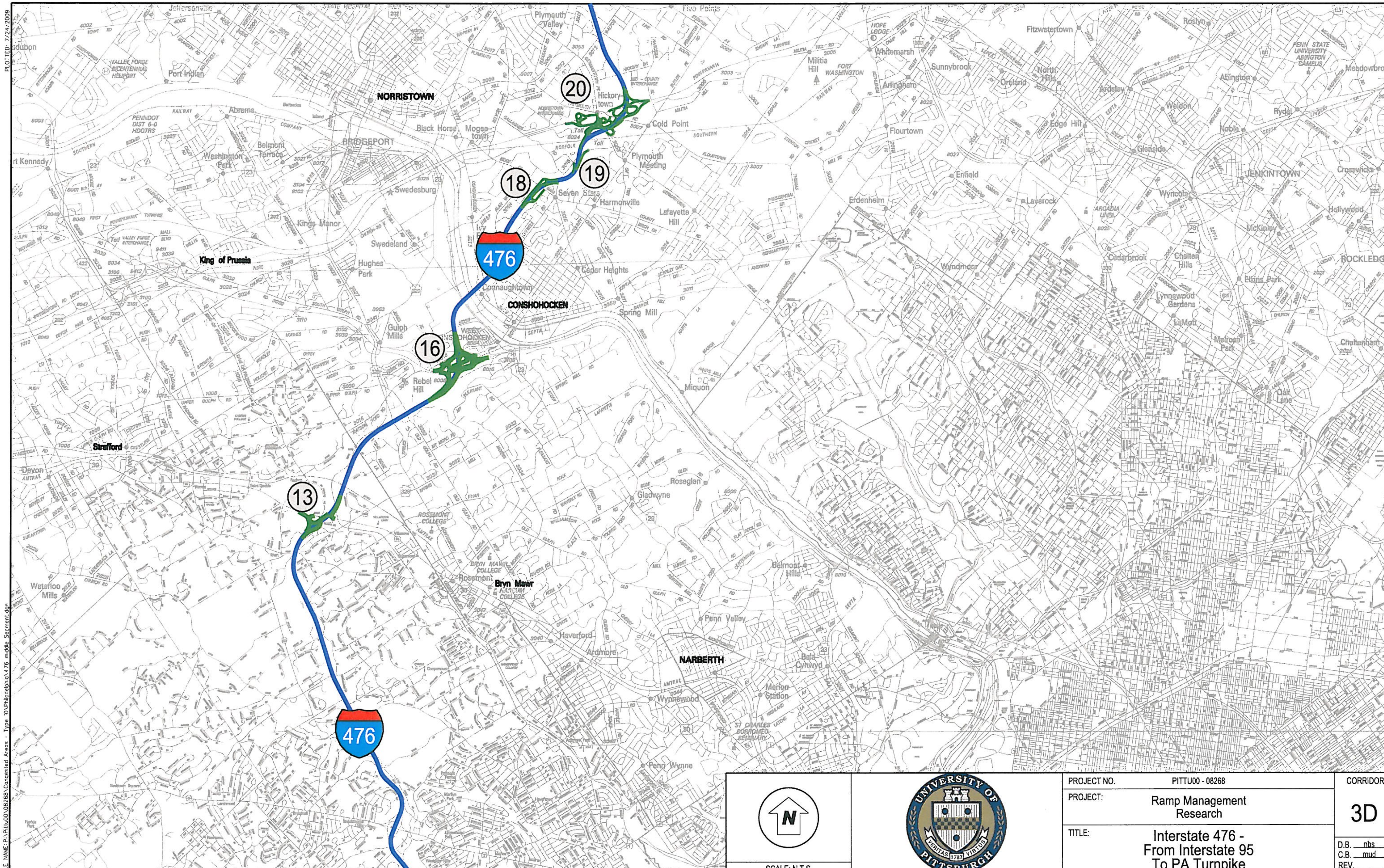

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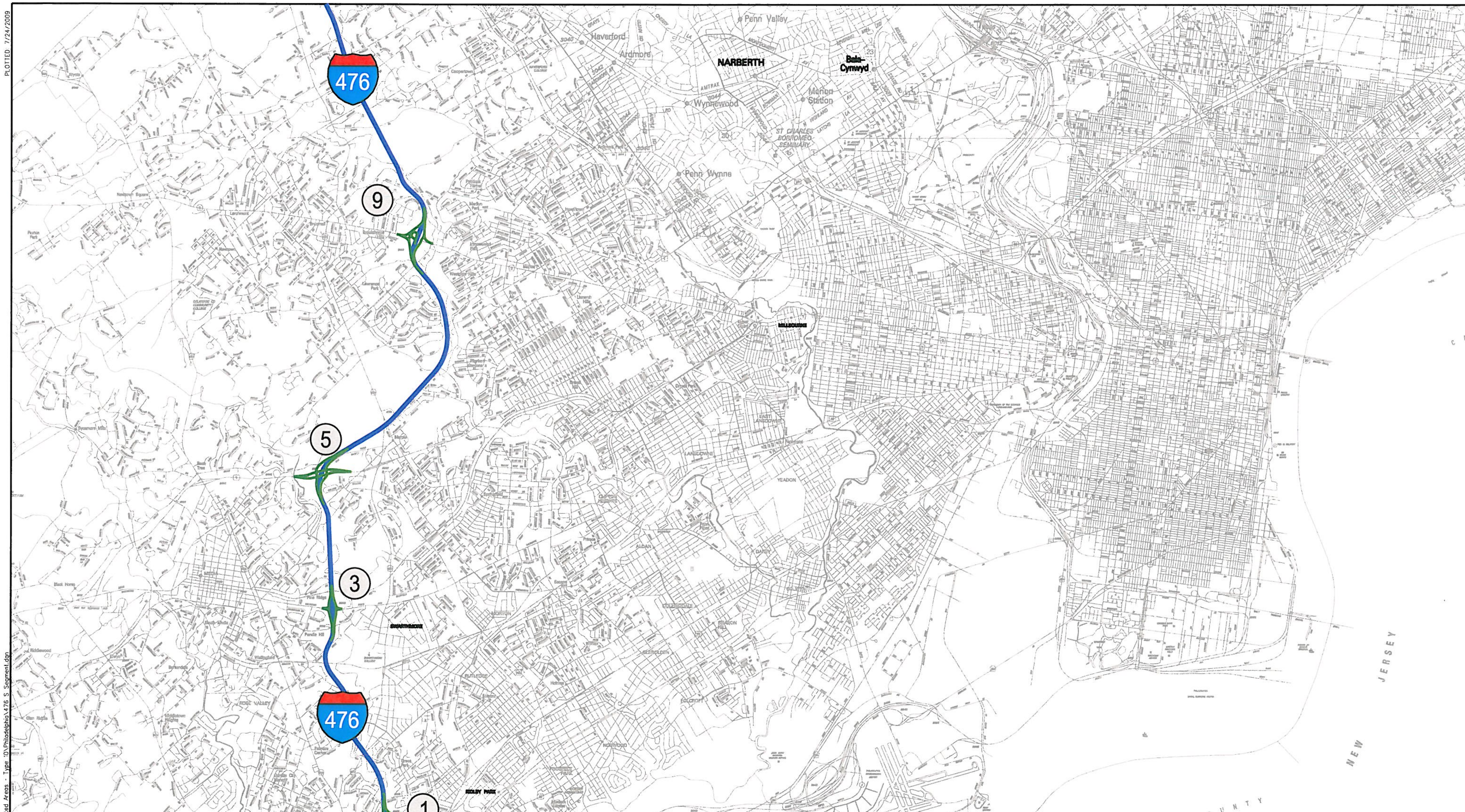

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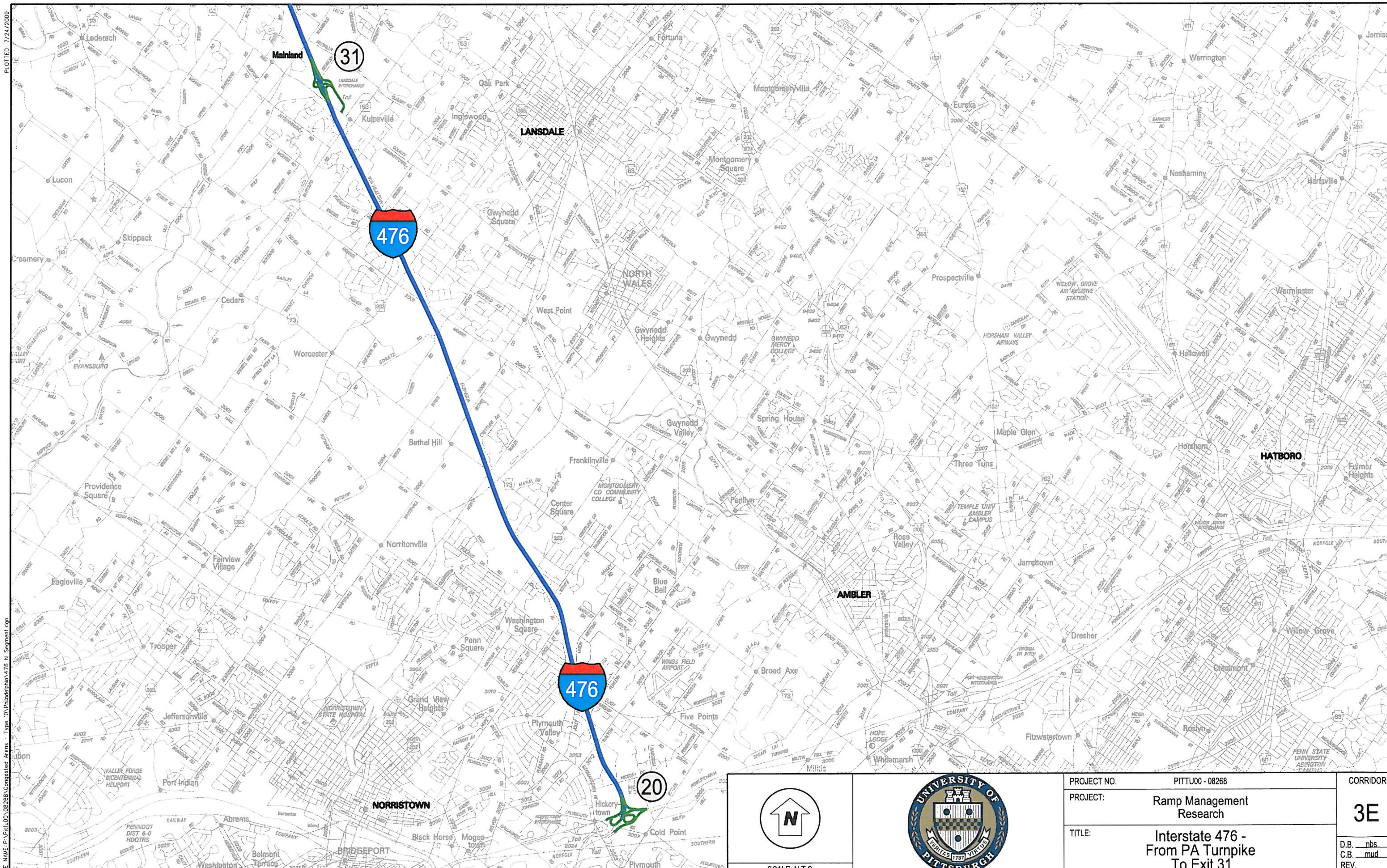

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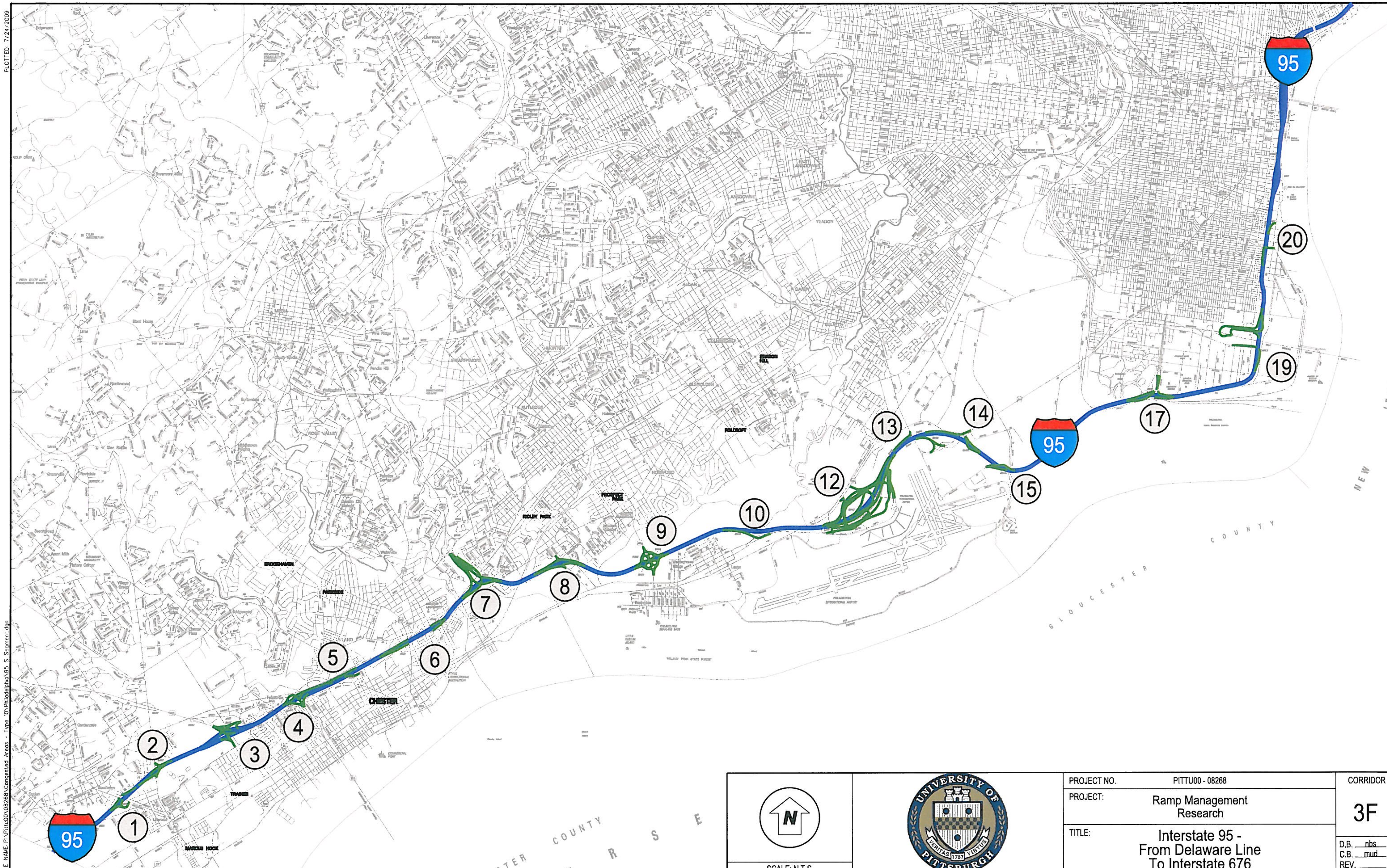

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PLOTTED 7/24/2009

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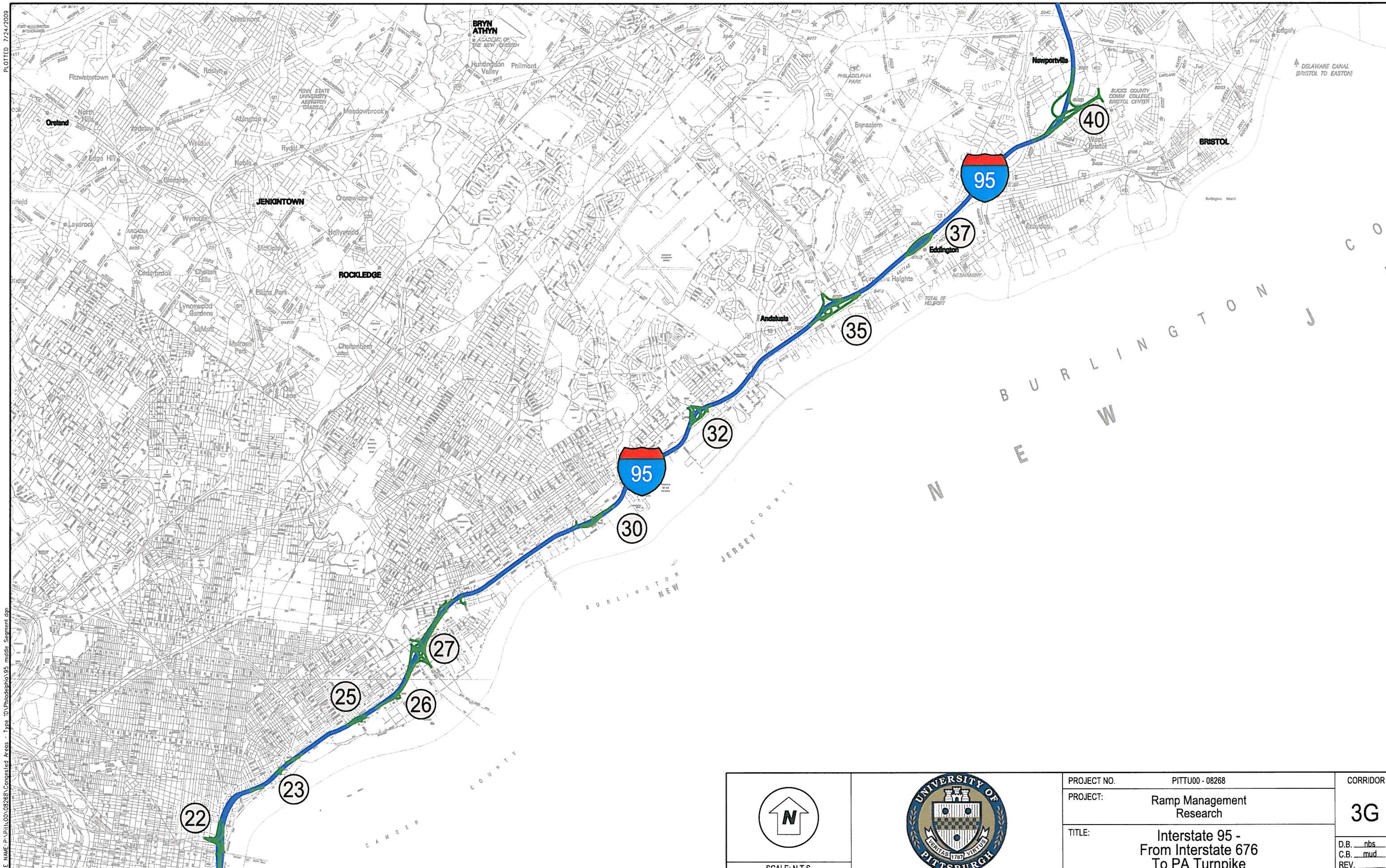


N

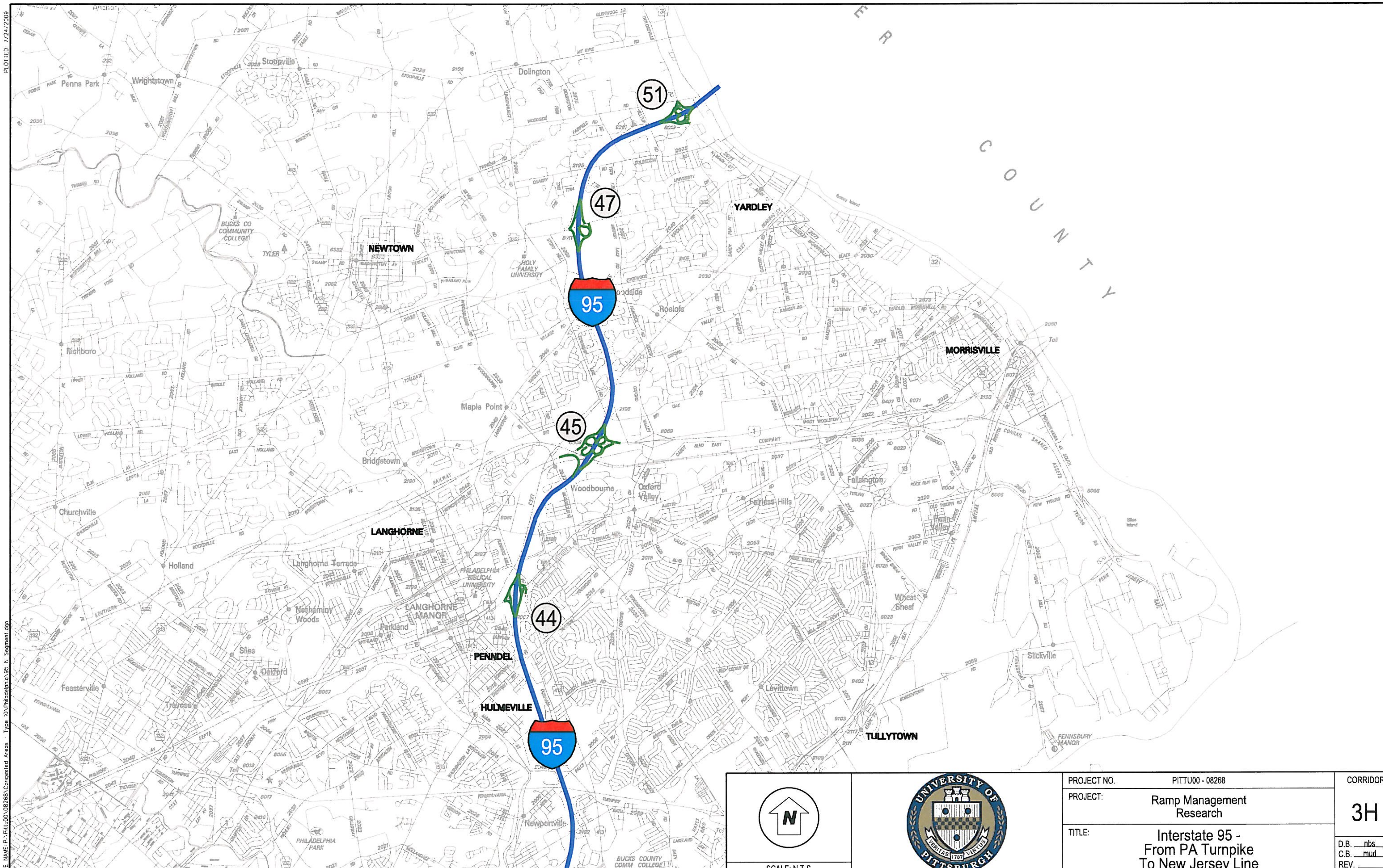
SCALE: N.T.S.

PROJECT NO.	PITTU00 - 08268
PROJECT:	Ramp Management Research
TITLE:	Interstate 95 - From Interstate 676 To PA Turnpike

CORRIDOR

3G

D.B. nbs
C.B. mud
REV. ______



PROJECT NO. PITTU00 - 08268

PROJECT: Ramp Management Research

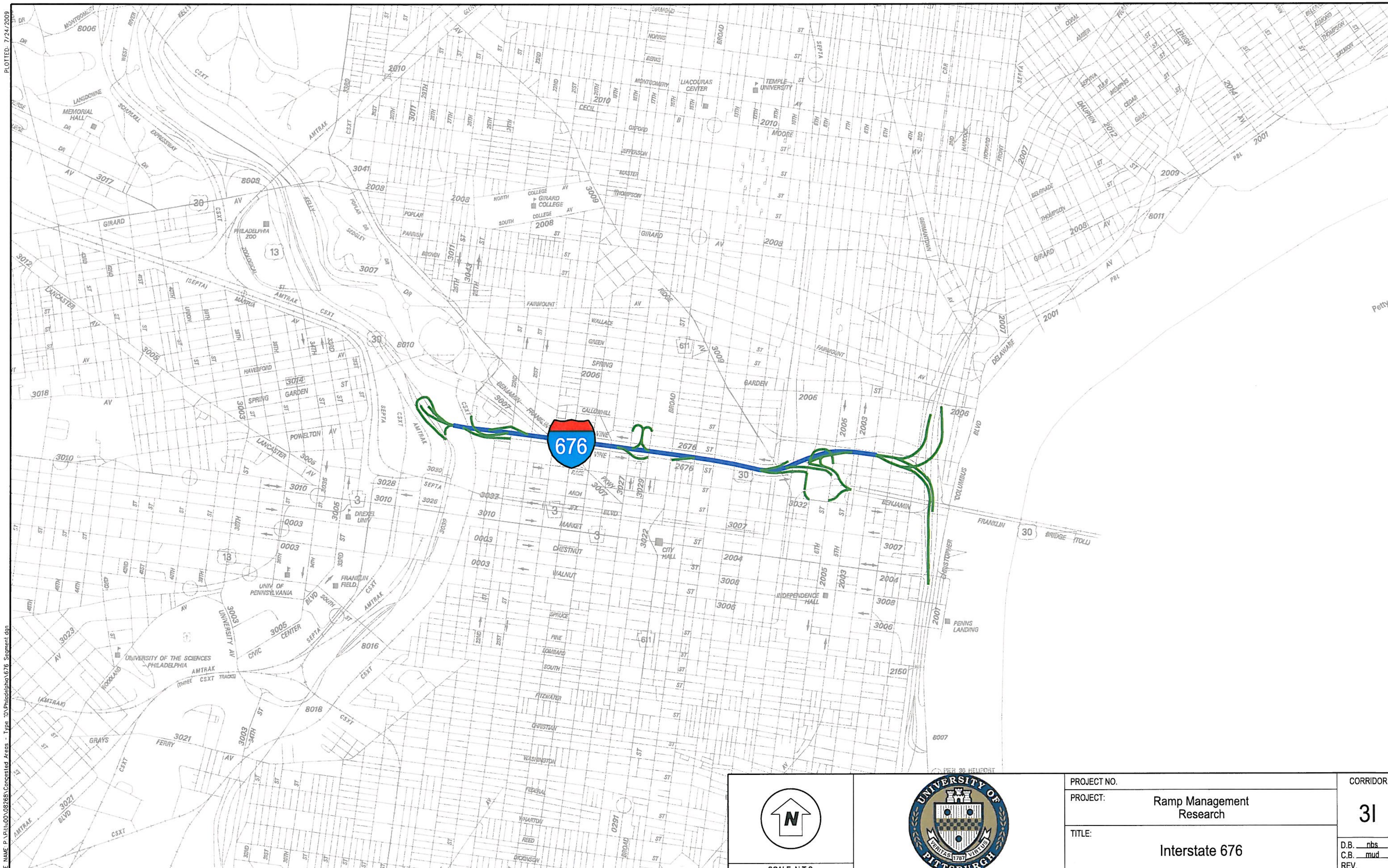
TITLE: Interstate 95 - From PA Turnpike To New Jersey Line

CORRIDOR 3H

D.B. nbs
C.B. mud
REV.

PLOTTED 7/24/2009

FILE NAME P:\Pittu00\08268\Congested Areas - Type '0'\Philadelphia\95 N Segment.dgn

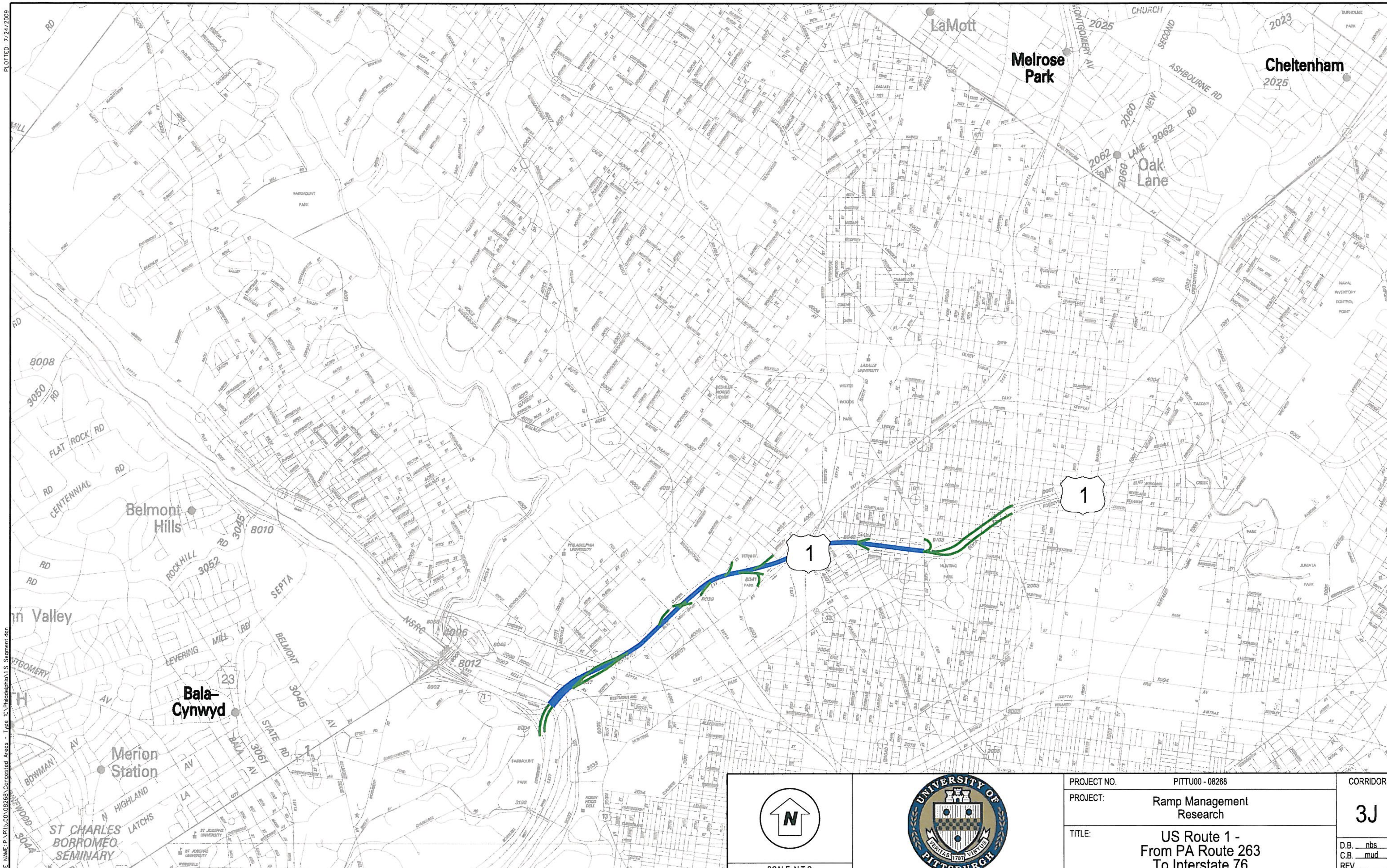


N

SCALE: N.T.S.

PROJECT NO.		CORRIDOR
PROJECT:	Ramp Management Research	31
TITLE:	Interstate 676	D.B. nbs C.B. mud REV.

PLOTTED: 7/24/2009



SCALE: N.T.S.

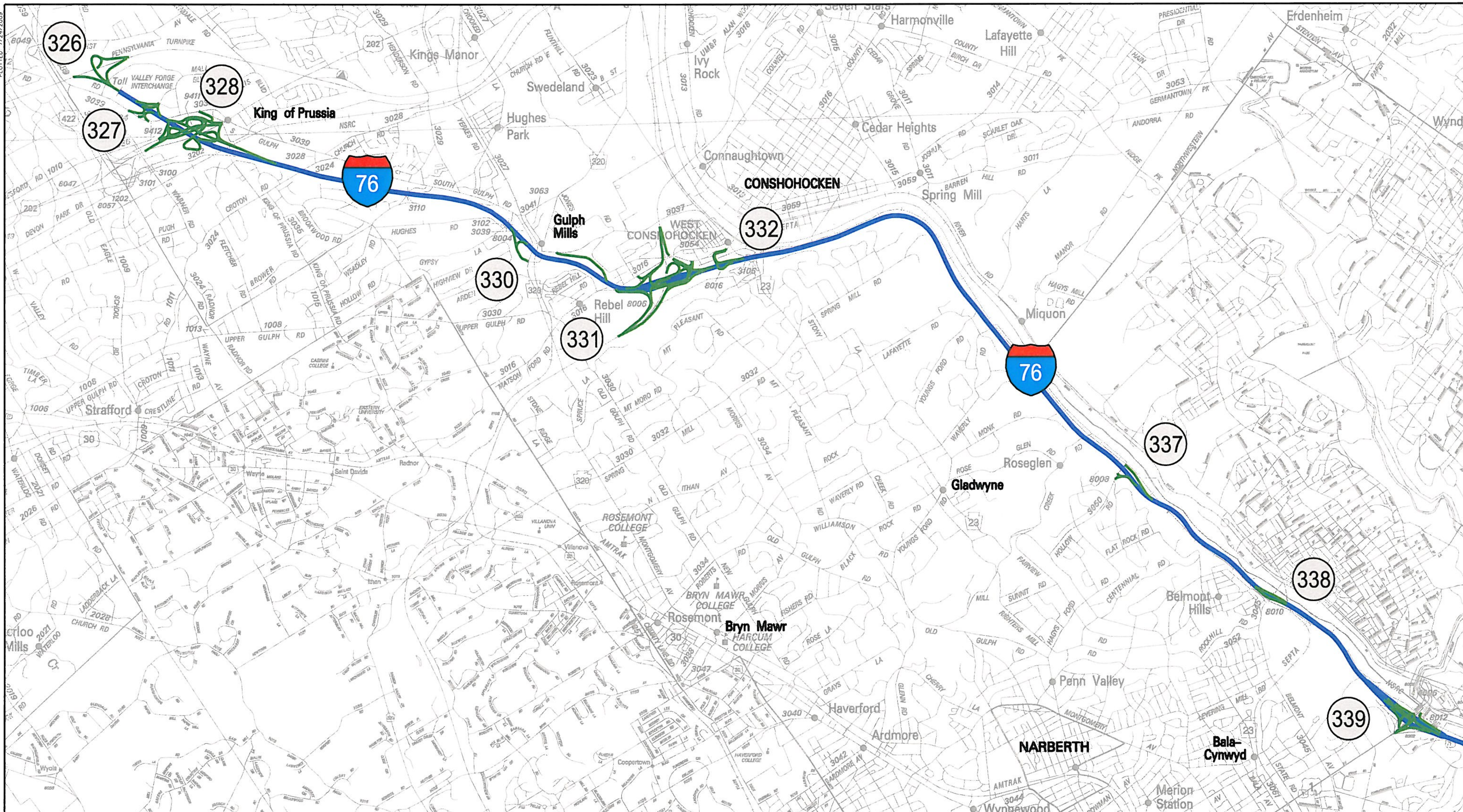
PROJECT NO.	PITTU00 - 08268
PROJECT:	Ramp Management Research
TITLE:	US Route 1 - From PA Route 263 To Interstate 76

CORRIDOR

3J

D.B. nbs
C.B. mud
REV. ______

PLOTTED 7/24/2009



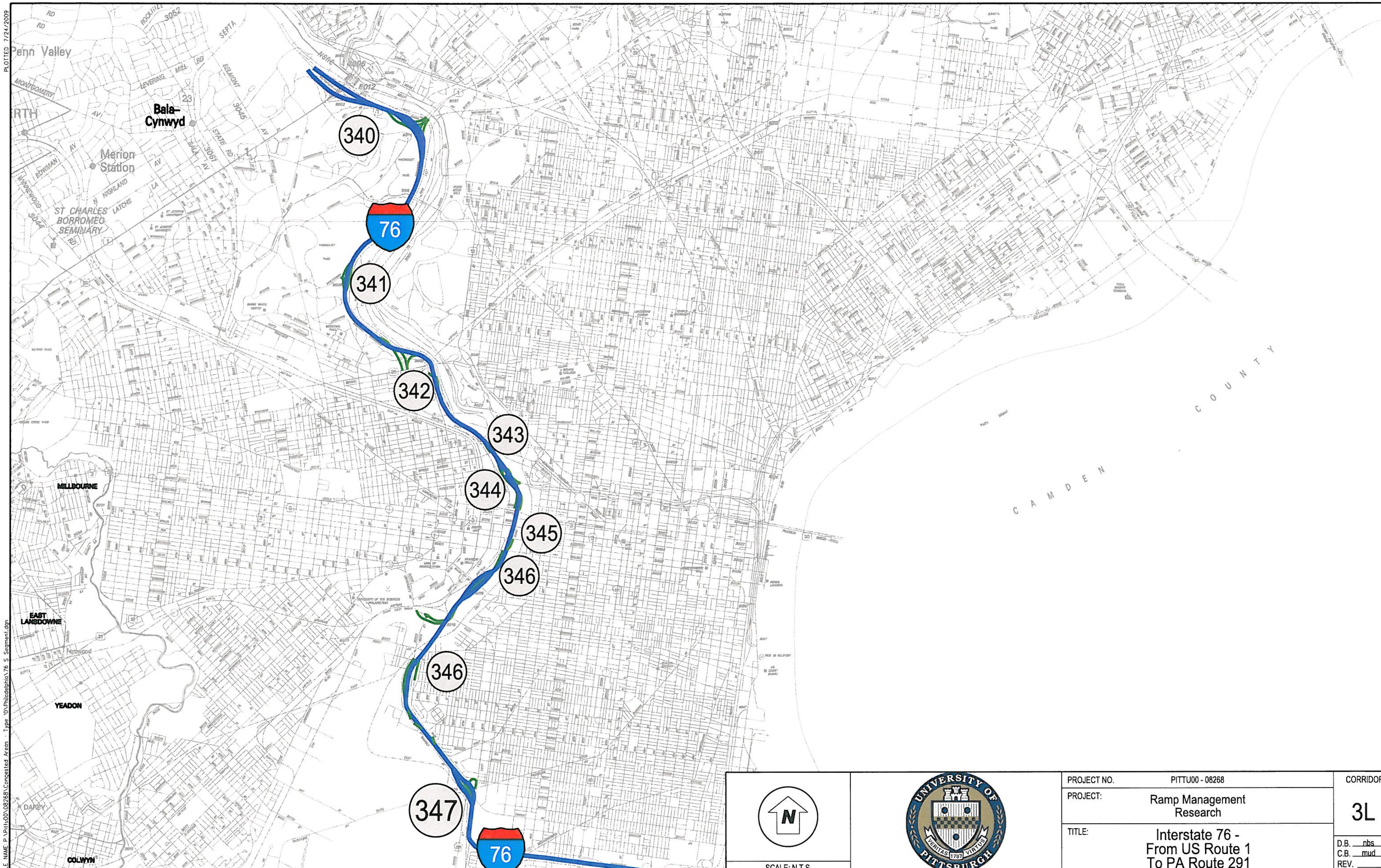
SCALE: N.T.S.

PROJECT NO.	PITTU00 - 08268
PROJECT:	Ramp Management Research
TITLE:	Interstate 76 - From PA Turnpike To US Route 1

CORRIDOR

3K

D.B. nbs
C.B. mud
REV. ______



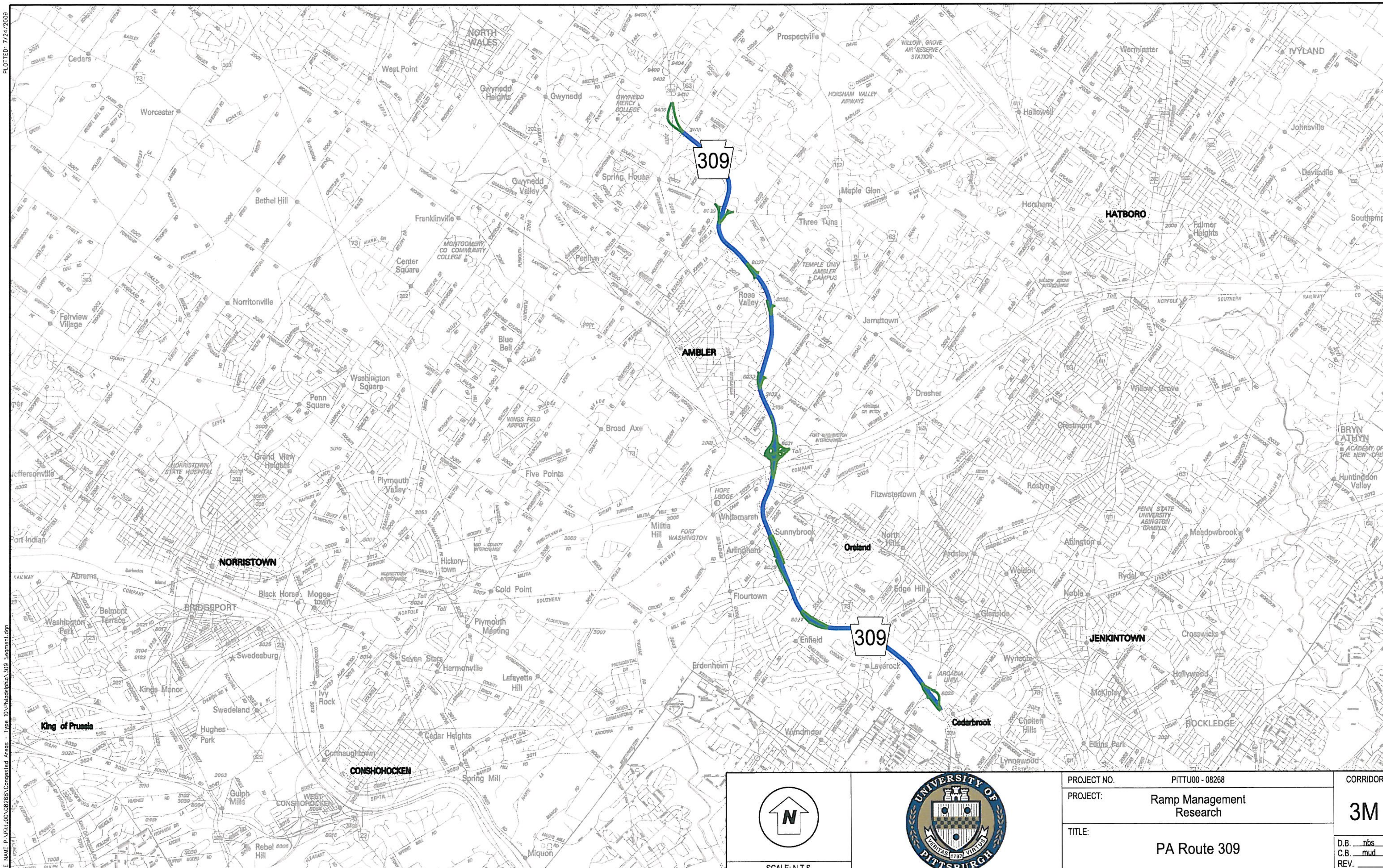
PLOTTED 7/24/2009

FILE NAME: P:\Pitt\u00\08268\Congested Areas - Type '0'\Philadelphia 76 S Segment.dgn

N

SCALE: N.T.S.

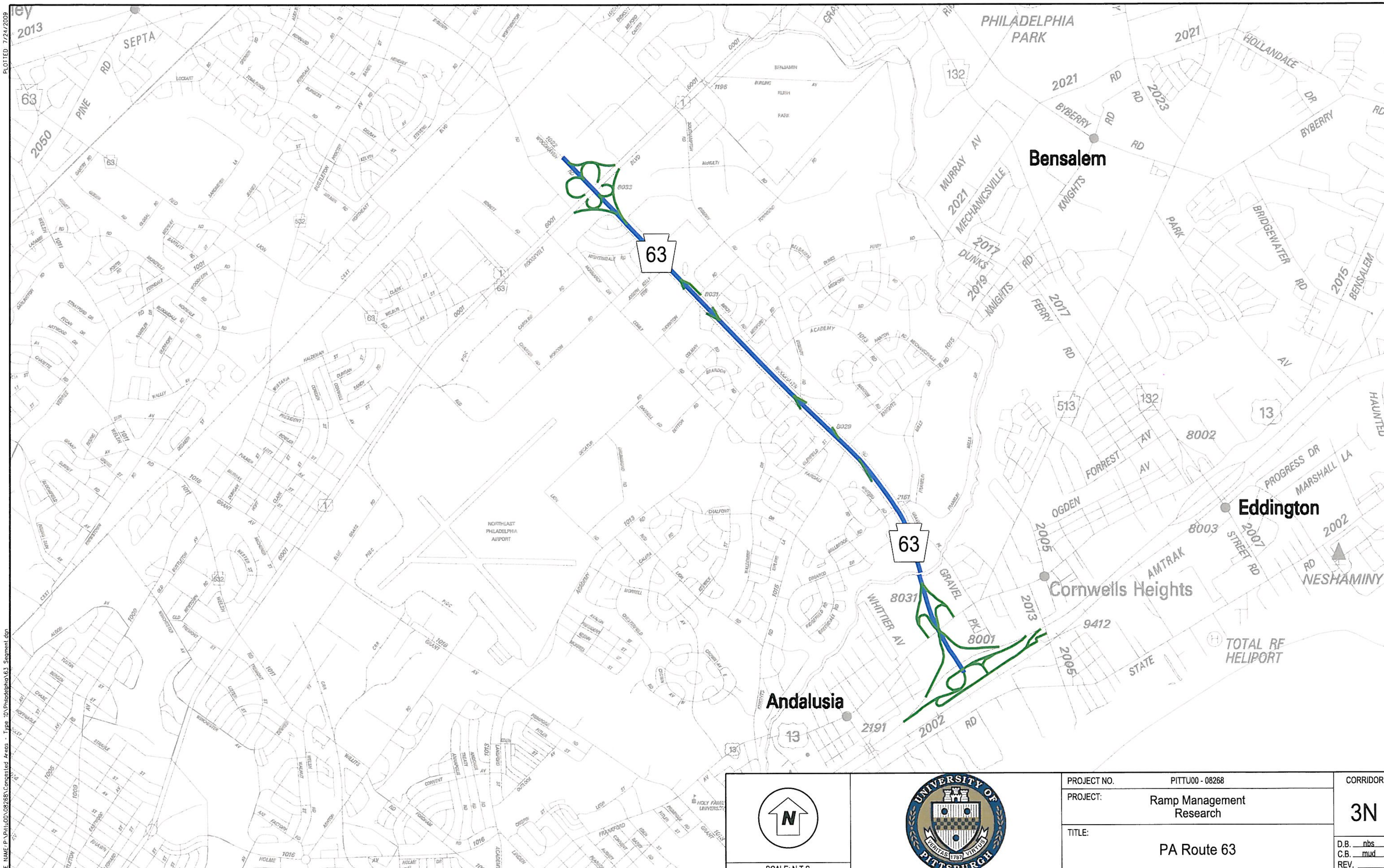
PROJECT NO.	PITTU00 - 08268	CORRIDOR
PROJECT:	Ramp Management Research	3L
TITLE:	Interstate 76 - From US Route 1 To PA Route 291	D.B. nbs C.B. mud REV.



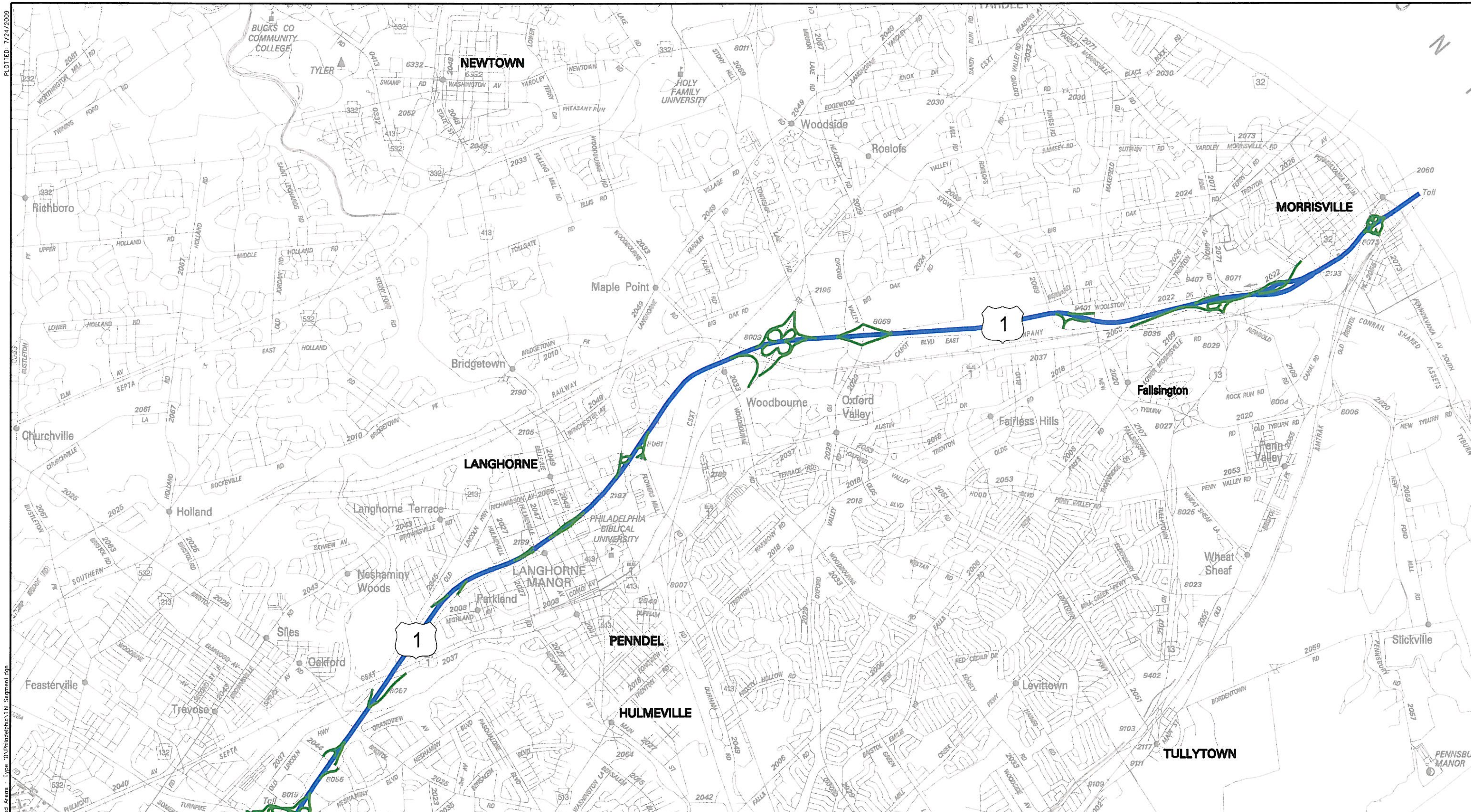
PLOTTED: 7/24/2009

FILE NAME: P:\Pittu00\08268\Congested Areas - Type 10\Philadelphia\309 Segment.dgn

N		PROJECT NO. PITTU00 - 08268	CORRIDOR
		PROJECT: Ramp Management Research	3M
		TITLE: PA Route 309	D.B. nbs C.B. mud REV. ______
SCALE: N.T.S.			



N SCALE: N.T.S.	UNIVERSITY OF PITTSBURGH VERITAS 1787 VIRTUS	PROJECT NO. PITTU00 - 08268 PROJECT: Ramp Management Research TITLE: PA Route 63	CORRIDOR 3N D.B. nbs C.B. mud REV.



PROJECT NO.	PITTU00 - 08268
PROJECT:	Ramp Management Research
TITLE:	US Route 1 - From PA Turnpike To New Jersey Line

CORRIDOR

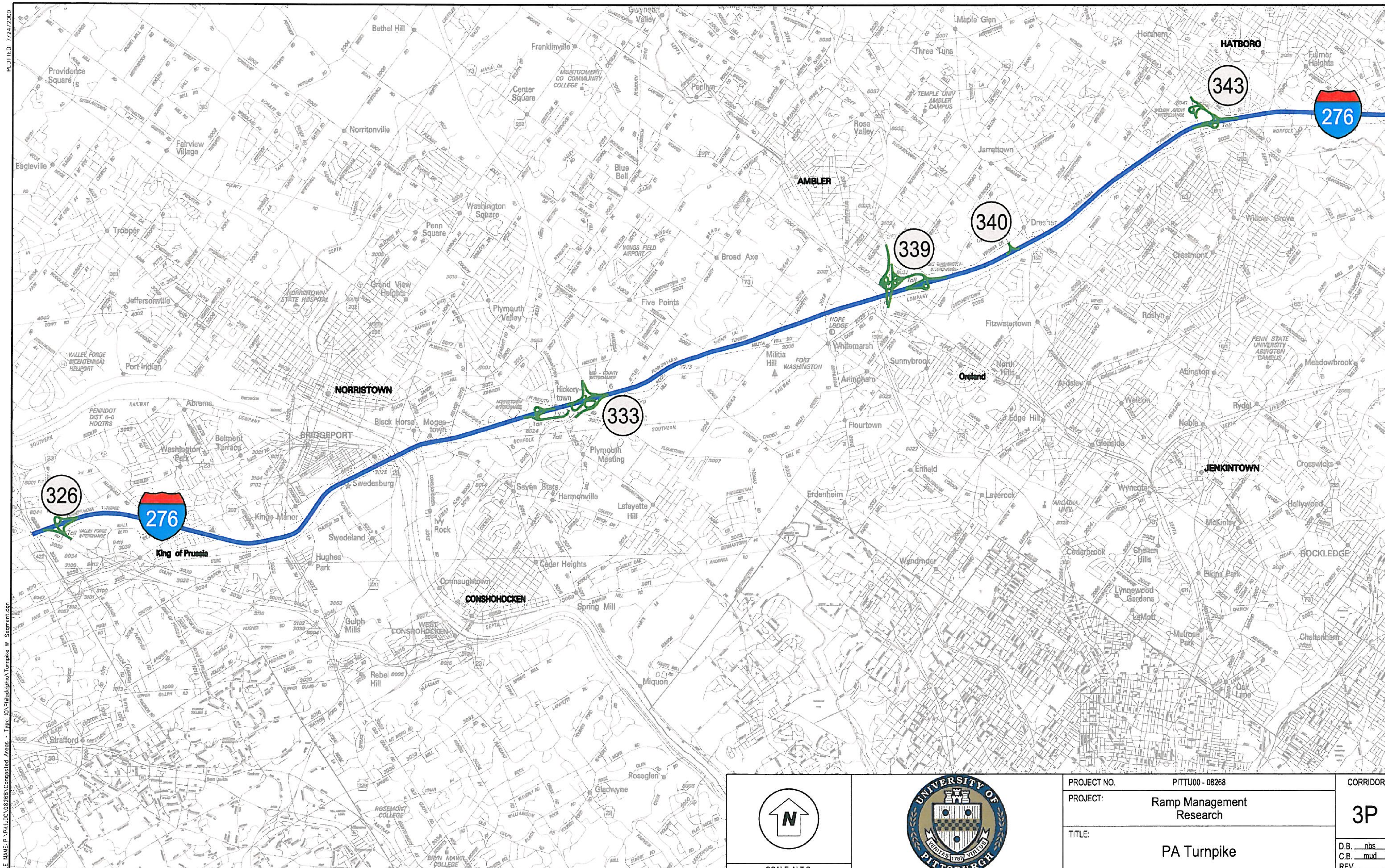
30

D.B. nbs
C.B. mud
REV. ______

SCALE: N.T.S.

PLOTTED 7/24/2009

FILE NAME P:\Pitt\u00\08268\Congested Areas - Type '0'\Philadelphia\1 N Segment.dgn



PLOTTED 7/24/2009

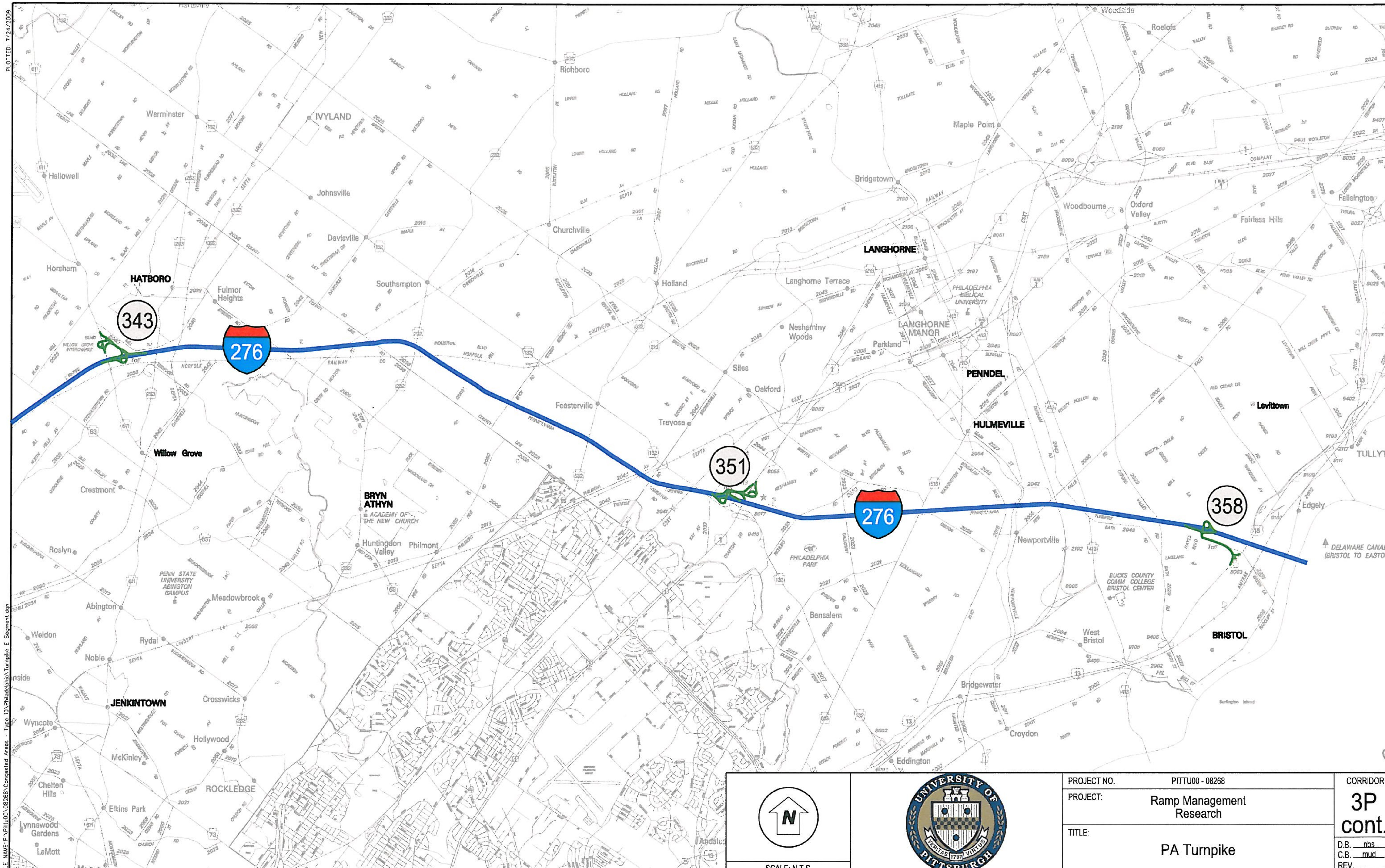
FILE NAME: P:\Pitt\u00\08268\Congested Areas Type 10\Philadelphia Turnpike W Segment.dgn

N

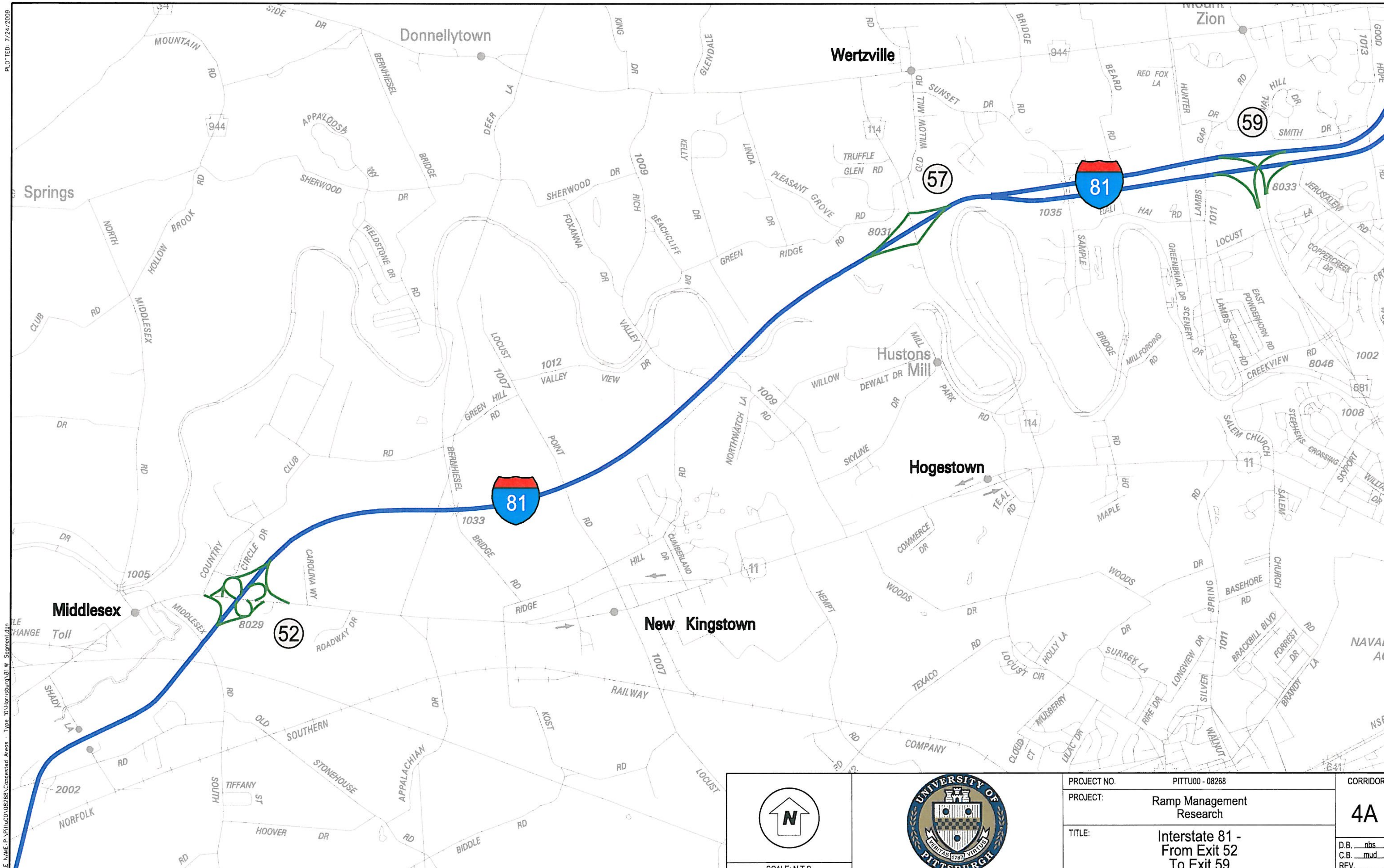
SCALE: N.T.S.

UNIVERSITY OF PITTSBURGH
VERITAS 1787 VIRTUS

PROJECT NO.	PITTU00 - 08268	CORRIDOR
PROJECT:	Ramp Management Research	3P
TITLE:	PA Turnpike	D.B. nbs C.B. mud REV.



343
276
351
358
HATBORO
Horsham
Warminster
IVYLAND
Richboro
Johnsville
Davisville
Churchville
Southampton
Holland
Fulmor Heights
Hallowell
Willow Grove
Crestmont
Roslyn
Abington
Weldon
Rydal
Noble
JENKINTOWN
Wyncote
McKinley
Chelten Hills
Elkins Park
Lynnewood Gardens
LaMott
ROCKLEDGE
Hollywood
Crosswicks
Meadowbrook
PENN STATE UNIVERSITY ABINGTON CAMPUS
BRYN ATHYN
ACADEMY OF THE NEW CHURCH
Huntingdon Valley
Philmont
Feasterville
Trevose
Oakford
Siles
Neshaminy Woods
Parkland
LANGHORNE
Langhorne Terrace
LANGHORNE MANOR
PHILADELPHIA BIBLICAL UNIVERSITY
PENNDEL
HULMEVILLE
Bridgetown
Maple Point
Woodbourne
Oxford Valley
Fairless Hills
Fallsington
Roelofs
Woodside
Levittown
TULLYTOWN
Edgely
DELAWARE CANAL (BRISTOL TO EASTON)
Newportville
BUCKS COUNTY COMM COLLEGE BRISTOL CENTER
BRISTOL
West Bristol
Bridgewater
Croydon
Eddington
Bensalem
PHILADELPHIA PARK
PLOTTED 7/24/2009
SCALE: N.T.S.
PROJECT NO. PITTU00 - 08268
PROJECT: Ramp Management Research
TITLE: PA Turnpike
CORRIDOR
3P cont.
D.B. nbs
C.B. mud
REV.



SCALE: N.T.S.

PROJECT NO. PITTU00 - 08268

PROJECT: Ramp Management Research

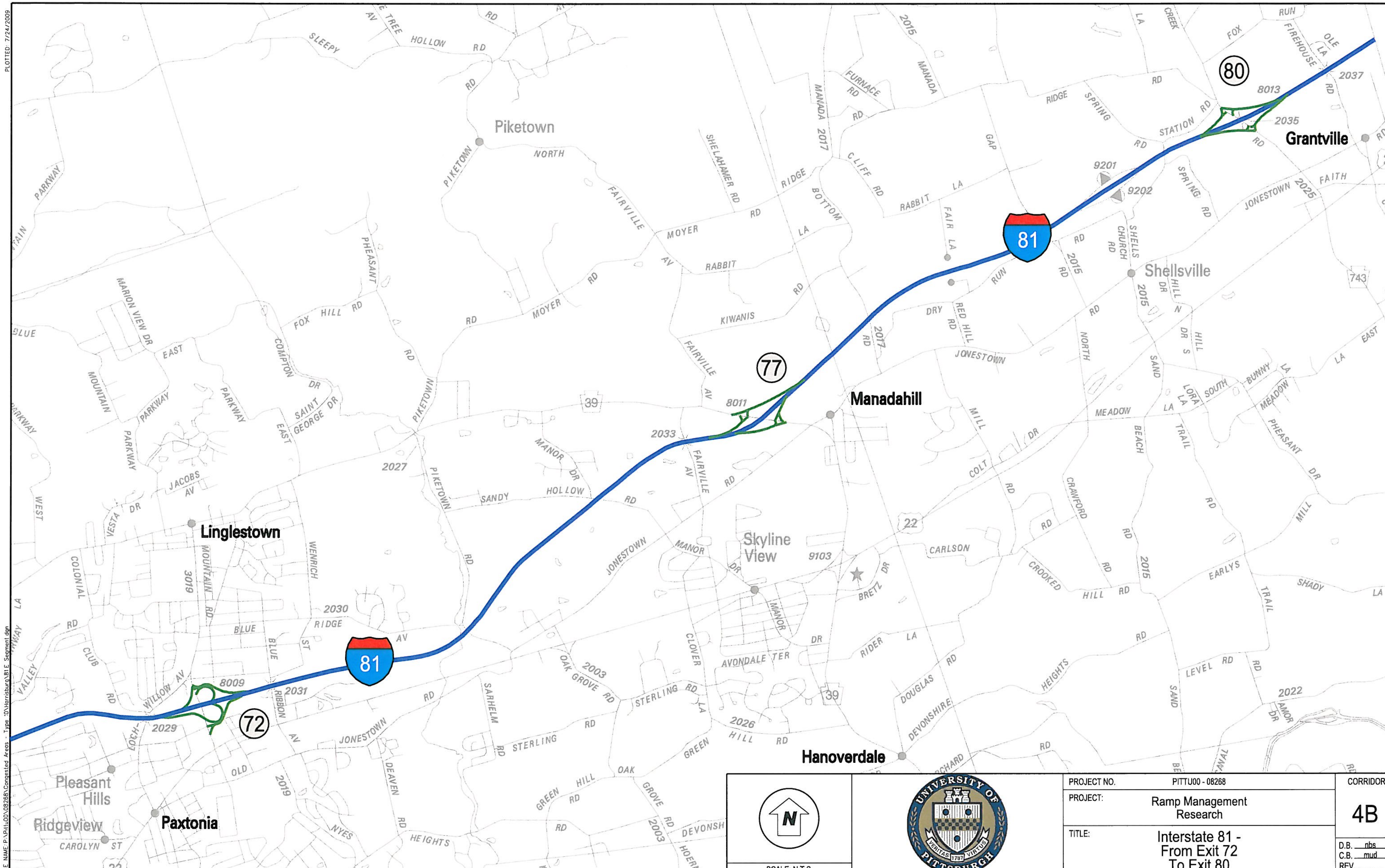
TITLE: Interstate 81 - From Exit 52 To Exit 59

CORRIDOR 4A

D.B. nbs
C.B. mud
REV.

PLOTTED: 7/24/2009

FILE NAME: P:\Pitt\u00\08268\Congested Areas - Type "D"\Harrisburg\81 W Segment.dgn



SCALE: N.T.S.

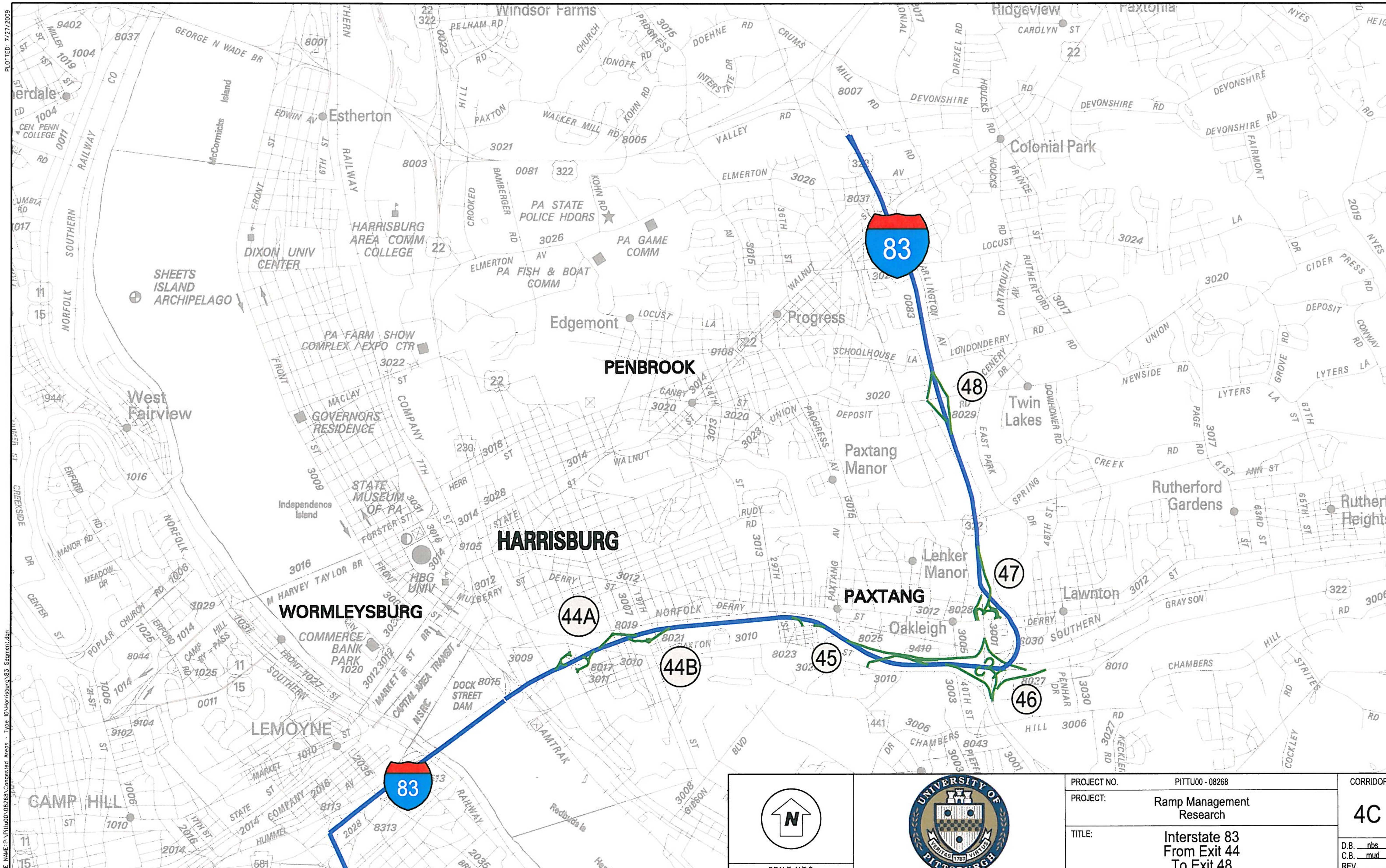
PROJECT NO.	PITTU00 - 08268
PROJECT:	Ramp Management Research
TITLE:	Interstate 81 - From Exit 72 To Exit 80

CORRIDOR

4B

D.B. nbs
C.B. mud
REV.

PLOTTED 7/24/2009

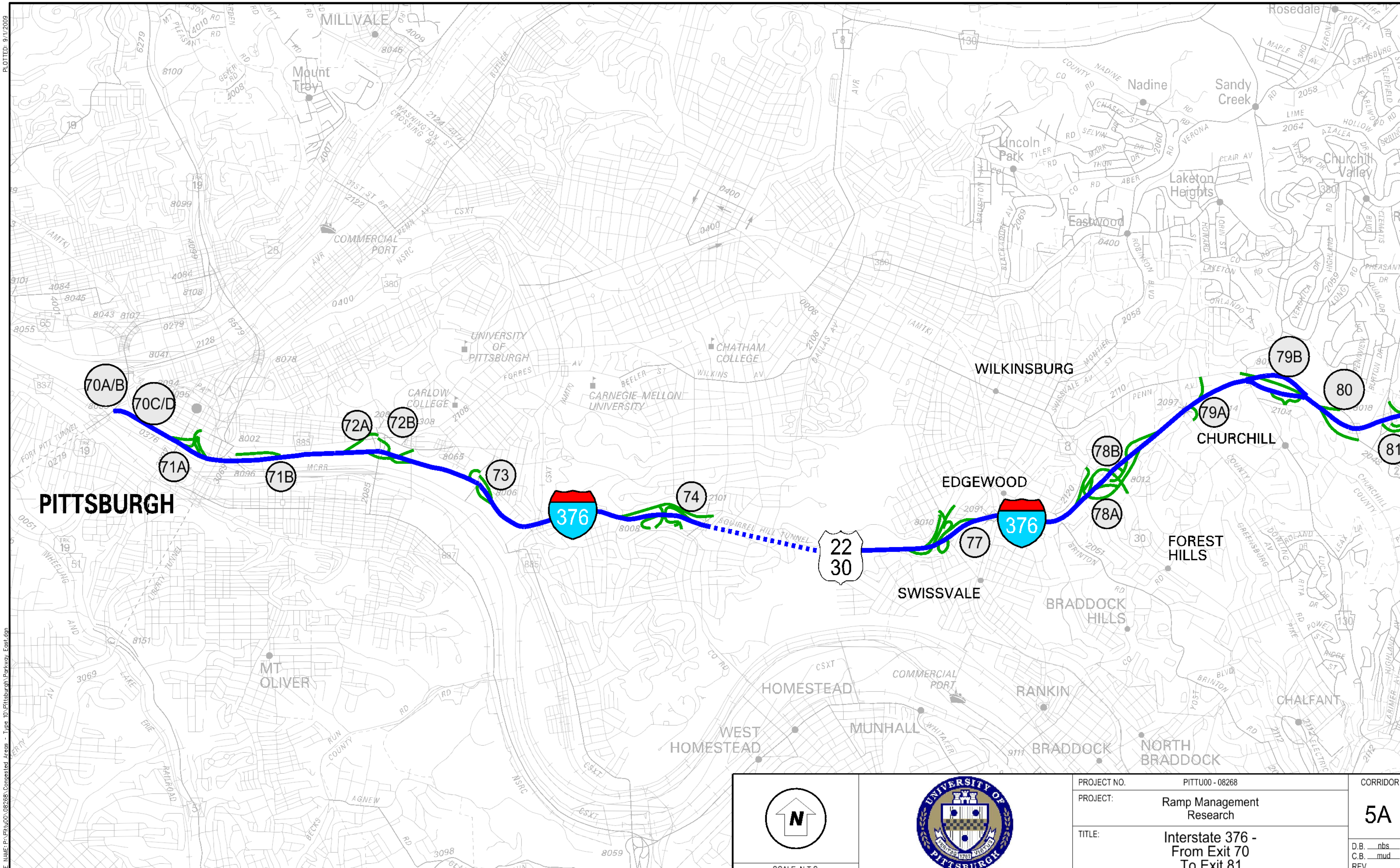


PROJECT NO.	PITTU00 - 08268
PROJECT:	Ramp Management Research
TITLE:	Interstate 83 From Exit 44 To Exit 48
CORRIDOR	4C
D.B.	nbs
C.B.	mud
REV.	

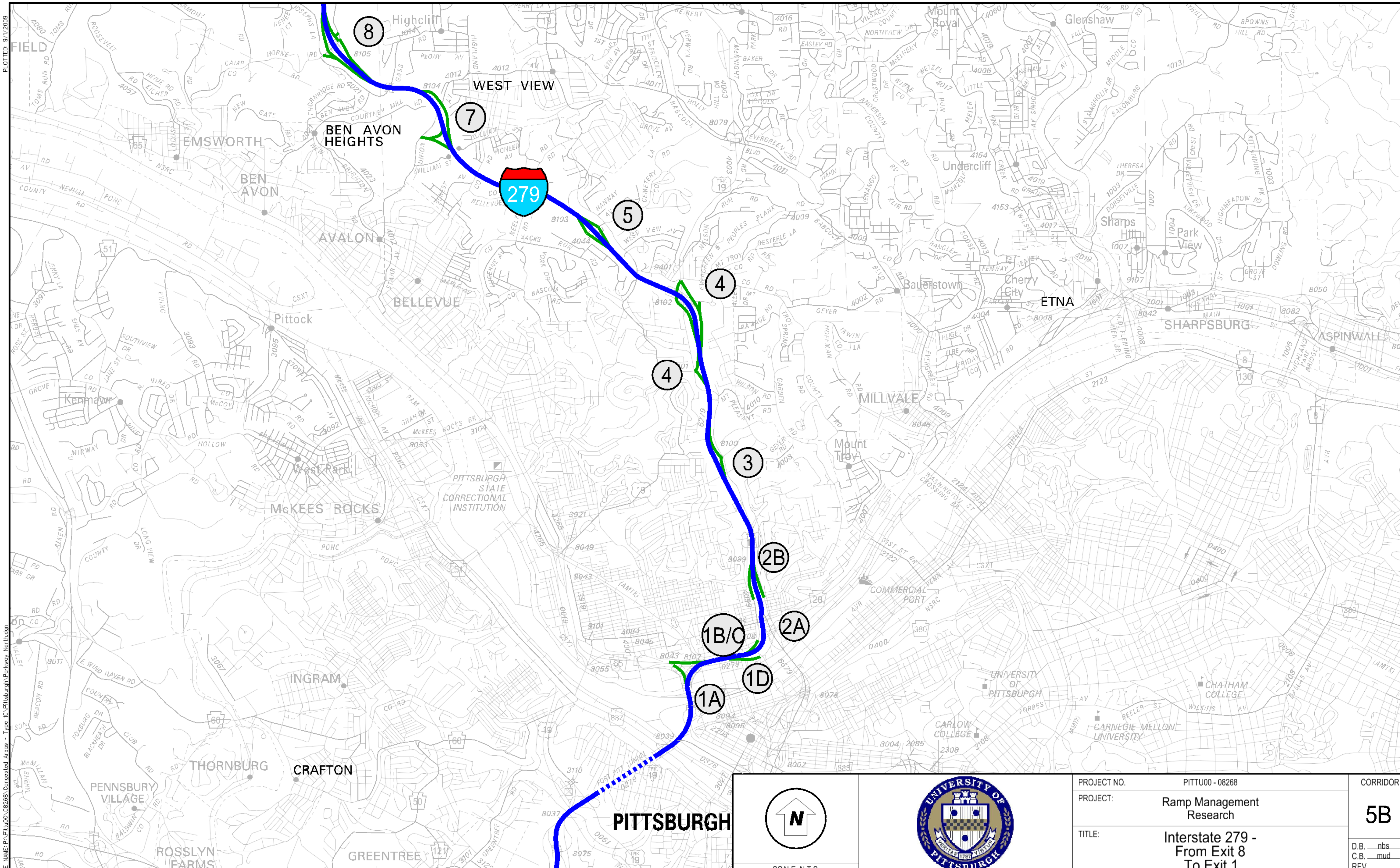
PLOTTED 7/27/2009

FILE NAME: P:\Pitt\00\08268\Congested Areas - Type 10\Harrisburg\83 Segment.dgn

PLOTTED: 9/1/2009



FILE NAME: P:\Pittu00\08268\Congested Areas - Type 10\Pittsburgh\Parkway East.dgn



N

SCALE: N.T.S.

PROJECT NO. PITTU00 - 08268

PROJECT: Ramp Management Research

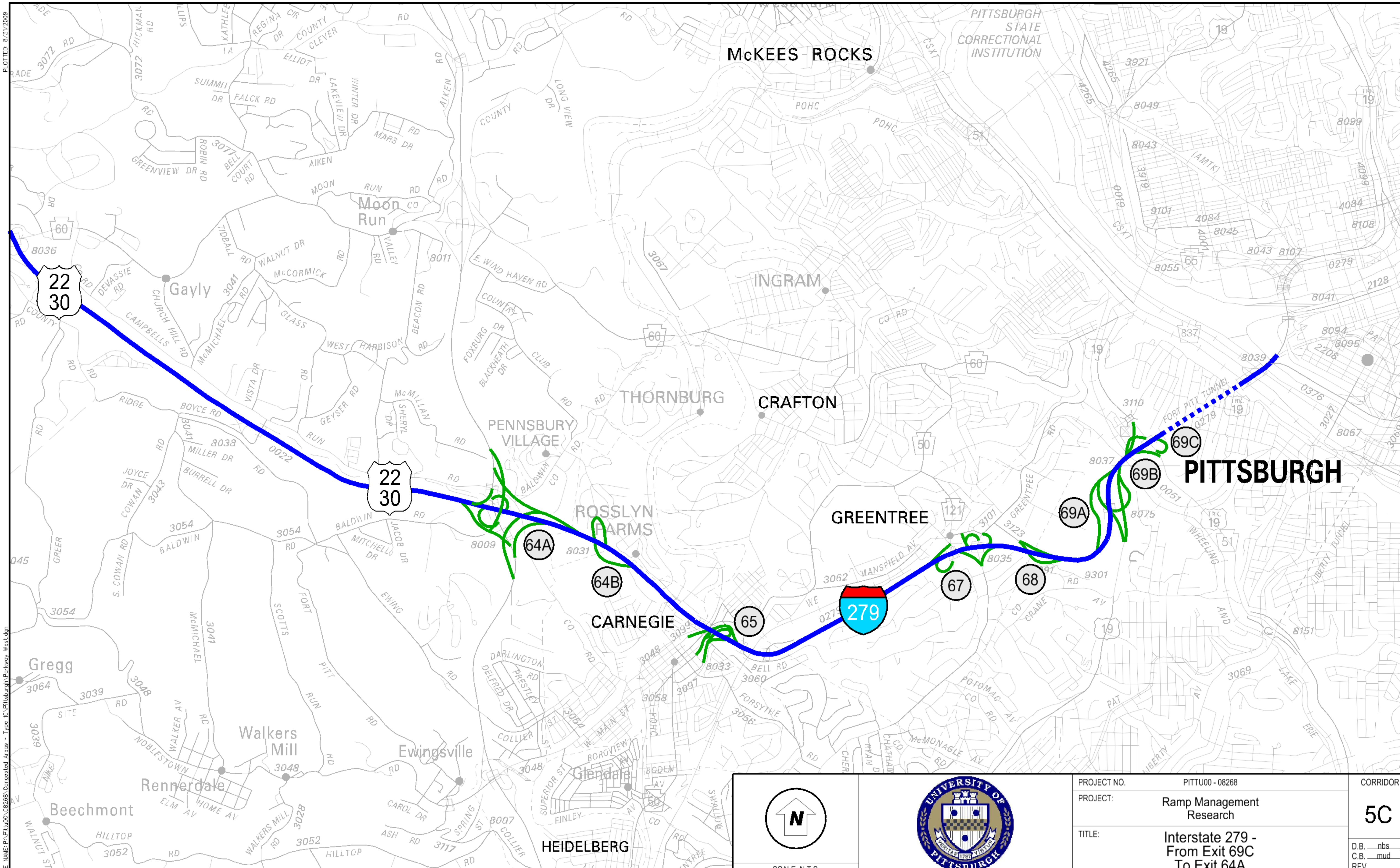
TITLE: Interstate 279 - From Exit 8 To Exit 1

CORRIDOR 5B

D.B. nbs
C.B. mud
REV.

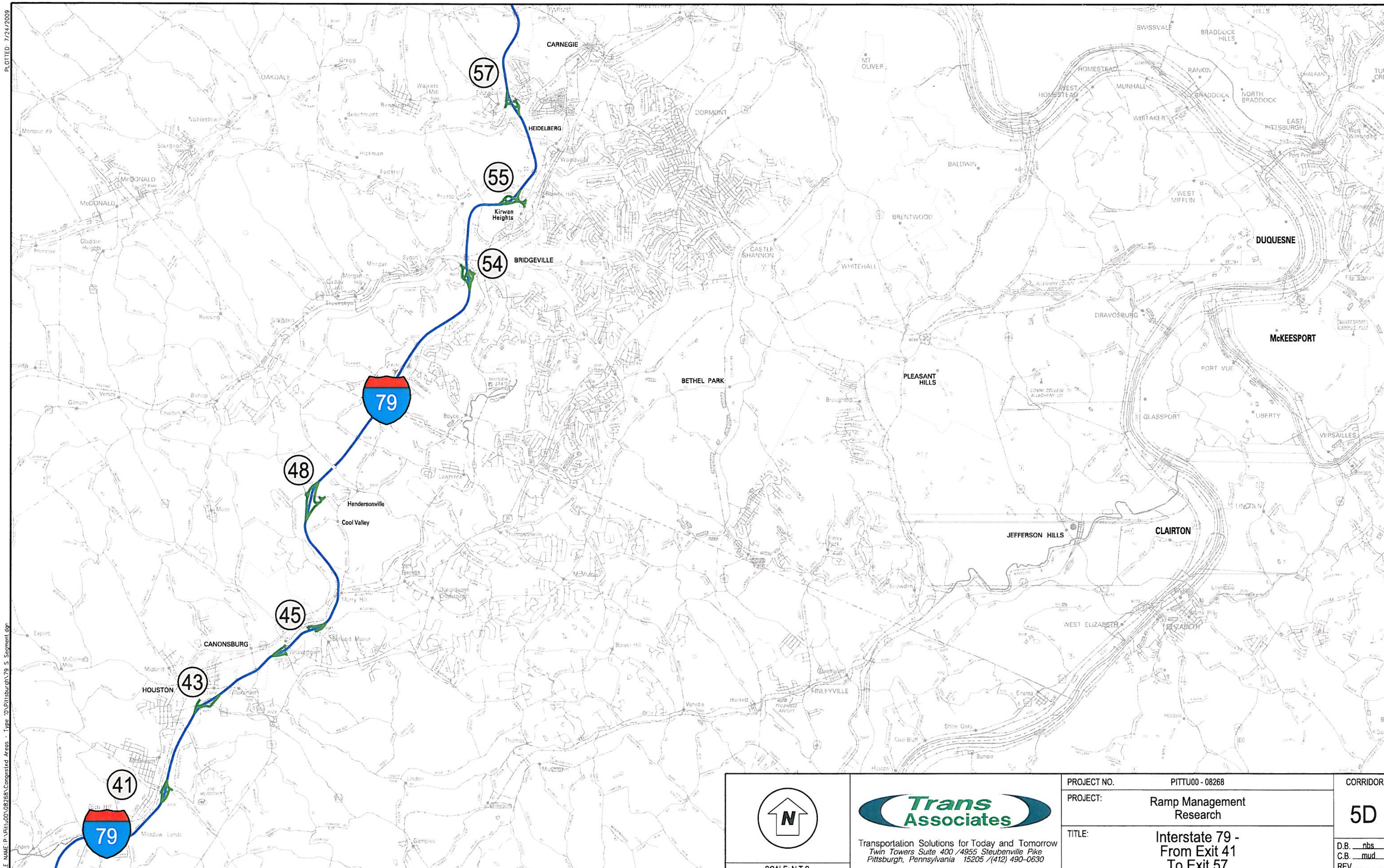
PLOTTED: 9/1/2009

FILE NAME: P:\Pittu00\08268\Congested Areas - Type 10\Pittsburgh\Parkway North.dgn



McKEES ROCKS
PITTSBURGH STATE CORRECTIONAL INSTITUTION
Moon Run
Gayly
INGRAM
THORNBURG
CRAFTON
PENNSBURY VILLAGE
ROSSLYN FARMS
GREENTREE
CARNEGIE
PITTSBURGH
Gregg
Walkers Mill
Ewingsville
Rennerdale
Beechmont
Glendale
HEIDELBERG
22
30
279
64A
64B
65
67
68
69A
69B
69C
FORT PITT TUNNEL
SCALE: N.T.S.
N
PROJECT NO. PITTU00 - 08268
PROJECT: Ramp Management Research
TITLE: Interstate 279 - From Exit 69C To Exit 64A
CORRIDOR 5C
D.B. nbs
C.B. mud
REV.
PLOTTED: 8/31/2009

PLOTTED: 7/24/2009



SCALE: N.T.S.

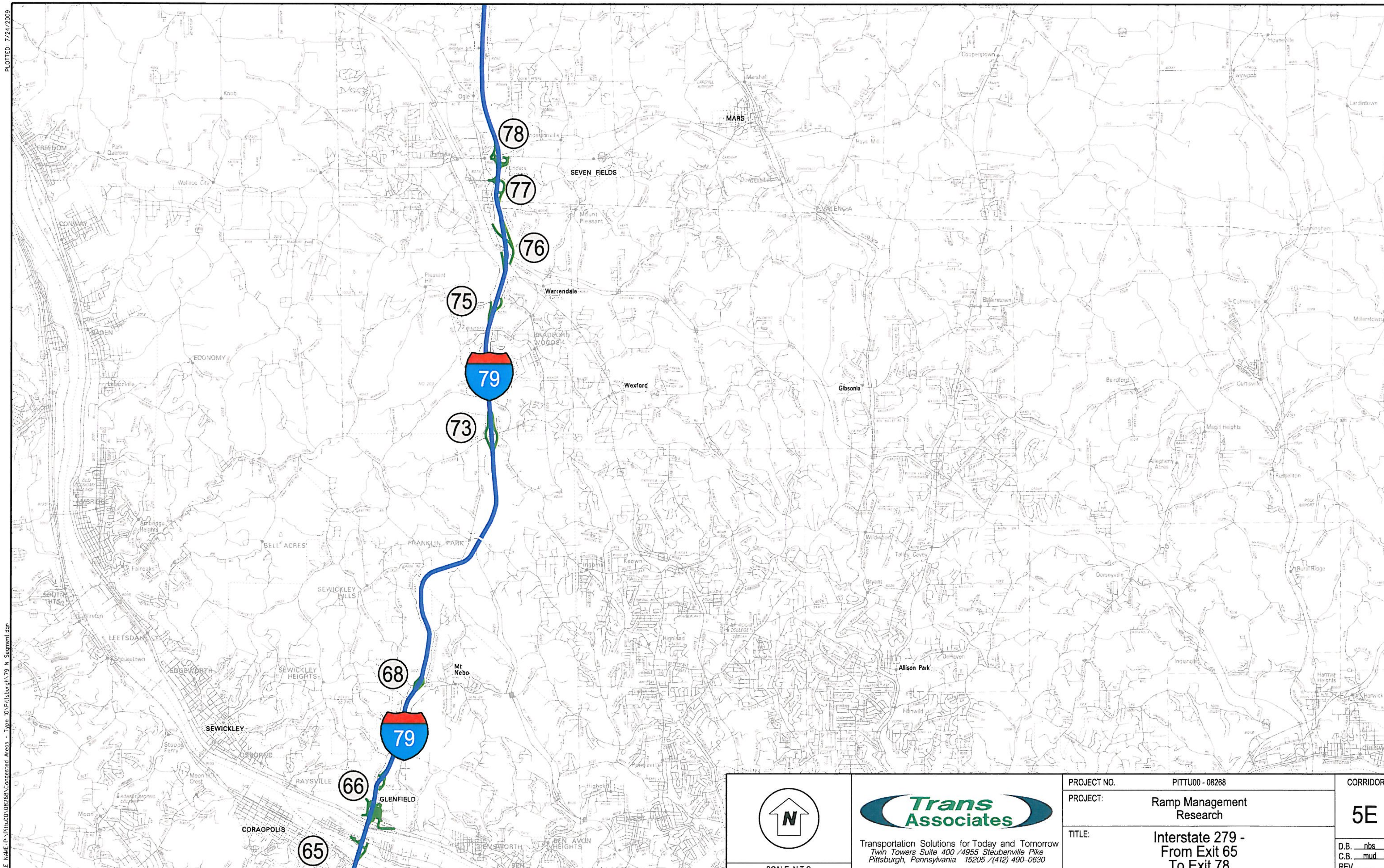
Trans Associates

Transportation Solutions for Today and Tomorrow
Twin Towers Suite 400 / 4955 Steubenville Pike
Pittsburgh, Pennsylvania 15205 / (412) 490-0630

PROJECT NO.	PITTU00 - 08268	CORRIDOR
PROJECT:	Ramp Management Research	5D
TITLE:	Interstate 79 - From Exit 41 To Exit 57	D.B. nbs C.B. mud REV.

FILE NAME: P:\Pittu00\08268\Congested Areas - Type '0'\Pittsburgh\79 S Segment.dgn

PLOTTED 7/24/2009



PROJECT NO.	PITTU00 - 08268	CORRIDOR
PROJECT:	Ramp Management Research	5E
TITLE:	Interstate 279 - From Exit 65 To Exit 78	D.B. nbs C.B. mud REV.

N

SCALE: N.T.S.

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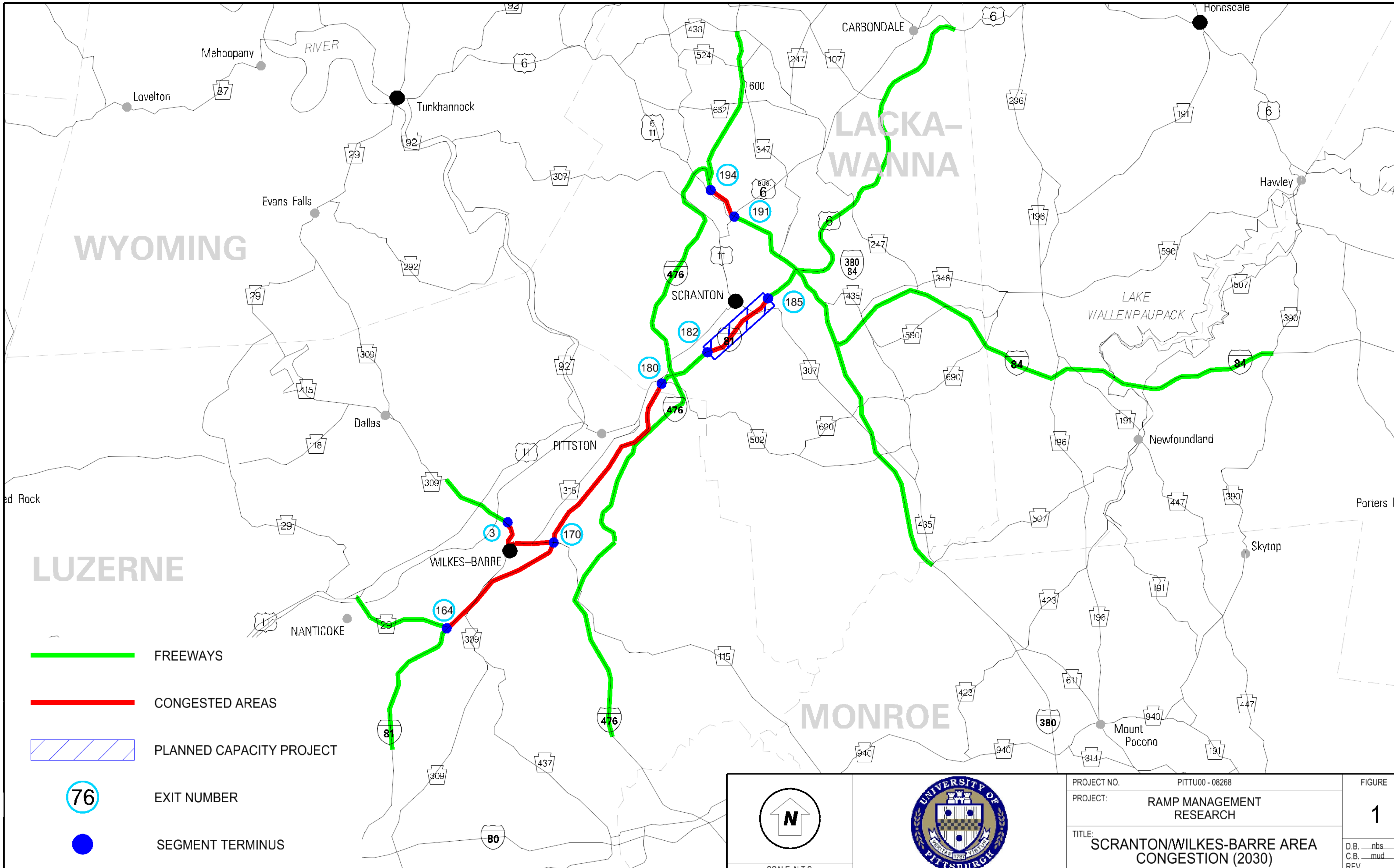
Pittsburgh, Pennsylvania 15205 /(412) 490-0630

APPENDIX B

Candidate Ramp Management Freeway Corridor Maps


WYOMING
LUZERNE
LACKA-
WANNA
MONROE
Mehoopany
RIVER
Lovelton
Tunkhannock
CARBONDALE
Honesdale
Evans Falls
Hawley
SCRANTON
LAKE
WALLENPAUPACK
Dallas
PITTSTON
Newfoundland
WILKES-BARRE
NANTICOKE
Skytop
Porters Lak
Mount
Pocono
FREEWAYS
CONGESTED AREAS
PLANNED CAPACITY PROJECT
76
EXIT NUMBER
SEGMENT TERMINUS
N
SCALE: N.T.S.
PROJECT NO.
PITTU00 - 08268
PROJECT:
RAMP MANAGEMENT
RESEARCH
TITLE:
SCRANTON/WILKES-BARRE AREA
CONGESTION (2030)
FIGURE
1
D.B. nbs
C.B. mud
REV.

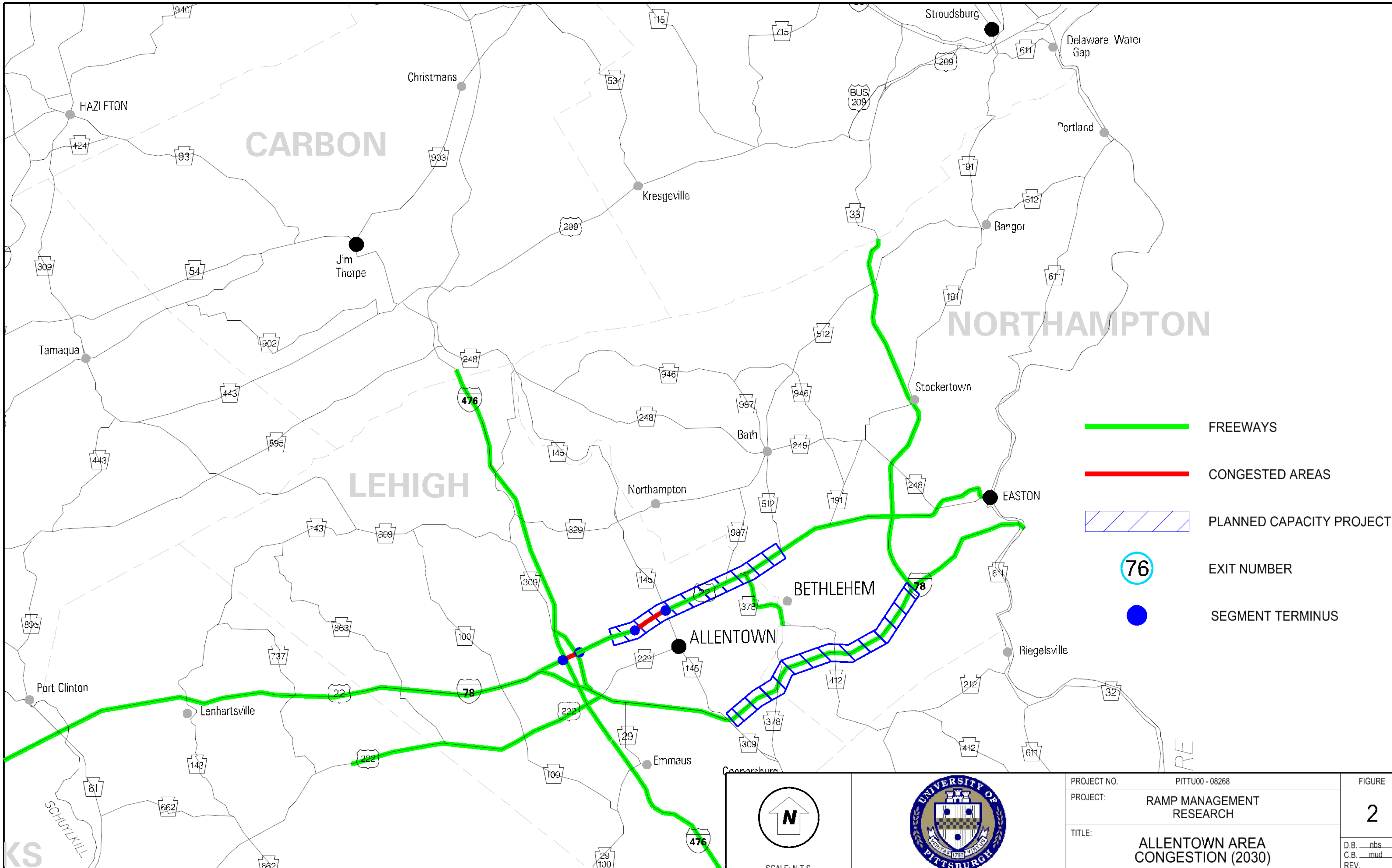
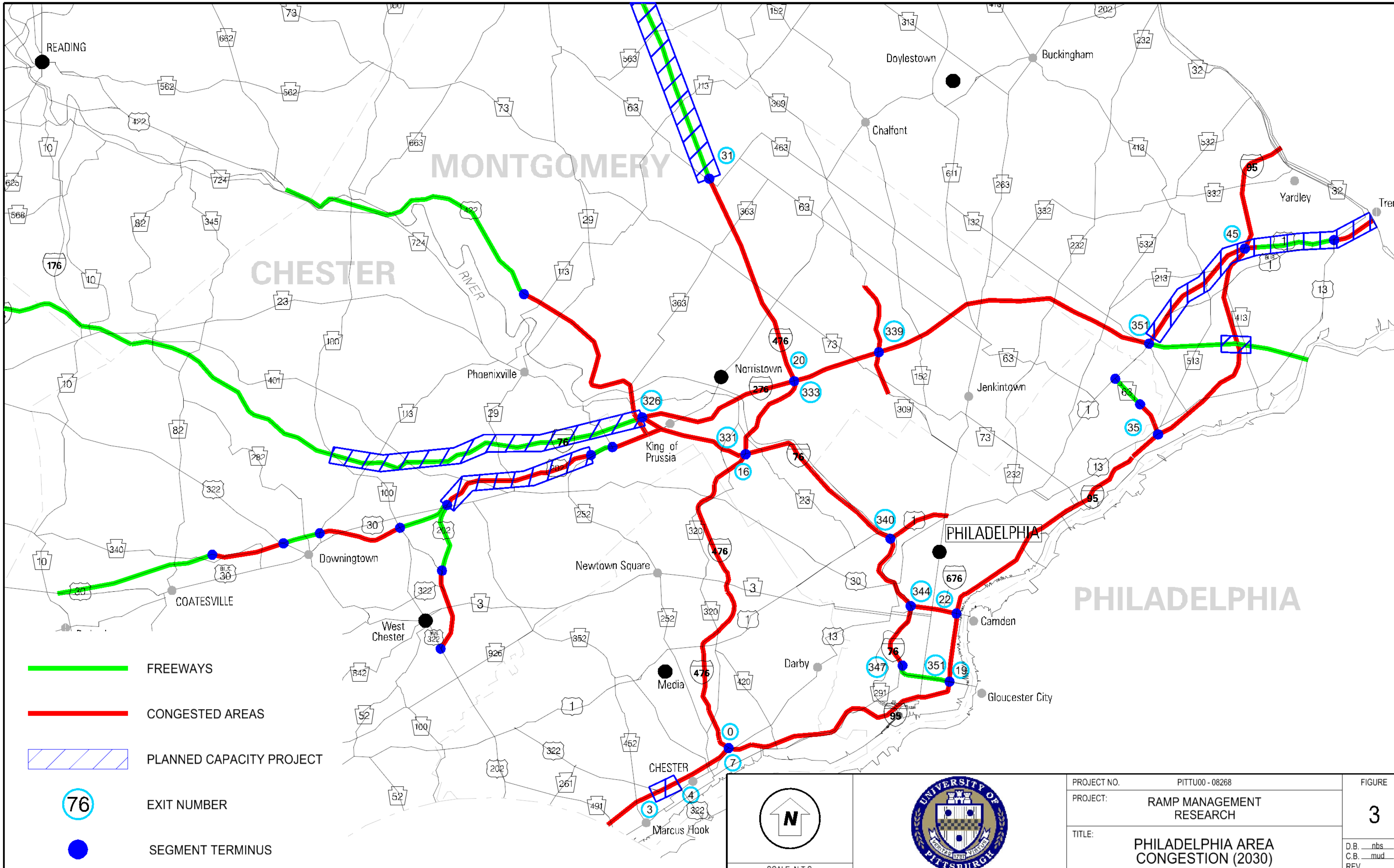


FIGURE 2

TITLE: ALLENTOWN AREA CONGESTION (2030)



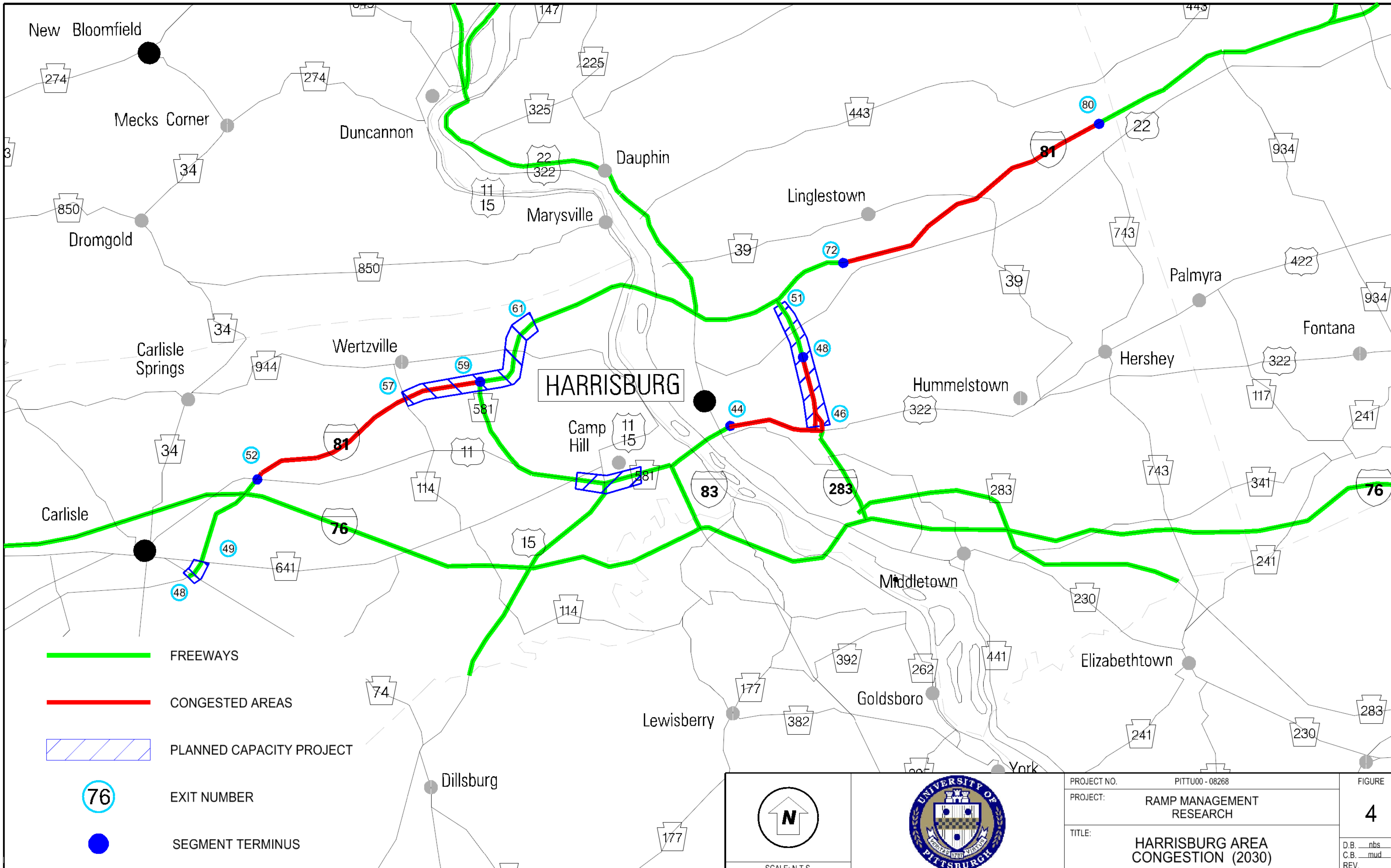
PROJECT NO. PITTU00 - 08268

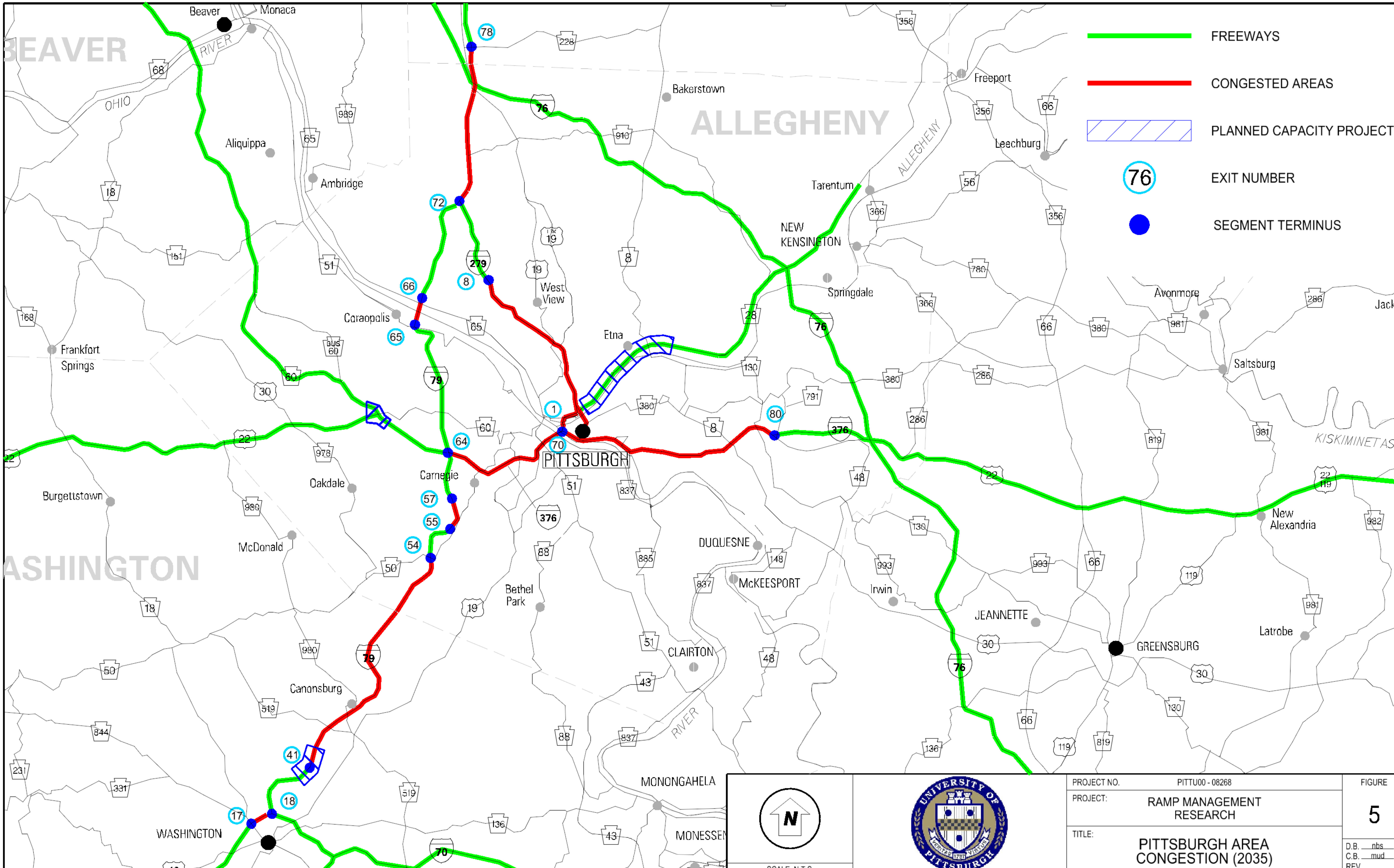
PROJECT: RAMP MANAGEMENT RESEARCH

TITLE: PHILADELPHIA AREA CONGESTION (2030)

FIGURE 3

D.B. nbs
C.B. mud
REV.


New Bloomfield
Mecks Corner
Duncannon
Dauphin
Marysville
Linglestown
Dromgold
Carlisle Springs
Wertzville
HARRISBURG
Camp Hill
Hummelstown
Palmyra
Hershey
Fontana
Carlisle
Middletown
Elizabethtown
Goldsboro
Lewisberry
Dillsburg
York
FREEWAYS
CONGESTED AREAS
PLANNED CAPACITY PROJECT
76 EXIT NUMBER
SEGMENT TERMINUS
N
SCALE: N.T.S.
UNIVERSITY OF PITTSBURGH
PROJECT NO. PITTU00 - 08268
PROJECT: RAMP MANAGEMENT RESEARCH
TITLE: HARRISBURG AREA CONGESTION (2030)
FIGURE 4
D.B. nbs
C.B. mud
REV.


FREEWAYS
CONGESTED AREAS
PLANNED CAPACITY PROJECT
76
EXIT NUMBER
SEGMENT TERMINUS
BEAVER
ALLEGHENY
ASHINGTON
Beaver
Monaca
OHIO
RIVER
Aliquippa
Ambridge
Bakerstown
Freeport
Leechburg
Tarentum
NEW KENSINGTON
Springdale
Avonmore
Saltsburg
Jackso
KISKIMINETAS
West View
Etna
Coraopolis
Frankfort Springs
PITTSBURGH
Carnegie
Oakdale
Burgettstown
McDonald
DUQUESNE
McKEESPORT
Irwin
JEANNETTE
GREENSBURG
New Alexandria
Latrobe
Bethel Park
CLAIRTON
Canonsburg
MONONGAHELA
MONESSEN
WASHINGTON
SCALE: N.T.S.
PROJECT NO. PITTU00 - 08268
PROJECT: RAMP MANAGEMENT RESEARCH
TITLE: PITTSBURGH AREA CONGESTION (2035)
FIGURE
5
D.B. nbs
C.B. mud
REV.

APPENDIX C

Candidate Ramp Management Freeway Ranking Calculations

Freeway Ramp Management Appendix C

Scranton/Wilkes-Barre

		(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
Corridor ID	Description	Number of Interchanges	Rating 1	Number Spaced < 1 mile	Rating 2	covered by PennDOT cameras?	Rating 3	Alternate Routes?	Rating 4	# of Storage lanes < 1000 ft	Rating 5	V/C ratio
1 A	I-81, exit 164 to 185	10	3	4	2	some	2	yes	3	5	2	1.11
1 B	I-81, exit 191 to 194	3	2	1	2	some	2	yes	2	1	2	1.33
1 C	PA-309, exit 3 to I-81	5	2	2	2	no	1	no	1	2	2	1.58

Notes

(A) Counted from Google Maps June 2009 The interchanges per congested corridor were counted using an aerial map of each location. Because the foc of this study is metering or closing interchange on-ramps only, each on-ramp along the congested corridor was counted. Some corridors had more on-ramps in one direction than the other. In those instances, the greater of the two was used.

(B) 1 for 0-2 interchange ramps. 2 for 3-6 interchange ramps. 3 for > 6 interchange ramps.

(C) Estimated from Google Maps, June 2009. the spacing of the interchanges and the length of the on-ramps were estimated using aerial maps. Becau spacing and the ramp lengths were different for each corridor direction, the worst-case scenario was used (i.e. closest spaced interchanges and shor

(D) 1 for greater than 50% of interchanges spaced less than a mile apart. 2 for between 25% and 50% of interchanges spaced less than a mile apart. 3 for less than 25% of interchanges spaced less than a mile apart.

(E) Based on information obtained from the PennDOT website, June 2009

(F) 1 for no cameras. 2 for some cameras. 3 for extensive camera coverage.

(G) Based on brief assesment of area mapping, June 2009

(H) 1 for no alternate routes. 2 for one main alternate route. 3 for more than one main alternate routes.

(I) Estimated from Google Map aerials, June 2009

(J) 1 for less than 25% of interchange ramps longer than 1000 ft. 2 for between 25% and 50% of interchange ramps longer than 1000 ft. 3 for more than 50% of interchange ramps longer than 1000 ft.

(K) Based upon average v/c ratios by segment calculated in Task 3

(L) 1 for v/c ratio 1.0-1.49. 2 for v/c ratio 1.5-2.0. 3 for v/c ratio > 2.0.

Freeway Ramp Management Appendix C

Allentown

Corridor ID	Description	(A) Number of Interchanges	(B) Rating 1	(C) Number Spaced < 1 mile	(D) Rating 2	(E) covered by PennDOT cameras?	(F) Rating 3	(G) Alternate Routes?	(H) Rating 4	(I) # of Storage lanes < 1000 ft	(J) Rating 5	(K) V/C ratic
2 A	US 22 PA Turnpike to PA 309	3	2	2	1	yes	3	yes	2	1	2	1.1
2 A	US 22 15th Street to PA 145	3	2	1	2	yes	3	yes	2	2	1	1.01

Notes

(A) Counted from Google Maps June 2009 The interchanges per congested corridor were counted using an aerial map of each location. Because the focus of this study is metering or closing interchange on-ramps only, each on-ramp along the congested corridor was counted. Some corridors had more on-ramps in one direction than the other. In those instances, the greater of the two was used.
(B) 1 for 0-2 interchange ramps. 2 for 3-6 interchange ramps. 3 for > 6 interchange ramps.
(C) Estimated from Google Maps, June 2009. the spacing of the interchanges and the length of the on-ramps were estimated using aerial maps. Because t spacing and the ramp lengths were different for each corridor direction, the worst-case scenario was used (i.e. closest spaced interchanges and shortest
(D) 1 for greater than 50% of interchanges spaced less than a mile apart. 2 for between 25% and 50% of interchanges spaced less than a mile apart. 3 for less than 25% of interchanges spaced less than a mile apart.
(E) Based on information obtained from the PennDOT website, June 2009
(F) 1 for no cameras. 2 for some cameras. 3 for extensive camera coverage.
(G) Based on brief assesment of area mapping, June 2009
(H) 1 for no alternate routes. 2 for one main alternate route. 3 for more than one main alternate routes.
(I) Estimated from Google Map aerials, June 2009
(J) 1 for less than 25% of interchange ramps longer than 1000 ft. 2 for between 25% and 50% of interchange ramps longer than 1000 ft. 3 for more than 50% of interchange ramps longer than 1000 ft.
(K) Based upon average v/c ratios by segment calculated in Task 3
(L) 1 for v/c ratio 1.0-1.49. 2 for v/c ratio 1.5-2.0. 3 for v/c ratio > 2.0.

Freeway Ramp Management Appendix C

Philadelphia

		(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K
Corridor ID	Description	Number of Interchanges	Rating 1	Number Spaced < 1 mile	Rating 2	covered by PennDOT cameras?	Rating 3	Alternate Routes?	Rating 4	# of Storage lanes < 1000 ft	Rating 5	V/(rati
3 K	I-76, Turnpike to US-1	10	3	5	2	yes	3	yes	2	5	2	2.0
3 F	I-95, DE to I-676	16	3	6	2	some	2	yes	3	3	3	1.5
3 D	I-476, I-95 to Turnpike (Blue Route)	9	3	2	3	some	2	yes	2	1	3	1.7
3 I	I-676, I-76 to I-95	2	1	1	2	yes	3	yes	3	1	2	1.6
3 J	US-1, I-76 to PA 611	5	2	1	3	yes	3	yes	2	5	1	2.9
3 L	I-76, US-1 to PA 291	9	3	4	2	yes	3	yes	2	5	1	2.2
3 G	I-95, I-676 to Turnpike	14	3	4	2	some	2	yes	3	4	2	1.7
3 B	Rt 202, Section 200 to Section 400	14	3	7	2	yes	3	yes	3	10	1	1.4
3 C	Rt 422, Royersford to US 202	6	2	2	2	some	2	yes	3	2	2	1.2
3 A	Rt 30, Reeceville Road to PA 100	7	3	1	3	some	2	yes	3	5	1	1.0
3 M	PA 309, PA 152 to PA 63	8	3	1	3	no	1	yes	3	4	2	1.2
3 E	I-476, Exit 20 to Exit 31 (PA Turnpike)	2	1	0	3	no	1	yes	2	0	3	1.2
3 P	PA Turnpike, Exit 326 to Exit 351	6	2	1	3	no	1	no	1	0	3	1.3
3 H	I-95, Turnpike to NJ	5	2	3	1	no	1	yes	2	2	2	1.1
3 N	PA 63, Knights Road to I-95	3	2	1	2	no	1	yes	3	2	1	1.2
3 O	US-1, Turnpike to NJ	14	3	8	1	no	1	yes	3	11	1	1.3

Notes

(A) Counted from Google Maps June 2009 The interchanges per congested corridor were counted using an aerial map of each location. Because the focus of this study is metering or closing interchange on-ramps only, each on-ramp along the congested corridor was counted. Some corridors had more on-ramps in one direction than the other. In those instances, the greater of the two was used.

(B) 1 for 0-2 interchange ramps. 2 for 3-6 interchange ramps. 3 for > 6 interchange ramps.

(C) Estimated from Google Maps, June 2009. the spacing of the interchanges and the length of the on-ramps were estimated using aerial maps. Because the spacing and the ramp lengths were different for each corridor direction, the worst-case scenario was used (i.e. closest spaced interchanges and shortest ramps).

(D) 1 for greater than 50% of interchanges spaced less than a mile apart. 2 for between 25% and 50% of interchanges spaced less than a mile apart. 3 for less than 25% of interchanges spaced less than a mile apart.

(E) Based on information obtained from the PennDOT website, June 2009

(F) 1 for no cameras. 2 for some cameras. 3 for extensive camera coverage.

(G) Based on brief assesment of area mapping, June 2009

(H) 1 for no alternate routes. 2 for one main alternate route. 3 for more than one main alternate routes.

(I) Estimated from Google Map aerials, June 2009

(J) 1 for less than 25% of interchange ramps longer than 1000 ft. 2 for between 25% and 50% of interchange ramps longer than 1000 ft. 3 for more than 50% of interchange ramps longer than 1000 ft.

(K) Based upon average v/c ratios by segment calculated in Task 3

(L) 1 for v/c ratio 1.0-1.49. 2 for v/c ratio 1.5-2.0. 3 for v/c ratio > 2.0.

Freeway Ramp Management Appendix C

Harrisburg

Corridor ID	Description	(A) Number of Interchanges	(B) Rating 1	(C) Number Spaced < 1 mile	(D) Rating 2	(E) covered by PennDOT cameras?	(F) Rating 3	(G) Alternate Routes?	(H) Rating 4	(I) # of Storage lanes < 1000 ft	(J) Rating 5	(K) V/C ratio
4 C	I-83, exit 44 to exit 48	6	2	3	2	yes	3	yes	3	4	1	1.1
4 A	I-81, exit 52 to exit 59	4	2	1	2	some	2	yes	2	1	2	1.08
4 B	I-81, exit 72 to exit 80	4	2	1	2	some	2	yes	3	3	1	1.01

Notes

(A) Counted from Google Maps June 2009 The interchanges per congested corridor were counted using an aerial map of each location. Because the of this study is metering or closing interchange on-ramps only, each on-ramp along the congested corridor was counted. Some corridors had m on-ramps in one direction than the other. In those instances, the greater of the two was used.

(B) 1 for 0-2 interchange ramps. 2 for 3-6 interchange ramps. 3 for > 6 interchange ramps.

(C) Estimated from Google Maps, June 2009. the spacing of the interchanges and the length of the on-ramps were estimated using aerial maps. B spacing and the ramp lengths were different for each corridor direction, the worst-case scenario was used (i.e. closest spaced interchanges and

(D) 1 for greater than 50% of interchanges spaced less than a mile apart. 2 for between 25% and 50% of interchanges spaced less than a mile apa 3 for less than 25% of interchanges spaced less than a mile apart.

(E) Based on information obtained from the PennDOT website, June 2009

(F) 1 for no cameras. 2 for some cameras. 3 for extensive camera coverage.

(G) Based on brief assesment of area mapping, June 2009

(H) 1 for no alternate routes. 2 for one main alternate route. 3 for more than one main alternate routes.

(I) Estimated from Google Map aerials, June 2009

(J) 1 for less than 25% of interchange ramps longer than 1000 ft. 2 for between 25% and 50% of interchange ramps longer than 1000 ft. 3 for more than 50% of interchange ramps longer than 1000 ft.

(K) Based upon average v/c ratios by segment calculated in Task 3

(L) 1 for v/c ratio 1.0-1.49. 2 for v/c ratio 1.5-2.0. 3 for v/c ratio > 2.0.

Freeway Ramp Management Appendix C

Pittsburgh

Corridor ID	Description	(A) Number of Interchanges	(B) Rating 1	(C) Number Spaced < 1 mile	(D) Rating 2	(E) covered by PennDOT cameras?	(F) Rating 3	(G) Alternate Routes?	(H) Rating 4	(I) # of Storage lanes < 1000 ft	(J) Rating 5	(K) V/C ratio
5 A	I-376, exit 70 to exit 80	9	3	3	2	yes	3	yes	3	4	2	1.51
5 C	I-376, exit 64 to exit 70	7	3	5	1	yes	3	yes	2	3	2	1.86
5 B	I-279, exit 1 to exit 8	8	3	3	2	yes	3	yes	2	2	2	1.05
5 E	I-79, exit 78 to exit 65	7	3	1	3	some	2	yes	3	2	2	1.04
5 D	I-79, exit 57 to exit 41	7	3	1	3	some	2	yes	2	3	2	1.13

Notes

(A) Counted from Google Maps June 2009 The interchanges per congested corridor were counted using an aerial map of each location. Because the of this study is metering or closing interchange on-ramps only, each on-ramp along the congested corridor was counted. Some corridors had m on-ramps in one direction than the other. In those instances, the greater of the two was used.

(B) 1 for 0-2 interchange ramps. 2 for 3-6 interchange ramps. 3 for > 6 interchange ramps.

(C) Estimated from Google Maps, June 2009. the spacing of the interchanges and the length of the on-ramps were estimated using aerial maps. B spacing and the ramp lengths were different for each corridor direction, the worst-case scenario was used (i.e. closest spaced interchanges and

(D) 1 for greater than 50% of interchanges spaced less than a mile apart. 2 for between 25% and 50% of interchanges spaced less than a mile apa 3 for less than 25% of interchanges spaced less than a mile apart.

(E) Based on information obtained from the PennDOT website, June 2009

(F) 1 for no cameras. 2 for some cameras. 3 for extensive camera coverage.

(G) Based on brief assesment of area mapping, June 2009

(H) 1 for no alternate routes. 2 for one main alternate route. 3 for more than one main alternate routes.

(I) Estimated from Google Map aerials, June 2009

(J) 1 for less than 25% of interchange ramps longer than 1000 ft. 2 for between 25% and 50% of interchange ramps longer than 1000 ft. 3 for more than 50% of interchange ramps longer than 1000 ft.

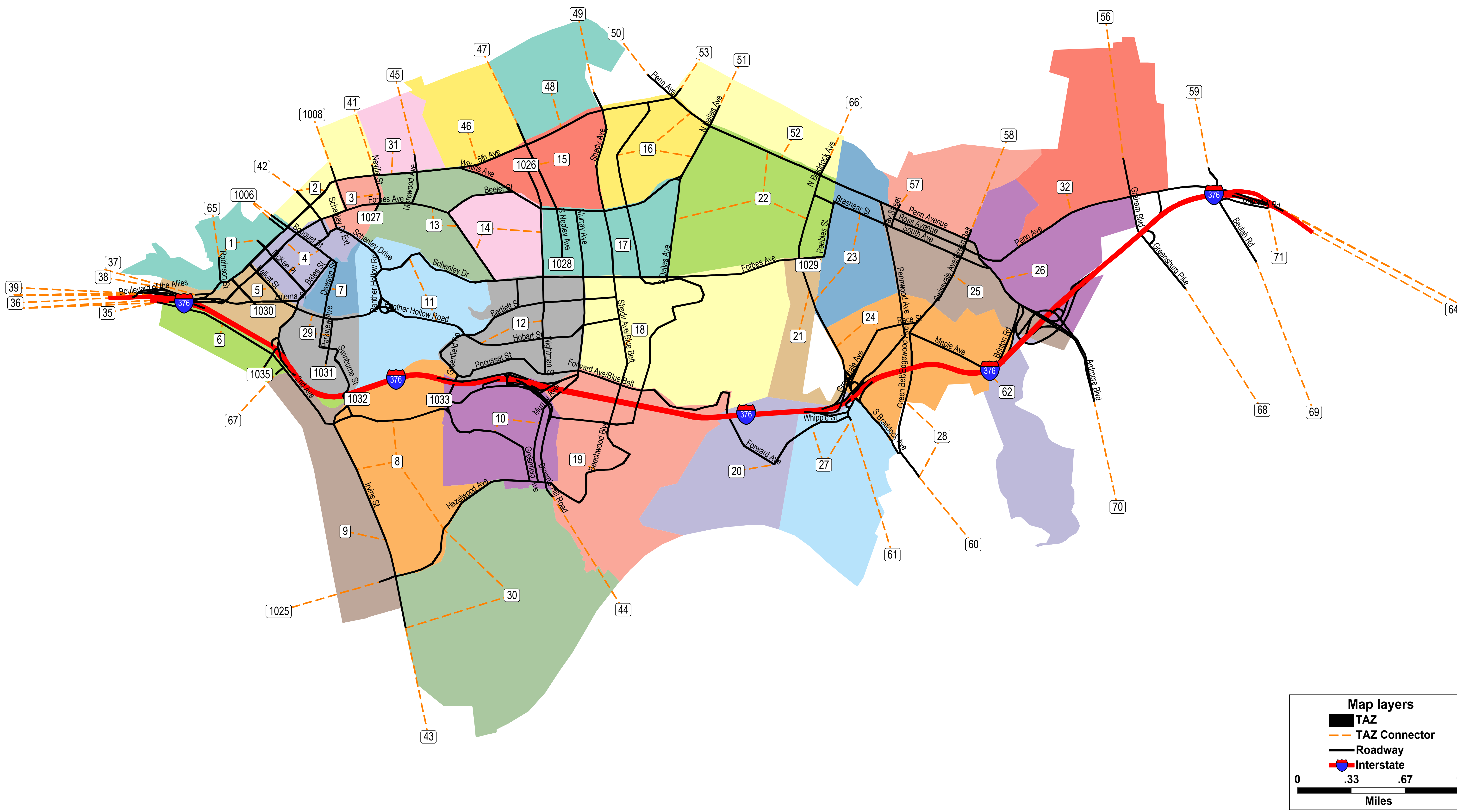
(K) Based upon average v/c ratios by segment calculated in Task 3

(L) 1 for v/c ratio 1.0-1.49. 2 for v/c ratio 1.5-2.0. 3 for v/c ratio > 2.0.

APPENDIX D

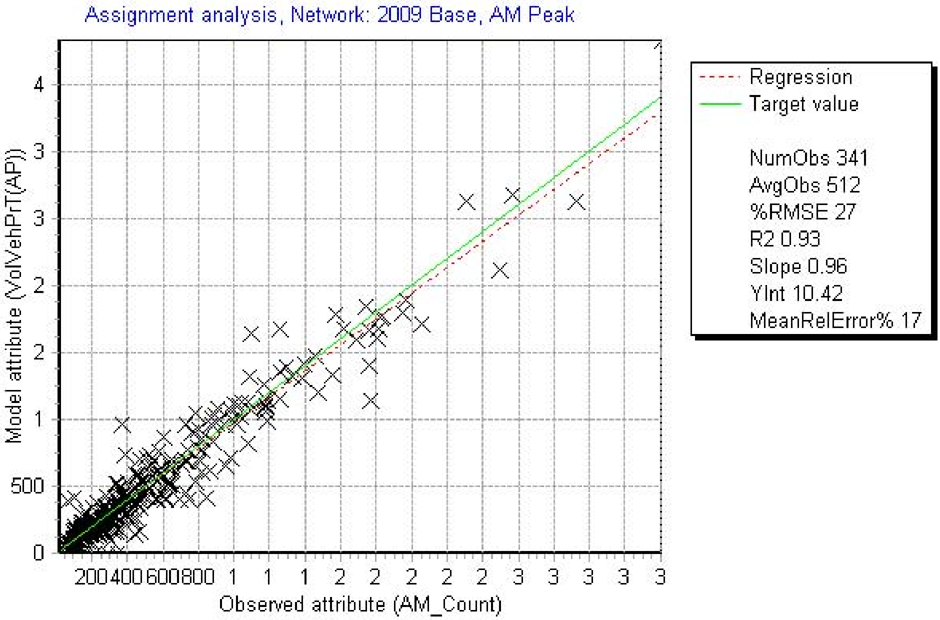
I-376 Model Zone and Link Network

Ramp Management Study Area

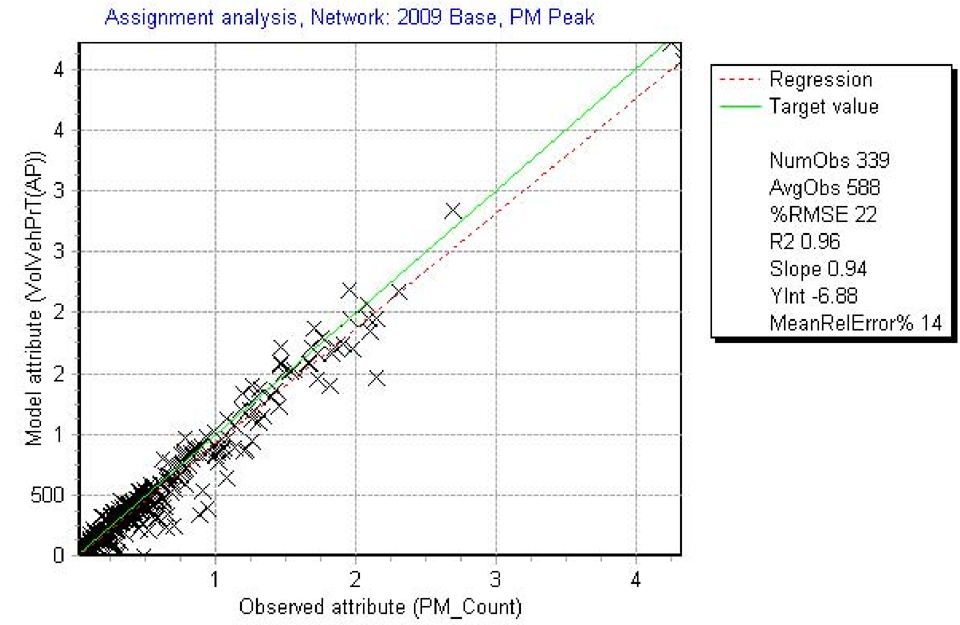


APPENDIX E

I-376 Model Calibration Results



Assignment analysis, Network: 2009 Base, AM Peak
Model attribute (VolVehPrT(AP))
Observed attribute (AM_Count)
0
500
1
2
2
3
3
4
200
400
600
800
1
1
1
2
2
2
2
2
3
3
3
3
3
Regression
Target value
NumObs 341
AvgObs 512
%RMSE 27
R2 0.93
Slope 0.96
YInt 10.42
MeanRelError% 17

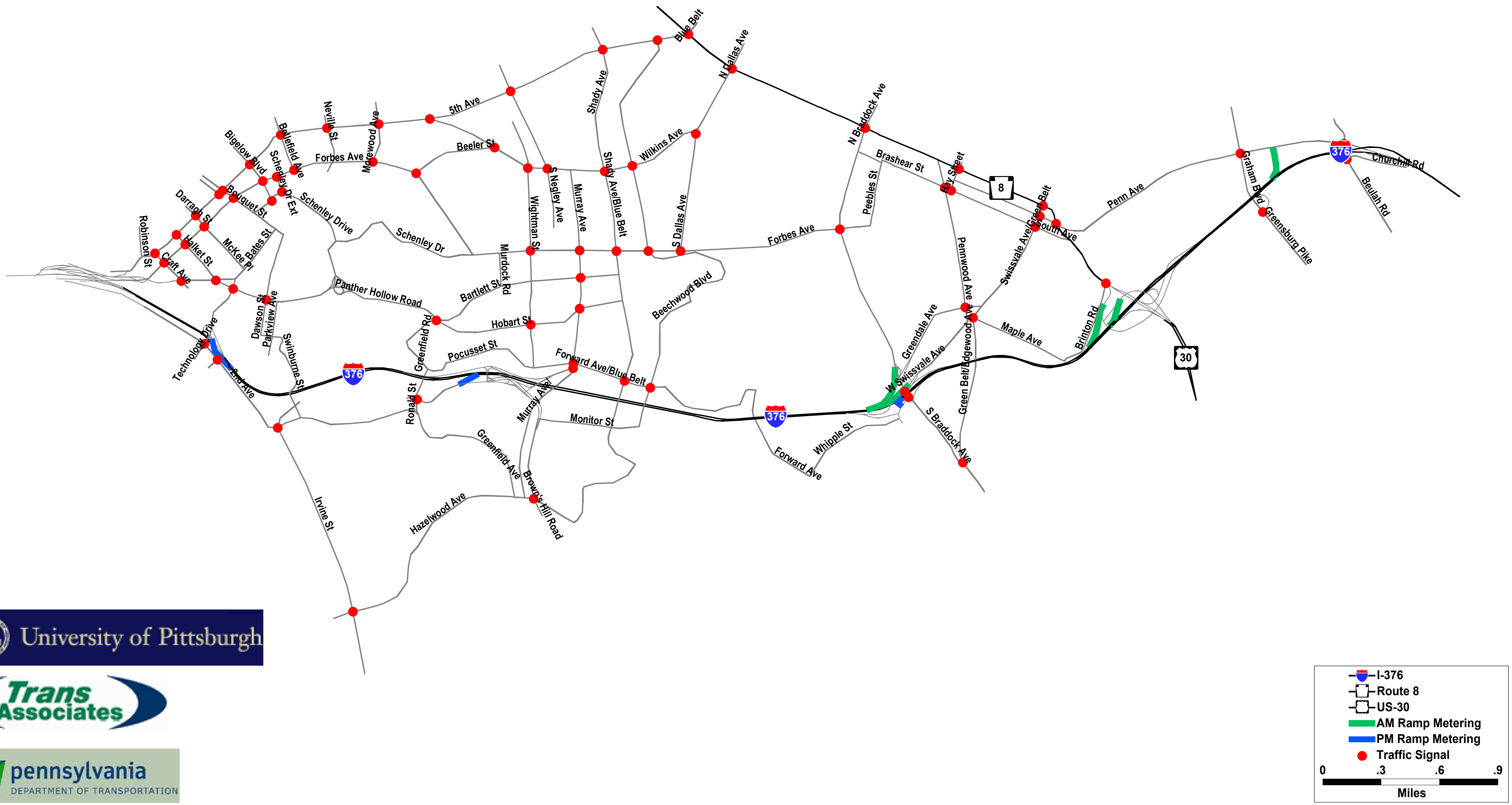


Assignment analysis, Network: 2009 Base, PM Peak
Regression
Target value
NumObs 339
AvgObs 588
%RMSE 22
R2 0.96
Slope 0.94
YInt -6.88
MeanRelError% 14
Model attribute (VolVehPrT(AP))
Observed attribute (PM_Count)
0
500
1
2
2
3
3
4
4
1
2
3
4

APPENDIX F

I-376 Ramp Management Option 1 and 2 Maps

Strategy 1 - Ramp Metering Only



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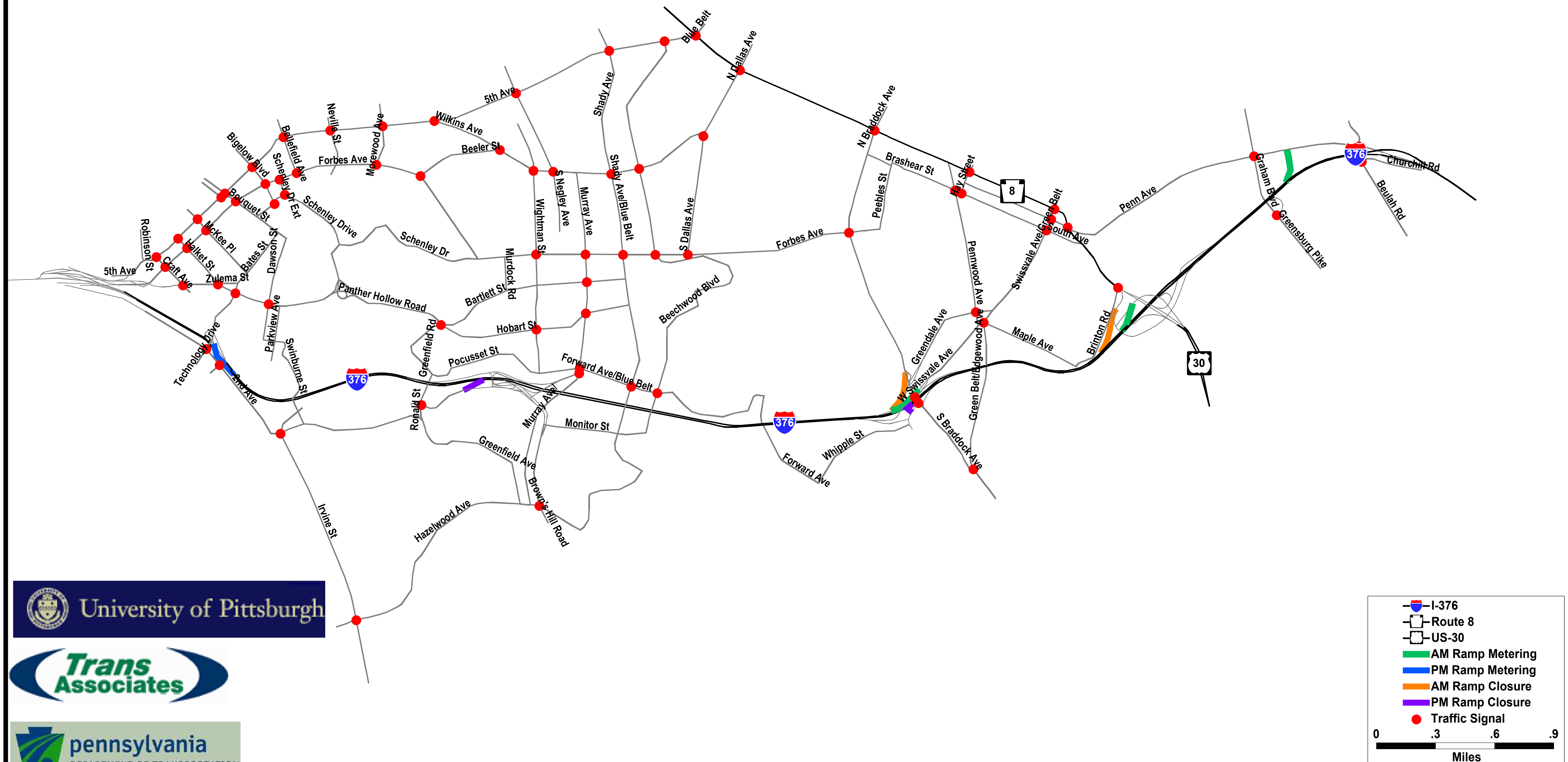
Strategy 2 - Ramp Metering and Ramp Closures



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APPENDIX G

I-376 Measures of Effectiveness Summary
For AM and PM Peak Hours

Appendix G - AM Simulation MOE's

AM PEAK INTERVAL (7:30-8:30)										
MOE	SCENARIO	VISSIM SIMULATION RUN					AVG	STDEV	t-stat Probability	Statistical Significance
		1	2	3	4	5				
Tunnel Queue (ft), EB	Base	0	0	0	0	246	49.200	110.015		
	Option 1	17	0	192	0	0	41.800	84.286	0.454	Change is not Statistically Significant
	Option 2	0	0	0	111	0	22.200	49.641	0.315	Change is not Statistically Significant
Tunnel Queue (ft), WB	Base	16790	18143	14956	17556	17379	16964.800	1222.197		
	Option 1	14321	17638	12371	12577	15504	14482.200	2186.097	0.029	Statistically Significant Decrease
	Option 2	6735	7072	5096	5898	6028	6165.800	771.422	0.000	Statistically Significant Decrease
I-376 Throughput EB	Base	67	89	92	70	78	79.200	11.122		
	Option 1	88	93	93	96	78	89.600	7.092	0.058	Change is not Statistically Significant
	Option 2	84	82	78	85	92	84.200	5.119	0.194	Change is not Statistically Significant
I-376 Throughput WB	Base	433	416	428	437	442	431.200	9.935		
	Option 1	417	444	437	433	433	432.800	9.910	0.403	Change is not Statistically Significant
	Option 2	511	531	503	468	481	498.800	24.844	0.000	Statistically Significant Increase
I-376 Travel Time (sec), EB	Base	557.1	549.4	542.6	552.9	556.7	551.740	5.994		
	Option 1	563	548.3	558.7	565.8	559.3	559.020	6.650	0.053	Change is not Statistically Significant
	Option 2	568.8	564	558	560	557.7	561.700	4.698	0.010	Statistically Significant Increase
I-376 Travel Time (sec), WB	Base	947.2	975.8	915	935.4	952.3	945.140	22.354		
	Option 1	861.7	887.5	769.4	935.8	888.4	868.560	61.549	0.015	Statistically Significant Decrease
	Option 2	626.7	596.5	586.1	633	616.8	611.820	19.944	0.000	Statistically Significant Decrease
I-376 Delay Time (sec), EB	Base	127.9	123.3	118.8	127.8	131.1	125.780	4.789		
	Option 1	136.5	125.1	132.1	140.8	136.4	134.180	5.935	0.020	Statistically Significant Increase
	Option 2	141.5	135.4	130.1	134.1	135.1	135.240	4.091	0.005	Statistically Significant Increase
I-376 Delay Time (sec), WB	Base	523.3	551.1	490.2	510.8	526.9	520.460	22.346		
	Option 1	437.1	462.6	346	511.4	461.7	443.760	60.937	0.015	Statistically Significant Decrease
	Option 2	199.3	172.1	160.8	207.5	191.8	186.300	19.369	0.000	Statistically Significant Decrease
Total Travel Time, (hours), Network Wide	Base	1074.434	1098.839	1031.336	1124.681	1096.485	1085.155	34.962		
	Option 1	1069.961	1035.442	1085.127	1119.998	1091.89	1080.484	31.034	0.414	Change is not Statistically Significant
	Option 2	1159.19	1125.763	1170.035	1178.31	1126.576	1151.975	24.515	0.004	Statistically Significant Increase
Stops, Network Wide	Base	55246	57547	50419	60341	57396	56189.800	3698.725		
	Option 1	47259	43276	44494	52532	49397	47391.600	3734.875	0.003	Statistically Significant Decrease
	Option 2	36809	35593	38776	42497	36954	38125.800	2695.009	0.000	Statistically Significant Decrease

Statistics based on the final 15-minutes (8:15-8:30) of VISSIM simulation of AM Peak Hour (7:30-8:30) conditions.

Appendix G - PM Simulation MOE's

PM PEAK INTERVAL (17:15-17:30)										
MOE	SCENARIO	VISSIM SIMULATION RUN 1	2	3	4	5	AVG	STDEV	t-stat Probability	Statistical Significance
Tunnel Queue (ft), EB	Base	11547	11482	10626	11901	9866	11084	827		
	Option 1	11810	11995	10704	11975	10650	11427	688	0.248	Change is not Statistically Significant
	Option 2	7862	8349	7620	8427	6632	7778	723	0.000	Statistically Significant Decrease
	Option 3	9876	10303	9585	10370	9198	9866	493	0.011	Statistically Significant Decrease
Tunnel Queue (ft), WB	Base	3980	1261	1312	4221	2338	2622	1419		
	Option 1	3077	3901	1102	2903	2397	2676	1033	0.474	Change is not Statistically Significant
	Option 2	2642	3255	317	3982	73	2054	1764	0.295	Change is not Statistically Significant
	Option 3	3584	2604	1603	4112	2130	2807	1031	0.410	Change is not Statistically Significant
I-376 Throughput EB	Base	415	422	384	402	390	403	16		
	Option 1	403	409	430	415	410	413	10	0.120	Change is not Statistically Significant
	Option 2	451	499	446	447	459	460	22	0.001	Statistically Significant Increase
	Option 3	447	423	425	417	442	431	13	0.008	Statistically Significant Increase
I-376 Throughput WB	Base	332	331	291	340	325	324	19		
	Option 1	331	325	277	340	303	315	25	0.281	Change is not Statistically Significant
	Option 2	349	333	254	346	330	322	39	0.472	Change is not Statistically Significant
	Option 3	299	350	270	326	334	316	32	0.320	Change is not Statistically Significant
I-376 Travel Time (sec), EB	Base	1013.8	1158.8	1068.1	1078.7	1159.6	1095.8	62.9		
	Option 1	1091.6	1102.1	1098.6	1114.8	1188.3	1119.1	39.6	0.252	Change is not Statistically Significant
	Option 2	788.5	878.4	841.1	840.0	865.8	842.8	34.5	0.000	Statistically Significant Decrease
	Option 3	1018.4	990.9	932.6	1015.1	961.5	983.7	36.6	0.004	Statistically Significant Decrease
I-376 Travel Time (sec), WB	Base	465.3	555.9	470.4	473.7	532.6	499.6	41.7		
	Option 1	488.4	513.3	529.1	565.7	551.9	529.7	30.7	0.115	Change is not Statistically Significant
	Option 2	519.1	594.3	535.6	560.9	557.6	553.5	28.5	0.022	Statistically Significant Increase
	Option 3	587.7	512.7	644.2	553.9	474.7	554.6	65.7	0.076	Change is not Statistically Significant
I-376 Delay Time (sec), EB	Base	588.5	731.7	641.8	652.6	735.6	670.0	62.9		
	Option 1	665.4	674.5	673.1	688.3	736.3	687.5	28.5	0.294	Change is not Statistically Significant
	Option 2	363.8	451.0	414.4	415.8	443.0	417.6	34.2	0.000	Statistically Significant Decrease
	Option 3	595.1	565.8	506.3	587.1	536.5	558.2	36.8	0.004	Statistically Significant Decrease
I-376 Delay Time (sec), WB	Base	39.9	132.2	45.6	49.5	107.6	75.0	42.1		
	Option 1	62.7	89.7	104.2	141.2	126.6	104.9	30.8	0.118	Change is not Statistically Significant
	Option 2	72.9	151.2	87.4	116.8	110.2	107.7	30.0	0.097	Change is not Statistically Significant
	Option 3	162.8	88.8	219.3	130.0	48.9	130.0	65.8	0.077	Change is not Statistically Significant
Total Travel Time, (hours), Network Wide	Base	1211.4	1340.0	1215.4	1248.5	1283.9	1259.8	53.5		
	Option 1	1239.5	1342.3	1273.6	1341.8	1335.5	1306.5	47.3	0.091	Change is not Statistically Significant
	Option 2	1315.5	1316.6	1248.0	1338.4	1345.6	1312.8	38.6	0.055	Change is not Statistically Significant
	Option 3	1309.4	1273.3	1203.9	1322.5	1224.4	1266.7	51.7	0.421	Change is not Statistically Significant
Stops, Network Wide	Base	64979	80088	68899	70669	74217	71770	5717		
	Option 1	73139	78787	74271	81013	84060	78254	4573	0.042	Statistically Significant Increase
	Option 2	59293	63898	58144	64042	65117	62099	3148	0.005	Statistically Significant Decrease
	Option 3	68794	64783	65725	68571	63339	66242	2385	0.041	Statistically Significant Decrease

Statistics based on the final 15-minutes (17:15-17:30) of VISSIM simulation of PM Peak Hour (16:30-17:30) conditions.

APPENDIX H

I-376 Modeling Peak Hour Queue Length Summaries

MAXIMUM TOTAL INTERSECTION QUEUE - 2009 OPTION 1, AM PEAK

NODE ID	NODE NAME	VISSIM RUN ID 1	2	3	4	5	AVG	Stdev	Ttest	AVG Change	Statistical Significance
140427286	Wightman St at Wilkins Ave	218	218	224	107	151	184	52	0.20	26	
140428522	South Ave at Swissvale Ave/Green Belt	345	260	238	477	258	316	99	0.33	31	
140427849	South Ave at Hay Street	218	217	185	218	216	211	15	0.12	36	
140429954	Shady Ave/Blue Belt at Tilbury Ave	343	343	343	342	343	343	0	0.06	110	
140427394	Shady Ave at Wilkins Ave	109	131	88	178	85	118	38	0.46	-3	
140427707	Schenley Dr at Schenley Dr Ext	254	226	253	186	270	238	33	0.03	60	Statistically Significant Increase
140427312	S Negley Ave at Wilkins Ave	243	254	212	85	276	214	76	0.10	53	
140426630	S Dallas Ave at Wilkins Ave	163	139	133	163	138	147	15	0.15	17	
140426716	S Dallas Ave at Wilkins Ave	135	43	45	67	83	75	38	0.17	19	
140428330	Ross Avenue at Swissvale Ave/Green Belt	128	155	133	128	133	135	11	0.05	-41	Statistically Significant Decrease
140430949	Ronald St to Greenfield Ave at Ronald St	92	92	95	190	110	116	42	0.09	-42	
140430401	Pocusset St at Wightman St	21	46	23	23	50	33	14	0.01	-24	Statistically Significant Decrease
140427798	Pennwood Ave at South Ave	321	212	318	421	452	345	95	0.26	42	
140429715	Pennwood Ave at Race St	555	292	556	374	406	437	116	0.03	-120	Statistically Significant Decrease
140427307	Penn Avenue at Pennwood Ave	87	205	430	349	492	312	166	0.19	96	
140427492	Penn Avenue at Hay Street	367	338	1776	391	957	766	620	0.12	346	
140426681	Penn Ave at N Braddock Ave	254	288	322	230	262	271	35	0.23	-18	
140429881	Parkview Ave at Swinburne St/Swinburne St	156	272	83	79	144	147	78	0.11	47	
140428471	Panther Hollow Road at Schenley Dr	930	177	505	996	434	608	347	0.04	-340	Statistically Significant Decrease
140427245	Old Gate Rd at William Penn Hwy	1981	1983	1982	1736	1982	1933	110	0.00	1913	Statistically Significant Increase
140425584	N Dallas Ave at S Dallas Ave	205	220	212	156	149	188	33	0.05	31	Statistically Significant Increase
140427343	Murray Ave at Wilkins Ave	115	98	173	63	113	113	40	0.24	14	
140430403	Murray Ave at Pocusset St	564	688	1233	627	1485	920	413	0.01	-524	Statistically Significant Decrease
140431258	Monongahela Ave at Whipple St	164	163	148	162	148	157	8	0.01	-192	Statistically Significant Decrease
140430984	Monongahela Ave at S Braddock Ave	241	236	235	238	219	234	8	0.00	-103	Statistically Significant Decrease
140429786	Hobart St at Wightman St	42	23	89	21	22	39	29	0.01	-46	Statistically Significant Decrease
140429533	Hobart St at Shady Ave/Blue Belt	20	85	61	105	45	63	33	0.23	-14	
140429612	Hobart St at Murray Ave	261	259	176	440	353	298	101	0.01	125	Statistically Significant Increase
140432477	Hazelwood Ave at Murray Ave/Blue Belt	282	456	283	282	282	317	78	0.17	35	
140430374	Greenfield Brg at Pocusset St	450	130	685	37	69	274	283	0.06	226	
140461875	Greenfield Ave at Saline St	438	325	327	385	370	369	47	0.27	23	
140432458	Greenfield Ave at Hazelwood Ave	203	289	275	277	276	264	35	0.24	26	
140430731	Greendale Ave at S Braddock Ave	64	107	204	45	87	102	62	0.05	-70	Statistically Significant Decrease
140429799	Greendale Ave at Race St	35	24	0	17	48	25	18	0.25	-8	
140432045	Green Belt/Edgewood Ave at S Braddock Ave/Gre	1014	1014	1013	1013	1014	1014	0	0.41	0	
140431059	Frazier St/Swinburne Brg at Greenfield Ave	186	79	226	76	361	186	118	0.15	66	
140430605	Forward Ave at Tilbury Ave	1329	1330	1330	1330	1329	1330	0	0.07	349	
140960077	Forward at Murray	684	381	401	474	255	439	158	0.27	69	
140428698	Forbes Ave at Wightman St	363	369	367	274	375	350	42	0.09	50	
140428751	Forbes Ave at Shady Ave/Blue Belt	250	449	299	296	401	339	83	0.38	24	
140427317	Forbes Ave at Schenley Dr	176	181	247	116	290	202	68	0.39	9	
140428755	Forbes Ave at Schenley Dr	266	154	251	384	176	246	91	0.24	38	
140428790	Forbes Ave at S Dallas Ave	154	212	130	150	152	159	31	0.36	14	
140428485	Forbes Ave at S Braddock Ave	953	695	376	889	381	659	273	0.37	-54	
140427656	Forbes Ave at S Bouquet St	91	153	113	134	122	123	23	0.21	-10	
140427239	Forbes Ave at S Bellefield Ave	351	334	316	443	342	357	50	0.03	-66	Statistically Significant Decrease
140428710	Forbes Ave at Murray Ave	104	146	175	257	250	186	66	0.33	-19	
140427103	Forbes Ave at Morewood Ave	261	352	239	272	272	279	43	0.31	21	
140428473	Forbes Ave at Halket St	175	111	122	126	129	133	25	0.11	-18	
140428739	Forbes at Murdock	304	212	467	333	194	302	109	0.00	195	Statistically Significant Increase
140428135	Forbes at McKee Pl	132	171	108	128	175	143	29	0.36	6	
140427943	Fifth Avenue at Darragh St	284	240	278	347	266	283	39	0.46	5	
140427589	Fifth Ave at De Soto Ave	152	153	153	153	153	153	0	0.12	0	
140429849	Edgewood at Maple	329	392	623	444	424	442	110	0.08	-307	
140429702	E Swissvale Ave/Green Belt at Race St	392	388	808	485	388	492	181	0.04	-436	Statistically Significant Decrease
140429882	Dawson St at Swinburne St/Swinburne St	331	336	157	154	329	261	97	0.03	99	Statistically Significant Increase
140428760	Craft Ave at Forbes Ave	181	153	150	148	172	161	15	0.20	-9	
140432217	Commercial St at Whipple St	64	56	30	79	74	61	19	0.02	31	Statistically Significant Increase
140427706	Clemente St at Schenley Dr	151	190	153	213	151	172	28	0.25	13	
140427928	Clemente St at S Bouquet St	160	196	228	229	228	208	31	0.02	46	Statistically Significant Increase
140427144	Brashear St at S Braddock Ave	658	722	721	638	570	662	64	0.00	314	Statistically Significant Increase
140429073	Boulevard of the Allies at Zulema St	520	519	516	518	518	518	1	0.32	1	
140429427	Boulevard of the Allies at Parkview Ave	1512	1512	1511	1512	1512	1512	0	0.14	276	
140429402	Boulevard of the Allies at Dawson St	952	952	798	747	953	880	100	0.30	53	
140429054	Boulevard of the Allies at Craft Ave	296	297	297	296	297	296	1	0.06	36	
140427399	Bigelow Blvd at Schenley Dr	155	218	254	250	146	205	51	0.39	-9	
140427203	Beulah Rd at William Penn Hwy	513	664	664	598	491	586	81	0.05	94	Statistically Significant Increase
140427478	Beulah Rd at Churchill Rd	327	283	123	440	397	314	123	0.10	-83	
140426905	Beeler St at Wilkins Ave	108	105	123	65	83	97	23	0.10	-30	
140427313	Beeler St at Forbes Ave	166	190	180	135	223	179	32	0.04	-55	Statistically Significant Decrease
140427298	Beechwood Blvd at Wilkins Ave	88	86	153	171	109	122	39	0.35	9	
140428885	Beechwood Blvd at S Dallas Ave	150	151	150	150	150	150	0	0.15	1	
140430818	Beechwood Blvd at Ronald St	295	296	295	275	296	291	9	0.09	41	
140431310	Beechwood Blvd at Monitor St	1939	1939	1939	1939	1939	1939	0	0.17	143	
140432495	Beechwood Blvd at Hazelwood Ave	444	443	517	444	444	458	33	0.04	-42	Statistically Significant Decrease
140430723	Beechwood Blvd at Forward Ave	297	400	201	234	295	285	76	0.14	46	
140428773	Beechwood Blvd at Forbes Ave	302	285	212	338	361	300	57	0.23	41	

MAXIMUM TOTAL INTERSECTION QUEUE - 2009 OPTION 1, AM PEAK

NODE ID	NODE NAME	VISSIM RUN ID					AVG	Stdev	Ttest	AVG Change	Statistical Significance
		1	2	3	4	5					
140429079	Bates St at Zulema St	295	295	295	295	295	295	0	0.43	0	
140428198	Bates St at S Bouquet St	125	301	341	213	159	228	92	0.31	-33	
140429839	Bates St at Ramp - Bates St to I-376 EB	105	106	104	105	106	105	1	0.05	1	
140429765	Bates St at Ramp - I-376 WB to Bates St SB	109	131	109	135	109	119	13	0.25	-16	
140429230	Bates St at Boulevard of the Allies	571	571	960	571	686	671	169	0.13	93	
140428934	Bates at McKee Pl	143	261	171	80	87	148	73	0.15	-50	
140429224	Bartlett St at Wightman St	86	136	43	60	66	78	36	0.46	-2	
140429169	Bartlett St at Shady Ave/Blue Belt	0	0	0	0	0	0	0	0.02	-11	Statistically Significant Decrease
140429720	Bartlett St at Panther Hollow Rd	1936	1936	1936	509	1553	1574	618	0.00	1145	Statistically Significant Increase
140429194	Bartlett St at Murray Ave	178	132	240	135	175	172	44	0.35	9	
140429296	Bartlett at Murdock	69	42	62	83	79	67	16	0.01	30	Statistically Significant Increase
140428121	Ardmore Blvd at Swissvale Ave/Green Belt	268	268	268	268	268	268	0	0.18	-9	
140428770	Ardmore Blvd at South Ave	52	74	153	84	57	84	41	0.05	-69	
140428491	Ardmore Blvd at Ross Avenue	274	586	559	527	572	504	130	0.28	52	
140430786	Alger St at Greenfield Brg	134	134	134	134	134	134	0	0.04	0	Statistically Significant Increase
140430785	Alger St at Beechwood Blvd	161	161	161	132	161	155	13	0.03	45	Statistically Significant Increase
140426333	5th Ave at Wilkins Ave	157	110	150	149	203	154	33	0.03	33	Statistically Significant Increase
140425193	5th Ave at Shady Ave	152	160	108	84	194	140	44	0.23	16	
140426446	5th Ave at S Neville St	304	395	393	302	348	348	45	0.11	43	
140425876	5th Ave at S Negley Ave	339	384	358	421	312	363	42	0.43	8	
140427518	5th Ave at S Bouquet St	89	245	153	105	89	136	66	0.03	69	Statistically Significant Increase
140426563	5th Ave at S Bellefield Ave	375	440	462	405	453	427	36	0.23	16	
140428668	5th Ave at Robinson St	386	386	386	386	386	386	0	0.03	123	Statistically Significant Increase
140424984	5th Ave at Penn Avenue	263	239	285	287	325	280	32	0.01	-66	Statistically Significant Decrease
140426398	5th Ave at Morewood Ave	349	444	276	351	326	349	61	0.08	53	
140428280	5th Ave at Halket St	33	0	220	66	0	64	91	0.47	3	
140428583	5th Ave at Craft Ave	780	401	185	122	650	428	286	0.12	199	
140427081	5th Ave at Bigelow Blvd	533	353	639	461	543	506	106	0.08	-86	
140425061	5th Ave at Beechwood Blvd	86	85	92	119	92	95	14	0.11	-11	
140434097	2nd Ave at Irvine St	259	362	315	641	175	351	177	0.17	82	
140490672	2nd Ave at Hot Metal St	442	408	500	545	465	472	53	0.45	-8	
140432138	2nd Ave at Greenfield Ave	293	292	292	292	293	292	0	0.12	0	
140429958	2nd Ave at Bates St	446	451	523	573	576	514	63	0.37	-14	

Statistics based on the final 15-minutes (8:15-8:30) of VISSIM simulation of AM Peak Hour (7:30-8:30) conditions.

MAXIMUM TOTAL INTERSECTION QUEUE - 2009 OPTION 2, AM PEAK

NODE ID	NODE NAME	VISSIM RUN ID					AVG	Stdev	Ttest	AVG Change	Statistical Significance
		1	2	3	4	5					
140427286	Wightman St at Wilkins Ave	213	322	206	316	263	264	55	0.00	106	Statistically Significant Increase
140428522	South Ave at Swissvale Ave/Green Belt	267	359	239	290	375	306	59	0.36	21	
140427849	South Ave at Hay Street	217	215	216	215	209	215	3	0.09	39	
140429954	Shady Ave/Blue Belt at Tilbury Ave	343	343	343	343	343	343	0	0.06	110	
140427394	Shady Ave at Wilkins Ave	151	184	154	171	199	172	20	0.03	51	Statistically Significant Increase
140427707	Schenley Dr at Schenley Dr Ext	181	215	203	217	199	203	15	0.17	25	
140427312	S Negley Ave at Wilkins Ave	187	317	269	238	263	255	48	0.00	94	Statistically Significant Increase
140426630	S Dallas Ave at Wilkins Ave	79	79	133	78	81	90	24	0.03	-40	Statistically Significant Decrease
140426716	S Dallas Ave at Wilkins Ave	44	48	64	22	62	48	17	0.27	-7	
140428330	Ross Avenue at Swissvale Ave/Green Belt	132	128	220	192	111	156	47	0.26	-20	
140430949	Ronald St to Greenfield Ave at Ronald St	92	92	141	195	134	131	43	0.19	-27	
140430401	Pocusset St at Wightman St	95	23	61	23	98	60	37	0.43	3	
140427798	Pennwood Ave at South Ave	253	258	618	527	254	382	177	0.20	79	
140429715	Pennwood Ave at Race St	490	227	483	339	272	362	120	0.00	-194	Statistically Significant Decrease
140427307	Penn Avenue at Pennwood Ave	92	36	113	59	117	84	35	0.06	-132	
140427492	Penn Avenue at Hay Street	415	382	447	413	454	422	29	0.46	2	
140426681	Penn Ave at N Braddock Ave	313	201	280	302	677	355	185	0.23	66	
140429881	Parkview Ave at Swinburne St/Swinburne St	92	442	187	93	92	181	152	0.13	82	
140428471	Panther Hollow Road at Schenley Dr	395	270	278	306	179	286	77	0.00	-663	Statistically Significant Decrease
140427245	Old Gate Rd at William Penn Hwy	1981	1983	1982	1982	1983	1982	1	0.00	1962	Statistically Significant Increase
140425584	N Dallas Ave at S Dallas Ave	209	152	155	197	190	181	26	0.06	24	
140427343	Murray Ave at Wilkins Ave	226	344	217	118	173	216	84	0.01	117	Statistically Significant Increase
140430403	Murray Ave at Pocusset St	1486	1486	1486	1486	1486	1486	0	0.14	42	
140431258	Monongahela Ave at Whipple St	165	155	148	148	164	156	8	0.01	-194	Statistically Significant Decrease
140430984	Monongahela Ave at S Braddock Ave	219	220	220	215	219	218	2	0.00	-119	Statistically Significant Decrease
140429786	Hobart St at Wightman St	131	88	171	151	271	162	68	0.02	77	Statistically Significant Increase
140429533	Hobart St at Shady Ave/Blue Belt	0	0	0	0	0	0	0	0.00	-77	Statistically Significant Decrease
140429612	Hobart St at Murray Ave	248	280	407	280	561	355	130	0.01	183	Statistically Significant Increase
140432477	Hazelwood Ave at Murray Ave/Blue Belt	282	282	281	283	281	282	1	0.42	0	
140430374	Greenfield Brg at Pocusset St	23	33	23	22	45	29	10	0.03	-19	Statistically Significant Decrease
140461875	Greenfield Ave at Saline St	668	668	668	668	668	668	0	0.00	323	Statistically Significant Increase
140432458	Greenfield Ave at Hazelwood Ave	81	80	256	181	119	143	75	0.04	-95	Statistically Significant Decrease
140430731	Greendale Ave at S Braddock Ave	68	85	81	79	59	74	11	0.00	-97	Statistically Significant Decrease
140429799	Greendale Ave at Race St	64	44	51	40	42	48	10	0.06	16	
140432045	Green Belt/Edgewood Ave at S Braddock Ave/Gre	1013	1013	1014	1013	1013	1013	0	0.24	0	
140431059	Frazier St/Swinburne Brg at Greenfield Ave	1355	1229	1355	1355	1355	1330	57	0.00	1211	Statistically Significant Increase
140430605	Forward Ave at Tilbury Ave	1329	1330	1330	1330	1329	1330	0	0.07	349	
140960077	Forward at Murray	419	639	684	391	684	564	146	0.05	194	
140428698	Forbes Ave at Wightman St	214	171	172	110	135	161	40	0.00	-139	Statistically Significant Decrease
140428751	Forbes Ave at Shady Ave/Blue Belt	278	311	290	275	268	284	17	0.33	-31	
140427317	Forbes Ave at Schenley Dr	274	321	262	383	241	296	57	0.00	103	Statistically Significant Increase
140428755	Forbes Ave at Schenley Dr	200	109	159	47	95	122	59	0.04	-86	Statistically Significant Decrease
140428790	Forbes Ave at S Dallas Ave	414	376	331	370	302	359	43	0.00	213	Statistically Significant Increase
140428485	Forbes Ave at S Braddock Ave	365	280	525	346	386	380	90	0.01	-333	Statistically Significant Decrease
140427656	Forbes Ave at S Bouquet St	80	46	52	71	86	67	18	0.00	-65	Statistically Significant Decrease
140427239	Forbes Ave at S Bellefield Ave	384	416	304	324	275	341	58	0.02	-82	Statistically Significant Decrease
140428710	Forbes Ave at Murray Ave	327	209	311	259	176	256	64	0.12	51	
140427103	Forbes Ave at Morewood Ave	212	261	196	305	194	233	48	0.29	-25	
140428473	Forbes Ave at Halket St	112	107	128	153	125	125	18	0.02	-26	Statistically Significant Decrease
140428739	Forbes at Murdock	21	20	21	17	16	19	2	0.00	-88	Statistically Significant Decrease
140428135	Forbes at McKee Pl	171	132	173	133	193	160	27	0.07	23	
140427943	Fifth Avenue at Darragh St	279	199	194	219	209	220	34	0.13	-58	
140427589	Fifth Ave at De Soto Ave	154	154	154	154	154	154	0	0.00	1	Statistically Significant Increase
140429849	Edgewood at Maple	446	341	342	458	280	373	76	0.04	-376	Statistically Significant Decrease
140429702	E Swissvale Ave/Green Belt at Race St	376	376	372	376	372	375	2	0.01	-554	Statistically Significant Decrease
140429882	Dawson St at Swinburne St/Swinburne St	331	336	331	154	153	261	98	0.03	98	Statistically Significant Increase
140428760	Craft Ave at Forbes Ave	185	155	144	231	176	179	34	0.31	9	
140432217	Commercial St at Whipple St	26	31	74	0	0	26	31	0.42	-4	
140427706	Clemente St at Schenley Dr	204	193	237	172	258	213	34	0.02	54	Statistically Significant Increase
140427928	Clemente St at S Bouquet St	78	228	165	63	88	124	70	0.14	-38	
140427144	Brashear St at S Braddock Ave	16	19	0	21	110	33	44	0.00	-314	Statistically Significant Decrease
140429073	Boulevard of the Allies at Zulema St	518	519	519	519	518	519	1	0.25	2	
140429427	Boulevard of the Allies at Parkview Ave	1511	959	1512	1511	1512	1401	247	0.28	165	
140429402	Boulevard of the Allies at Dawson St	952	953	953	528	760	829	188	0.50	2	
140429054	Boulevard of the Allies at Craft Ave	262	289	228	308	224	262	37	0.47	2	
140427399	Bigelow Blvd at Schenley Dr	295	355	241	265	304	292	43	0.02	78	Statistically Significant Increase
140427203	Beulah Rd at William Penn Hwy	446	741	664	739	740	666	127	0.02	174	Statistically Significant Increase
140427478	Beulah Rd at Churchill Rd	335	514	1437	238	666	638	476	0.15	241	
140426905	Beeler St at Wilkins Ave	148	129	153	106	166	141	23	0.27	14	
140427313	Beeler St at Forbes Ave	85	107	114	129	100	107	16	0.00	-126	Statistically Significant Decrease
140427298	Beechwood Blvd at Wilkins Ave	213	214	256	262	284	246	31	0.00	133	Statistically Significant Increase
140428885	Beechwood Blvd at S Dallas Ave	151	151	151	151	151	151	0	0.02	2	Statistically Significant Increase
140430818	Beechwood Blvd at Ronald St	295	204	296	249	226	254	41	0.46	3	
140431310	Beechwood Blvd at Monitor St	1939	1939	1939	1939	1939	1939	0	0.17	143	
140432495	Beechwood Blvd at Hazelwood Ave	444	444	462	444	444	447	8	0.00	-53	Statistically Significant Decrease
140430723	Beechwood Blvd at Forward Ave	232	430	348	259	329	320	78	0.04	81	Statistically Significant Increase
140428773	Beechwood Blvd at Forbes Ave	247	171	262	228	194	220	38	0.23	-38	
140429079	Bates St at Zulema St	295	295	295	295	295	295	0	0.41	0	

MAXIMUM TOTAL INTERSECTION QUEUE - 2009 OPTION 2, AM PEAK

NODE ID	NODE NAME	VISSIM RUN ID					AVG	Stdev	Ttest	AVG Change	Statistical Significance
		1	2	3	4	5					
140428198	Bates St at S Bouquet St	48	176	78	87	93	97	48	0.01	-164	Statistically Significant Decrease
140429839	Bates St at Ramp - Bates St to I-376 EB	104	105	105	104	106	105	1	0.17	0	
140429765	Bates St at Ramp - I-376 WB to Bates St SB	283	119	110	154	109	155	74	0.31	21	
140429230	Bates St at Boulevard of the Allies	570	569	570	570	572	570	1	0.31	-9	
140428934	Bates at McKee Pl	171	131	231	101	153	157	49	0.16	-42	
140429224	Bartlett St at Wightman St	38	18	44	42	60	40	15	0.01	-40	Statistically Significant Decrease
140429169	Bartlett St at Shady Ave/Blue Belt	45	18	67	39	18	37	20	0.02	27	Statistically Significant Increase
140429720	Bartlett St at Panther Hollow Rd	277	213	203	259	257	242	32	0.01	-187	Statistically Significant Decrease
140429194	Bartlett St at Murray Ave	213	324	284	447	238	301	92	0.01	139	Statistically Significant Increase
140429296	Bartlett at Murdock	23	23	23	23	23	23	0	0.03	-14	Statistically Significant Decrease
140428121	Ardmore Blvd at Swissvale Ave/Green Belt	268	268	268	268	268	268	0	0.18	-9	
140428770	Ardmore Blvd at South Ave	365	74	281	294	180	239	113	0.10	86	
140428491	Ardmore Blvd at Ross Avenue	3410	3567	3563	1545	1750	2767	1026	0.00	2315	Statistically Significant Increase
140430786	Alger St at Greenfield Brg	133	134	134	133	134	134	0	0.45	0	
140430785	Alger St at Beechwood Blvd	77	78	161	161	101	115	42	0.43	5	
140426333	5th Ave at Wilkins Ave	156	252	171	258	209	209	46	0.00	89	Statistically Significant Increase
140425193	5th Ave at Shady Ave	218	284	239	258	210	242	30	0.00	119	Statistically Significant Increase
140426446	5th Ave at S Neville St	175	199	147	206	172	179	24	0.00	-126	Statistically Significant Decrease
140425876	5th Ave at S Negley Ave	345	447	618	410	303	425	122	0.18	70	
140427518	5th Ave at S Bouquet St	116	139	155	170	187	153	27	0.00	86	Statistically Significant Increase
140426563	5th Ave at S Bellefield Ave	266	344	348	375	307	328	42	0.00	-83	Statistically Significant Decrease
140428668	5th Ave at Robinson St	386	386	386	386	384	385	1	0.03	122	Statistically Significant Increase
140424984	5th Ave at Penn Avenue	258	240	312	230	233	255	34	0.00	-91	Statistically Significant Decrease
140426398	5th Ave at Morewood Ave	211	198	300	153	195	211	54	0.01	-85	Statistically Significant Decrease
140428280	5th Ave at Halket St	51	146	20	75	64	71	47	0.32	11	
140428583	5th Ave at Craft Ave	407	786	153	466	172	397	258	0.14	168	
140427081	5th Ave at Bigelow Blvd	637	534	342	515	640	534	121	0.18	-59	
140425061	5th Ave at Beechwood Blvd	86	93	88	112	90	94	10	0.07	-12	
140434097	2nd Ave at Irvine St	745	621	700	433	404	581	155	0.00	312	Statistically Significant Increase
140490672	2nd Ave at Hot Metal St	417	594	586	430	474	500	85	0.38	20	
140432138	2nd Ave at Greenfield Ave	291	288	289	292	282	289	4	0.03	-4	Statistically Significant Decrease
140429958	2nd Ave at Bates St	453	578	574	509	422	507	70	0.32	-21	

Statistics based on the final 15-minutes (8:15-8:30) of VISSIM simulation of AM Peak Hour (7:30-8:30) conditions.

MAXIMUM TOTAL INTERSECTION QUEUE - 2009 OPTION 1, PM PEAK

NODE ID	NODE NAME	VISSIM RUN ID 1	2	3	4	5	AVG	Stdev	Ttest	AVG Change	Statistical Significance
140427286	Wightman St at Wilkins Ave	156	86	108	91	136	115	30	0.30	-15	
140428522	South Ave at Swissvale Ave/Green Belt	621	620	620	301	619	556	143	0.47	6	
140427849	South Ave at Hay Street	189	206	209	138	186	186	28	0.05	-23	
140429954	Shady Ave/Blue Belt at Tilbury Ave	47	64	88	48	115	72	29	0.30	-12	
140427394	Shady Ave at Wilkins Ave	111	107	126	124	109	116	9	0.21	-20	
140427707	Schenley Dr at Schenley Dr Ext	189	409	390	411	383	356	94	0.35	-20	
140427312	S Negley Ave at Wilkins Ave	192	210	343	283	299	265	63	0.09	-74	
140426630	S Dallas Ave at Wilkins Ave	163	161	165	165	162	163	2	0.15	7	
140426716	S Dallas Ave at Wilkins Ave	84	65	114	176	114	111	42	0.25	16	
140428330	Ross Avenue at Swissvale Ave/Green Belt	357	337	484	333	333	369	65	0.45	-6	
140430949	Ronald St to Greenfield Ave at Ronald St	306	308	308	308	308	308	1	0.07	4	
140430401	Pocusset St at Wightman St	290	218	116	316	91	206	101	0.18	55	
140427798	Pennwood Ave at South Ave	193	189	240	220	216	212	21	0.20	9	
140429715	Pennwood Ave at Race St	870	870	870	870	870	870	0	0.10	135	
140427307	Penn Avenue at Pennwood Ave	397	640	144	753	547	496	236	0.29	79	
140427492	Penn Avenue at Hay Street	556	630	631	629	630	615	33	0.14	57	
140426681	Penn Ave at N Braddock Ave	345	462	300	490	416	403	79	0.23	33	
140429881	Parkview Ave at Swinburne St/Swinburne St	442	137	191	364	244	276	125	0.13	77	
140428471	Panther Hollow Road at Schenley Dr	1160	1549	89	1560	1354	1142	611	0.31	-188	
140427245	Old Gate Rd at William Penn Hwy	43	55	37	45	52	47	7	0.16	-10	
140425584	N Dallas Ave at S Dallas Ave	346	349	427	244	311	335	67	0.32	15	
140427343	Murray Ave at Wilkins Ave	267	122	117	160	131	159	63	0.13	35	
140430403	Murray Ave at Pocusset St	587	620	372	1052	414	609	270	0.41	36	
140431258	Monongahela Ave at Whipple St	1272	738	353	342	666	674	379	0.01	499	Statistically Significant Increase
140430984	Monongahela Ave at S Braddock Ave	220	219	219	220	219	219	0	0.01	-59	Statistically Significant Decrease
140429786	Hobart St at Wightman St	153	110	106	146	97	122	26	0.29	7	
140429533	Hobart St at Shady Ave/Blue Belt	68	62	68	59	41	60	11	0.13	-57	
140429612	Hobart St at Murray Ave	212	195	277	205	152	208	45	0.09	-81	
140432477	Hazelwood Ave at Murray Ave/Blue Belt	280	282	281	282	282	281	1	0.15	0	
140430374	Greenfield Brg at Pocusset St	0	0	415	19	19	91	181	0.21	69	
140461875	Greenfield Ave at Saline St	296	296	297	297	297	297	0	0.24	0	
140432458	Greenfield Ave at Hazelwood Ave	143	144	283	424	368	272	128	0.09	102	
140430731	Greendale Ave at S Braddock Ave	144	121	180	78	204	146	49	0.25	24	
140429799	Greendale Ave at Race St	343	343	343	343	343	343	0	0.07	103	
140432045	Green Belt/Edgewood Ave at S Braddock Ave/Gre	346	394	701	1001	508	590	267	0.32	-78	
140431059	Frazier St/Swinburne Brg at Greenfield Ave	726	1540	2196	684	1097	1249	632	0.01	857	Statistically Significant Increase
140430605	Forward Ave at Tilbury Ave	357	392	279	343	375	349	43	0.35	12	
140960077	Forward at Murray	167	162	162	163	161	163	2	0.20	-4	
140428698	Forbes Ave at Wightman St	854	854	854	854	854	854	0	0.21	0	
140428751	Forbes Ave at Shady Ave/Blue Belt	175	209	150	185	150	174	25	0.09	-44	
140427317	Forbes Ave at Schenley Dr	386	431	414	436	368	407	29	0.44	-4	
140428755	Forbes Ave at Schenley Dr	2095	683	1365	1148	1148	1288	515	0.10	419	
140428790	Forbes Ave at S Dallas Ave	147	152	195	235	171	180	36	0.01	59	Statistically Significant Increase
140428485	Forbes Ave at S Braddock Ave	357	288	490	397	441	395	78	0.21	-84	
140427656	Forbes Ave at S Bouquet St	408	399	404	457	328	399	46	0.11	41	
140427239	Forbes Ave at S Bellefield Ave	90	174	152	228	174	164	50	0.34	-31	
140428710	Forbes Ave at Murray Ave	125	130	130	132	153	134	11	0.05	-19	
140427103	Forbes Ave at Morewood Ave	368	329	311	409	329	349	39	0.15	-393	
140428473	Forbes Ave at Halket St	196	262	142	207	172	196	45	0.18	-40	
140428739	Forbes at Murdock	747	747	747	747	747	747	0	0.17	65	
140428135	Forbes at McKee Pl	158	197	152	157	209	175	27	0.46	3	
140427943	Fifth Avenue at Darragh St	191	139	260	201	282	215	57	0.40	7	
140427589	Fifth Ave at De Soto Ave	153	153	153	153	153	153	0	0.19	0	
140429849	Edgewood at Maple	176	248	245	185	188	208	35	0.38	-13	
140429702	E Swissvale Ave/Green Belt at Race St	424	425	425	425	425	424	0	0.10	0	
140429882	Dawson St at Swinburne St/Swinburne St	80	151	191	149	128	140	41	0.14	-25	
140428760	Craft Ave at Forbes Ave	141	152	111	108	127	128	19	0.11	-14	
140432217	Commercial St at Whipple St	24	21	21	43	21	26	10	0.14	5	
140427706	Clemente St at Schenley Dr	294	430	276	597	195	359	158	0.32	51	
140427928	Clemente St at S Bouquet St	231	436	323	710	359	412	182	0.17	88	
140427144	Brashear St at S Braddock Ave	235	56	218	57	174	148	86	0.22	39	
140429073	Boulevard of the Allies at Zulema St	639	639	639	639	639	639	0	0.32	0	
140429427	Boulevard of the Allies at Parkview Ave	340	340	340	340	340	340	0	0.47	0	
140429402	Boulevard of the Allies at Dawson St	566	954	954	953	954	876	174	0.28	79	
140429054	Boulevard of the Allies at Craft Ave	326	308	306	301	492	346	82	0.20	-67	
140427399	Bigelow Blvd at Schenley Dr	289	192	379	915	308	417	286	0.05	233	
140427203	Beulah Rd at William Penn Hwy	598	414	394	316	396	424	105	0.00	-240	Statistically Significant Decrease
140427478	Beulah Rd at Churchill Rd	230	220	222	272	275	244	27	0.27	16	
140426905	Beeler St at Wilkins Ave	139	111	108	69	127	111	27	0.29	-19	
140427313	Beeler St at Forbes Ave	375	408	373	445	479	416	46	0.18	-35	
140427298	Beechwood Blvd at Wilkins Ave	119	133	127	135	105	124	12	0.44	2	
140428885	Beechwood Blvd at S Dallas Ave	78	77	135	146	132	113	33	0.04	-30	Statistically Significant Decrease
140430818	Beechwood Blvd at Ronald St	296	227	225	202	232	236	35	0.01	57	Statistically Significant Increase
140431310	Beechwood Blvd at Monitor St	331	582	598	695	306	503	174	0.00	-1437	Statistically Significant Decrease
140432495	Beechwood Blvd at Hazelwood Ave	1890	1890	1890	1890	1890	1890	0	0.01	745	Statistically Significant Increase
140430723	Beechwood Blvd at Forward Ave	179	178	176	235	195	193	25	0.43	-6	
140428773	Beechwood Blvd at Forbes Ave	133	167	175	188	163	165	20	0.09	-38	

MAXIMUM TOTAL INTERSECTION QUEUE - 2009 OPTION 1, PM PEAK

NODE ID	NODE NAME	VISSIM RUN ID					AVG	Stdev	Ttest	AVG Change	Statistical Significance
		1	2	3	4	5					
140429079	Bates St at Zulema St	293	327	327	327	292	313	19	0.04	77	Statistically Significant Increase
140428198	Bates St at S Bouquet St	493	477	493	336	494	459	69	0.02	146	Statistically Significant Increase
140429839	Bates St at Ramp - Bates St to I-376 EB	105	105	105	106	105	105	0	0.25	0	
140429765	Bates St at Ramp - I-376 WB to Bates St SB	1218	1218	1218	1218	586	1092	282	0.02	593	Statistically Significant Increase
140429230	Bates St at Boulevard of the Allies	577	577	577	577	577	577	0	0.29	0	
140428934	Bates at McKee Pl	108	564	850	850	147	504	363	0.02	385	Statistically Significant Increase
140429224	Bartlett St at Wightman St	0	0	0	0	17	3	7	0.04	-9	Statistically Significant Decrease
140429169	Bartlett St at Shady Ave/Blue Belt	0	0	0	0	0	0	0	0.09	-12	
140429720	Bartlett St at Panther Hollow Rd	1032	1031	1032	1031	1031	1031	0	0.28	0	
140429194	Bartlett St at Murray Ave	173	172	178	262	147	186	44	0.44	4	
140429296	Bartlett at Murdock	49	109	70	123	47	79	35	0.01	-161	Statistically Significant Decrease
140428121	Ardmore Blvd at Swissvale Ave/Green Belt	389	417	456	517	502	456	55	0.01	-104	Statistically Significant Decrease
140428770	Ardmore Blvd at South Ave	80	224	156	270	146	175	74	0.42	-9	
140428491	Ardmore Blvd at Ross Avenue	392	489	392	393	393	412	43	0.17	19	
140430786	Alger St at Greenfield Brg	618	153	777	193	271	403	279	0.05	238	Statistically Significant Increase
140430785	Alger St at Beechwood Blvd	161	117	119	119	80	119	29	0.04	42	Statistically Significant Increase
140426333	5th Ave at Wilkins Ave	64	89	65	65	63	69	11	0.02	-51	Statistically Significant Decrease
140425193	5th Ave at Shady Ave	223	195	240	230	193	216	21	0.11	-31	
140426446	5th Ave at S Neville St	281	271	196	221	282	250	39	0.02	-64	Statistically Significant Decrease
140425876	5th Ave at S Negley Ave	452	360	613	273	465	432	127	0.31	47	
140427518	5th Ave at S Bouquet St	108	133	172	148	132	138	24	0.08	22	
140426563	5th Ave at S Bellefield Ave	220	281	264	333	324	284	46	0.23	-20	
140428668	5th Ave at Robinson St	814	539	815	815	814	759	123	0.17	-55	
140424984	5th Ave at Penn Avenue	447	517	609	557	390	504	87	0.48	2	
140426398	5th Ave at Morewood Ave	261	191	194	261	303	242	48	0.19	-70	
140428280	5th Ave at Halket St	51	0	37	106	246	88	96	0.33	-50	
140428583	5th Ave at Craft Ave	337	176	780	437	788	504	272	0.41	-40	
140427081	5th Ave at Bigelow Blvd	130	236	216	219	169	194	44	0.08	36	
140425061	5th Ave at Beechwood Blvd	275	260	260	323	249	274	29	0.04	-27	Statistically Significant Decrease
140434097	2nd Ave at Irvine St	236	345	214	215	261	254	54	0.29	22	
140490672	2nd Ave at Hot Metal St	612	743	589	589	589	625	67	0.13	36	
140432138	2nd Ave at Greenfield Ave	291	291	314	727	542	433	195	0.11	121	
140429958	2nd Ave at Bates St	901	1927	1217	578	404	1005	602	0.31	-208	

Statistics based on the final 15-minutes (17:15-17:30) of VISSIM simulation of PM Peak Hour (16:30-17:30) conditions.

MAXIMUM TOTAL INTERSECTION QUEUE - 2009 OPTION 2, PM PEAK

NODE ID	NODE NAME	VISSIM RUN ID					AVG	Stdev	Ttest	AVG Change	Statistical Significance
		1	2	3	4	5					
140427286	Wightman St at Wilkins Ave	109	121	215	172	173	158	43	0.21	27	
140428522	South Ave at Swissvale Ave/Green Belt	816	848	636	660	801	752	97	0.01	202	Statistically Significant Increase
140427849	South Ave at Hay Street	210	209	210	210	210	210	0	0.02	1	Statistically Significant Increase
140429954	Shady Ave/Blue Belt at Tilbury Ave	66	67	95	23	130	76	40	0.37	-9	
140427394	Shady Ave at Wilkins Ave	156	90	111	86	108	110	28	0.18	-26	
140427707	Schenley Dr at Schenley Dr Ext	389	389	292	358	319	350	43	0.21	-27	
140427312	S Negley Ave at Wilkins Ave	277	308	390	215	270	292	64	0.19	-47	
140426630	S Dallas Ave at Wilkins Ave	163	161	136	164	163	157	12	0.44	1	
140426716	S Dallas Ave at Wilkins Ave	85	106	84	88	109	94	12	0.49	0	
140428330	Ross Avenue at Swissvale Ave/Green Belt	333	333	397	333	485	376	67	0.48	2	
140430949	Ronald St to Greenfield Ave at Ronald St	309	308	308	307	308	308	1	0.07	4	
140430401	Pocusset St at Wightman St	157	114	84	174	103	126	38	0.28	-25	
140427798	Pennwood Ave at South Ave	311	324	275	277	284	294	22	0.00	92	Statistically Significant Increase
140429715	Pennwood Ave at Race St	317	286	488	488	312	378	101	0.00	-356	Statistically Significant Decrease
140427307	Penn Avenue at Pennwood Ave	510	181	913	573	374	510	271	0.28	93	
140427492	Penn Avenue at Hay Street	629	291	550	631	476	515	141	0.30	-43	
140426681	Penn Ave at N Braddock Ave	1397	1397	1391	1396	1397	1395	3	0.00	1026	Statistically Significant Increase
140429881	Parkview Ave at Swinburne St/Swinburne St	118	171	173	282	177	184	60	0.37	-14	
140428471	Panther Hollow Road at Schenley Dr	169	1559	189	120	185	444	624	0.02	-886	Statistically Significant Decrease
140427245	Old Gate Rd at William Penn Hwy	34	99	19	18	0	34	38	0.14	-22	
140425584	N Dallas Ave at S Dallas Ave	323	481	279	343	320	349	77	0.22	29	
140427343	Murray Ave at Wilkins Ave	158	93	96	120	68	107	34	0.16	-17	
140430403	Murray Ave at Pocusset St	475	308	376	879	372	482	230	0.27	-91	
140431258	Monongahela Ave at Whipple St	1273	1272	1272	1273	1273	1273	0	0.00	1097	Statistically Significant Increase
140430984	Monongahela Ave at S Braddock Ave	219	219	218	247	219	224	12	0.01	-54	Statistically Significant Decrease
140429786	Hobart St at Wightman St	171	110	108	140	125	131	26	0.13	16	
140429533	Hobart St at Shady Ave/Blue Belt	0	0	34	0	31	13	18	0.03	-104	Statistically Significant Decrease
140429612	Hobart St at Murray Ave	201	196	174	224	216	202	20	0.06	-86	
140432477	Hazelwood Ave at Murray Ave/Blue Belt	290	281	278	283	282	283	5	0.20	2	
140430374	Greenfield Brg at Pocusset St	17	36	19	15	0	17	13	0.24	-4	
140461875	Greenfield Ave at Saline St	296	296	297	297	356	308	27	0.18	12	
140432458	Greenfield Ave at Hazelwood Ave	266	205	217	281	264	246	34	0.05	76	Statistically Significant Increase
140430731	Greendale Ave at S Braddock Ave	181	187	156	199	204	185	19	0.03	64	Statistically Significant Increase
140429799	Greendale Ave at Race St	85	87	109	50	105	87	23	0.02	-152	Statistically Significant Decrease
140432045	Green Belt/Edgewood Ave at S Braddock Ave/Gre	327	545	1012	763	415	613	277	0.37	-55	
140431059	Frazier St/Swinburne Brg at Greenfield Ave	815	2561	2725	815	2495	1882	978	0.00	1491	Statistically Significant Increase
140430605	Forward Ave at Tilbury Ave	282	349	305	344	396	335	44	0.47	-2	
140960077	Forward at Murray	162	163	162	162	183	167	9	0.45	-1	
140428698	Forbes Ave at Wightman St	854	854	854	854	854	854	0	0.21	0	
140428751	Forbes Ave at Shady Ave/Blue Belt	173	181	174	179	151	171	12	0.07	-46	
140427317	Forbes Ave at Schenley Dr	397	416	302	341	435	378	55	0.16	-32	
140428755	Forbes Ave at Schenley Dr	2627	797	1143	1557	1148	1454	708	0.08	585	
140428790	Forbes Ave at S Dallas Ave	237	194	197	144	495	253	139	0.04	133	Statistically Significant Increase
140428485	Forbes Ave at S Braddock Ave	674	908	541	487	447	612	187	0.16	133	
140427656	Forbes Ave at S Bouquet St	421	394	353	404	373	389	26	0.13	31	
140427239	Forbes Ave at S Bellefield Ave	151	134	186	270	178	184	53	0.44	-11	
140428710	Forbes Ave at Murray Ave	130	153	110	128	86	122	25	0.03	-31	Statistically Significant Decrease
140427103	Forbes Ave at Morewood Ave	405	373	313	388	313	359	43	0.16	-383	
140428473	Forbes Ave at Halket St	196	388	375	168	229	271	103	0.29	35	
140428739	Forbes at Murdock	747	747	747	747	747	747	0	0.17	65	
140428135	Forbes at McKee Pl	184	152	149	125	187	159	26	0.32	-13	
140427943	Fifth Avenue at Darragh St	831	449	854	201	854	638	299	0.01	430	Statistically Significant Increase
140427589	Fifth Ave at De Soto Ave	152	153	153	153	153	153	0	0.28	0	
140429849	Edgewood at Maple	391	391	646	410	412	450	110	0.00	229	Statistically Significant Increase
140429702	E Swissvale Ave/Green Belt at Race St	408	297	377	412	414	381	50	0.04	-43	Statistically Significant Decrease
140429882	Dawson St at Swinburne St/Swinburne St	105	156	158	156	158	147	23	0.13	-18	
140428760	Craft Ave at Forbes Ave	110	113	219	135	136	143	44	0.47	1	
140432217	Commercial St at Whipple St	810	314	19	42	343	305	319	0.04	285	Statistically Significant Increase
140427706	Clemente St at Schenley Dr	301	197	276	194	278	249	50	0.24	-59	
140427928	Clemente St at S Bouquet St	375	317	504	413	493	421	79	0.03	96	Statistically Significant Increase
140427144	Brashear St at S Braddock Ave	717	716	716	716	715	716	1	0.00	607	Statistically Significant Increase
140429073	Boulevard of the Allies at Zulema St	639	636	520	520	639	591	65	0.07	-49	
140429427	Boulevard of the Allies at Parkview Ave	339	340	340	381	315	343	24	0.38	3	
140429402	Boulevard of the Allies at Dawson St	533	451	438	779	816	603	182	0.09	-194	
140429054	Boulevard of the Allies at Craft Ave	496	306	307	303	308	344	85	0.19	-70	
140427399	Bigelow Blvd at Schenley Dr	111	227	220	220	241	204	52	0.23	20	
140427203	Beulah Rd at William Penn Hwy	421	563	417	314	436	430	89	0.00	-234	Statistically Significant Decrease
140427478	Beulah Rd at Churchill Rd	230	203	243	272	275	244	30	0.27	17	
140426905	Beeler St at Wilkins Ave	75	86	90	138	113	100	25	0.20	-29	
140427313	Beeler St at Forbes Ave	410	462	509	554	425	472	60	0.31	21	
140427298	Beechwood Blvd at Wilkins Ave	108	88	152	112	160	124	31	0.45	2	
140428885	Beechwood Blvd at S Dallas Ave	79	79	91	79	984	262	403	0.26	119	
140430818	Beechwood Blvd at Ronald St	257	233	256	239	257	248	11	0.00	69	Statistically Significant Increase
140431310	Beechwood Blvd at Monitor St	1939	1939	1939	1939	1514	1854	190	0.17	-85	
140432495	Beechwood Blvd at Hazelwood Ave	1890	1890	1890	1890	1890	1890	0	0.01	745	Statistically Significant Increase
140430723	Beechwood Blvd at Forward Ave	231	432	197	174	349	277	110	0.11	78	
140428773	Beechwood Blvd at Forbes Ave	229	208	151	195	863	329	300	0.19	126	
140429079	Bates St at Zulema St	231	327	326	129	258	254	82	0.37	18	

MAXIMUM TOTAL INTERSECTION QUEUE - 2009 OPTION 2, PM PEAK

NODE ID	NODE NAME	VISSIM RUN ID					AVG	Stdev	Ttest	AVG Change	Statistical Significance
		1	2	3	4	5					
140428198	Bates St at S Bouquet St	494	493	494	494	494	494	0	0.00	182	Statistically Significant Increase
140429839	Bates St at Ramp - Bates St to I-376 EB	105	105	103	105	103	104	1	0.17	-1	
140429765	Bates St at Ramp - I-376 WB to Bates St SB	121	146	153	149	109	136	19	0.06	-363	
140429230	Bates St at Boulevard of the Allies	577	576	577	570	577	575	3	0.09	-2	
140428934	Bates at McKee Pl	100	131	83	77	80	94	22	0.15	-24	
140429224	Bartlett St at Wightman St	15	15	15	17	15	15	1	0.22	3	
140429169	Bartlett St at Shady Ave/Blue Belt	89	39	60	40	17	49	27	0.02	37	Statistically Significant Increase
140429720	Bartlett St at Panther Hollow Rd	1031	1032	1031	1031	1032	1031	0	0.23	0	
140429194	Bartlett St at Murray Ave	152	131	190	170	133	155	25	0.08	-28	
140429296	Bartlett at Murdock	57	73	113	45	49	67	27	0.01	-173	Statistically Significant Decrease
140428121	Ardmore Blvd at Swissvale Ave/Green Belt	437	416	305	345	304	361	62	0.00	-199	Statistically Significant Decrease
140428770	Ardmore Blvd at South Ave	528	960	251	700	883	665	286	0.00	480	Statistically Significant Increase
140428491	Ardmore Blvd at Ross Avenue	509	509	508	499	509	507	4	0.00	115	Statistically Significant Increase
140430786	Alger St at Greenfield Brg	172	217	315	197	199	220	56	0.06	55	
140430785	Alger St at Beechwood Blvd	120	79	121	119	120	112	18	0.04	34	Statistically Significant Increase
140426333	5th Ave at Wilkins Ave	203	104	51	87	145	118	58	0.48	-2	
140425193	5th Ave at Shady Ave	442	318	286	285	261	318	72	0.05	71	
140426446	5th Ave at S Neville St	328	263	230	321	385	305	60	0.40	-8	
140425876	5th Ave at S Negley Ave	666	325	727	342	502	512	183	0.14	127	
140427518	5th Ave at S Bouquet St	106	105	69	135	578	198	213	0.21	82	
140426563	5th Ave at S Bellefield Ave	345	249	220	372	367	311	71	0.44	6	
140428668	5th Ave at Robinson St	815	815	814	814	815	814	0	0.20	0	
140424984	5th Ave at Penn Avenue	689	547	516	577	538	573	68	0.07	72	
140426398	5th Ave at Morewood Ave	262	235	195	261	303	251	40	0.22	-61	
140428280	5th Ave at Halket St	762	762	762	680	762	745	37	0.00	607	Statistically Significant Increase
140428583	5th Ave at Craft Ave	788	788	788	788	788	788	0	0.03	244	Statistically Significant Increase
140427081	5th Ave at Bigelow Blvd	231	136	212	215	208	200	37	0.04	42	Statistically Significant Increase
140425061	5th Ave at Beechwood Blvd	450	332	308	292	364	349	63	0.06	49	
140434097	2nd Ave at Irvine St	335	161	172	154	238	212	76	0.33	-21	
140490672	2nd Ave at Hot Metal St	589	372	589	589	589	546	97	0.17	-43	
140432138	2nd Ave at Greenfield Ave	332	292	433	293	411	352	66	0.15	40	
140429958	2nd Ave at Bates St	1480	1927	1926	1927	428	1537	650	0.23	324	

Statistics based on the final 15-minutes (17:15-17:30) of VISSIM simulation of PM Peak Hour (16:30-17:30) conditions.

MAXIMUM TOTAL INTERSECTION QUEUE - 2009 Option 3, PM PEAK

NODE ID	NODE NAME	VISSIM RUN ID					AVG	Stdev	Ttest	AVG Change	Statistical Significance
		1	2	3	4	5					
140427286	Wightman St at Wilkins Ave	109	113	106	208	168	141	45	0.38	10	
140428522	South Ave at Swissvale Ave/Green Belt	620	316	623	620	478	531	135	0.41	-18	
140427849	South Ave at Hay Street	207	208	210	209	210	209	1	0.42	0	
140429954	Shady Ave/Blue Belt at Tilbury Ave	21	59	93	23	45	48	29	0.07	-36	
140427394	Shady Ave at Wilkins Ave	152	104	152	130	87	125	29	0.35	-11	
140427707	Schenley Dr at Schenley Dr Ext	177	300	275	347	366	293	74	0.04	-83	Statistically Significant Decrease
140427312	S Negley Ave at Wilkins Ave	226	281	347	364	410	326	72	0.40	-13	
140426630	S Dallas Ave at Wilkins Ave	164	160	162	73	162	144	40	0.27	-12	
140426716	S Dallas Ave at Wilkins Ave	89	63	85	132	103	94	25	0.50	0	
140428330	Ross Avenue at Swissvale Ave/Green Belt	333	332	416	296	333	342	44	0.20	-32	
140430949	Ronald St to Greenfield Ave at Ronald St	308	308	308	306	307	307	1	0.09	4	
140430401	Pocusset St at Wightman St	158	176	84	216	85	144	58	0.44	-7	
140427798	Pennwood Ave at South Ave	181	193	189	178	148	178	18	0.01	-25	Statistically Significant Decrease
140429715	Pennwood Ave at Race St	333	261	350	439	251	327	76	0.00	-408	Statistically Significant Decrease
140427307	Penn Avenue at Pennwood Ave	542	325	480	320	170	367	147	0.33	-50	
140427492	Penn Avenue at Hay Street	445	456	528	631	430	498	83	0.17	-61	
140426681	Penn Ave at N Braddock Ave	705	411	307	425	706	511	183	0.07	141	
140429881	Parkview Ave at Swinburne St/Swinburne St	143	125	145	100	218	146	44	0.10	-52	
140428471	Panther Hollow Road at Schenley Dr	183	1297	264	219	173	427	488	0.01	-903	Statistically Significant Decrease
140427245	Old Gate Rd at William Penn Hwy	29	99	17	19	35	40	34	0.19	-16	
140425584	N Dallas Ave at S Dallas Ave	307	311	310	250	327	301	29	0.14	-19	
140427343	Murray Ave at Wilkins Ave	155	153	191	100	111	142	37	0.17	18	
140430403	Murray Ave at Pocusset St	407	307	298	687	560	452	169	0.18	-122	
140431258	Monongahela Ave at Whipple St	1273	292	1273	1273	1273	1077	438	0.00	901	Statistically Significant Increase
140430984	Monongahela Ave at S Braddock Ave	219	219	220	219	220	219	0	0.01	-59	Statistically Significant Decrease
140429786	Hobart St at Wightman St	194	110	87	148	125	133	41	0.19	18	
140429533	Hobart St at Shady Ave/Blue Belt	41	0	0	29	32	20	19	0.04	-97	Statistically Significant Decrease
140429612	Hobart St at Murray Ave	212	244	258	224	211	230	20	0.14	-59	
140432477	Hazelwood Ave at Murray Ave/Blue Belt	277	280	282	281	289	282	5	0.34	1	
140430374	Greenfield Brg at Pocusset St	0	0	0	20	45	13	20	0.18	-9	
140461875	Greenfield Ave at Saline St	297	264	297	297	297	290	15	0.19	-6	
140432458	Greenfield Ave at Hazelwood Ave	268	189	300	193	229	236	48	0.08	65	
140430731	Greendale Ave at S Braddock Ave	146	149	204	201	202	181	30	0.04	59	Statistically Significant Increase
140429799	Greendale Ave at Race St	42	22	53	25	133	55	46	0.01	-185	Statistically Significant Decrease
140432045	Green Belt/Edgewood Ave at S Braddock Ave/Gre	418	496	1010	387	628	588	254	0.31	-80	
140431059	Frazier St/Swinburne Brg at Greenfield Ave	882	930	454	705	946	783	207	0.00	392	Statistically Significant Increase
140430605	Forward Ave at Tilbury Ave	363	367	257	328	411	345	57	0.41	8	
140960077	Forward at Murray	231	162	163	162	163	176	31	0.28	9	
140428698	Forbes Ave at Wightman St	854	854	854	854	854	854	0	0.36	0	
140428751	Forbes Ave at Shady Ave/Blue Belt	197	174	173	268	164	195	42	0.26	-22	
140427317	Forbes Ave at Schenley Dr	382	407	339	333	296	351	44	0.03	-59	Statistically Significant Decrease
140428755	Forbes Ave at Schenley Dr	1593	1144	433	1148	310	926	539	0.43	57	
140428790	Forbes Ave at S Dallas Ave	136	153	204	196	186	175	29	0.01	54	Statistically Significant Increase
140428485	Forbes Ave at S Braddock Ave	331	619	420	356	397	424	114	0.31	-54	
140427656	Forbes Ave at S Bouquet St	425	400	420	332	326	380	48	0.25	22	
140427239	Forbes Ave at S Bellefield Ave	96	156	140	190	143	145	34	0.25	-50	
140428710	Forbes Ave at Murray Ave	106	88	167	194	152	141	44	0.30	-12	
140427103	Forbes Ave at Morewood Ave	439	354	277	358	310	348	61	0.15	-394	
140428473	Forbes Ave at Halket St	198	262	142	208	235	209	45	0.27	-27	
140428739	Forbes at Murdock	747	746	572	747	480	658	125	0.39	-24	
140428135	Forbes at McKee Pl	131	195	156	156	195	166	28	0.42	-6	
140427943	Fifth Avenue at Darragh St	260	231	259	168	225	229	37	0.18	21	
140427589	Fifth Ave at De Soto Ave	153	153	153	153	153	153	0	0.32	0	
140429849	Edgewood at Maple	388	391	391	391	413	395	10	0.00	174	Statistically Significant Increase
140429702	E Swissvale Ave/Green Belt at Race St	414	376	412	409	286	379	54	0.05	-45	Statistically Significant Decrease
140429882	Dawson St at Swinburne St/Swinburne St	159	209	115	157	154	159	34	0.38	-6	
140428760	Craft Ave at Forbes Ave	136	197	112	130	112	137	35	0.41	-4	
140432217	Commercial St at Whipple St	21	21	20	22	21	21	1	0.40	0	
140427706	Clemente St at Schenley Dr	233	293	296	343	160	265	70	0.31	-43	
140427928	Clemente St at S Bouquet St	321	242	389	312	308	315	52	0.40	-10	
140427144	Brashear St at S Braddock Ave	717	705	575	701	715	683	60	0.00	573	Statistically Significant Increase
140429073	Boulevard of the Allies at Zulema St	639	639	628	638	639	637	5	0.14	-3	
140429427	Boulevard of the Allies at Parkview Ave	314	314	340	339	339	329	14	0.06	-11	
140429402	Boulevard of the Allies at Dawson St	389	395	389	389	389	390	3	0.00	-407	Statistically Significant Decrease
140429054	Boulevard of the Allies at Craft Ave	619	307	295	619	599	488	171	0.24	74	
140427399	Bigelow Blvd at Schenley Dr	233	174	147	384	311	250	98	0.09	66	
140427203	Beulah Rd at William Penn Hwy	425	384	413	314	467	401	57	0.00	-263	Statistically Significant Decrease
140427478	Beulah Rd at Churchill Rd	230	203	271	272	275	250	32	0.21	23	
140426905	Beeler St at Wilkins Ave	121	118	88	68	98	99	22	0.18	-31	
140427313	Beeler St at Forbes Ave	422	418	366	463	461	426	39	0.24	-26	
140427298	Beechwood Blvd at Wilkins Ave	108	110	107	126	86	107	14	0.15	-14	
140428885	Beechwood Blvd at S Dallas Ave	141	125	77	127	147	123	27	0.08	-20	
140430818	Beechwood Blvd at Ronald St	205	179	180	148	179	178	20	0.45	-2	
140431310	Beechwood Blvd at Monitor St	1615	1939	828	1939	877	1440	552	0.04	-499	Statistically Significant Decrease
140432495	Beechwood Blvd at Hazelwood Ave	1890	1890	1890	1890	1890	1890	0	0.01	745	Statistically Significant Increase
140430723	Beechwood Blvd at Forward Ave	223	353	219	194	257	249	62	0.13	51	
140428773	Beechwood Blvd at Forbes Ave	110	195	170	171	167	163	31	0.09	-41	

MAXIMUM TOTAL INTERSECTION QUEUE - 2009 Option 3, PM PEAK

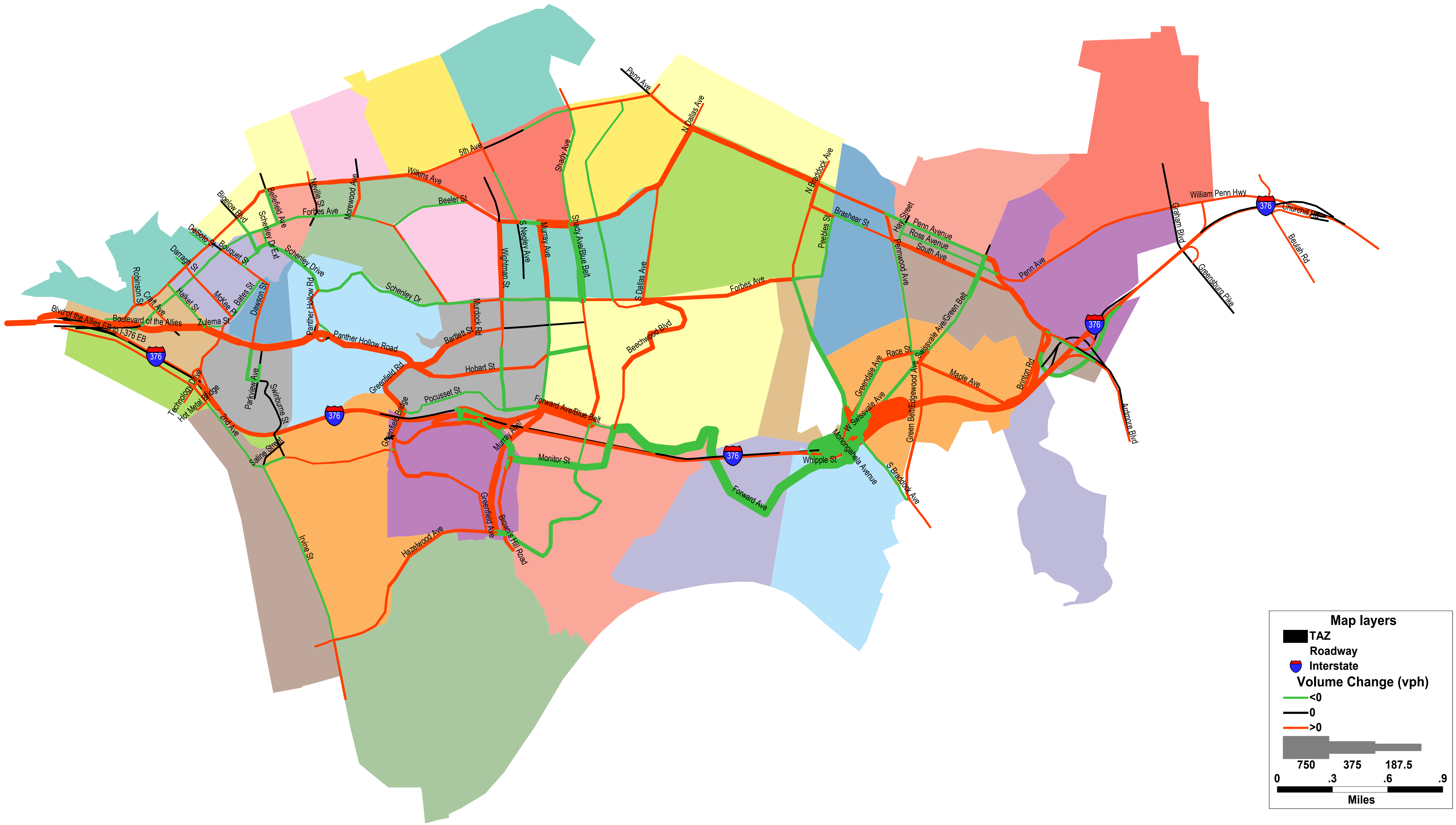
NODE ID	NODE NAME	VISSIM RUN ID					AVG	Stdev	Ttest	AVG Change	Statistical Significance
		1	2	3	4	5					
140429079	Bates St at Zulema St	327	326	327	255	290	305	32	0.07	69	
140428198	Bates St at S Bouquet St	494	494	494	494	494	494	0	0.00	181	Statistically Significant Increase
140429839	Bates St at Ramp - Bates St to I-376 EB	105	105	105	106	106	105	0	0.27	0	
140429765	Bates St at Ramp - I-376 WB to Bates St SB	1217	936	411	724	439	745	341	0.18	247	
140429230	Bates St at Boulevard of the Allies	577	577	577	577	577	577	0	0.07	0	
140428934	Bates at McKee Pl	170	115	724	121	137	253	264	0.15	134	
140429224	Bartlett St at Wightman St	16	0	17	14	16	12	7	0.47	0	
140429169	Bartlett St at Shady Ave/Blue Belt	90	39	45	18	18	42	30	0.05	30	Statistically Significant Increase
140429720	Bartlett St at Panther Hollow Rd	1031	1032	1031	1031	1032	1031	0	0.21	0	
140429194	Bartlett St at Murray Ave	192	189	256	173	177	197	34	0.25	15	
140429296	Bartlett at Murdock	57	201	47	43	101	90	66	0.02	-150	Statistically Significant Decrease
140428121	Ardmore Blvd at Swissvale Ave/Green Belt	284	307	286	490	462	365	101	0.00	-195	Statistically Significant Decrease
140428770	Ardmore Blvd at South Ave	150	142	95	203	106	139	43	0.13	-45	
140428491	Ardmore Blvd at Ross Avenue	280	391	392	414	391	373	53	0.22	-19	
140430786	Alger St at Greenfield Brg	185	166	382	228	330	258	94	0.04	93	Statistically Significant Increase
140430785	Alger St at Beechwood Blvd	118	119	120	121	121	120	1	0.01	42	Statistically Significant Increase
140426333	5th Ave at Wilkins Ave	71	106	89	103	85	91	14	0.11	-29	
140425193	5th Ave at Shady Ave	214	197	214	250	218	219	20	0.12	-29	
140426446	5th Ave at S Neville St	313	259	236	236	256	260	31	0.02	-54	Statistically Significant Decrease
140425876	5th Ave at S Negley Ave	434	346	591	370	528	454	104	0.23	68	
140427518	5th Ave at S Bouquet St	113	117	131	102	148	122	18	0.33	5	
140426563	5th Ave at S Bellefield Ave	286	278	189	219	298	254	48	0.05	-51	Statistically Significant Decrease
140428668	5th Ave at Robinson St	815	815	815	815	814	814	0	0.10	0	
140424984	5th Ave at Penn Avenue	427	485	400	558	389	452	70	0.14	-50	
140426398	5th Ave at Morewood Ave	260	200	189	261	303	242	47	0.19	-69	
140428280	5th Ave at Halket St	30	0	63	16	649	151	279	0.47	14	
140428583	5th Ave at Craft Ave	699	302	783	768	788	668	208	0.21	124	
140427081	5th Ave at Bigelow Blvd	215	237	212	278	208	230	29	0.00	71	Statistically Significant Increase
140425061	5th Ave at Beechwood Blvd	285	348	286	340	358	324	35	0.09	23	
140434097	2nd Ave at Irvine St	154	126	185	323	245	207	79	0.29	-26	
140490672	2nd Ave at Hot Metal St	1656	1095	591	2280	589	1242	728	0.04	654	Statistically Significant Increase
140432138	2nd Ave at Greenfield Ave	293	292	292	293	292	292	0	0.18	-20	
140429958	2nd Ave at Bates St	1205	1927	1924	1927	1927	1782	323	0.06	568	

Statistics based on the final 15-minutes (17:15-17:30) of VISSIM simulation of PM Peak Hour (16:30-17:30) conditions.

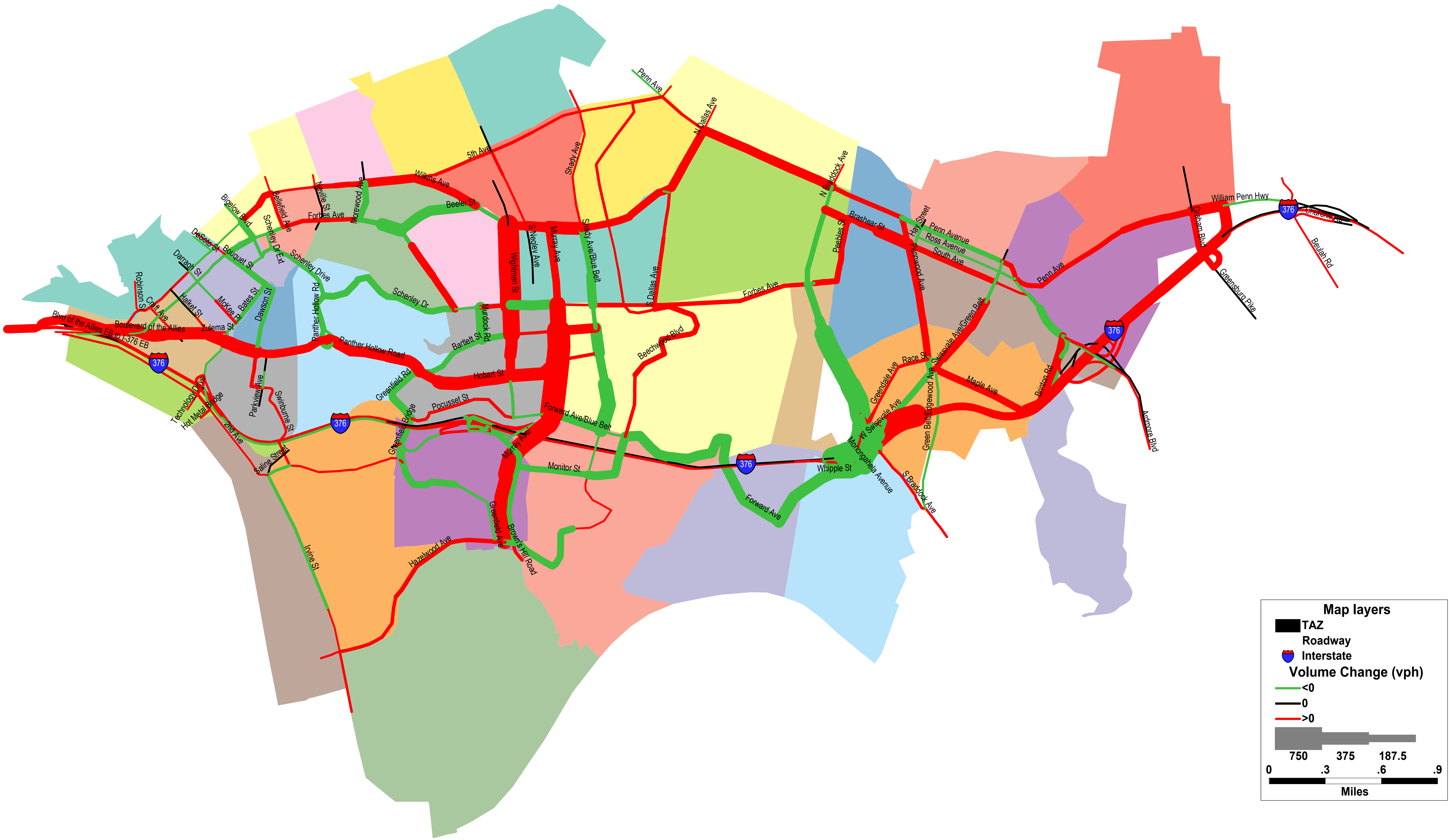
APPENDIX I

I-376 Maps of Traffic Diversions for Options 1 and 2

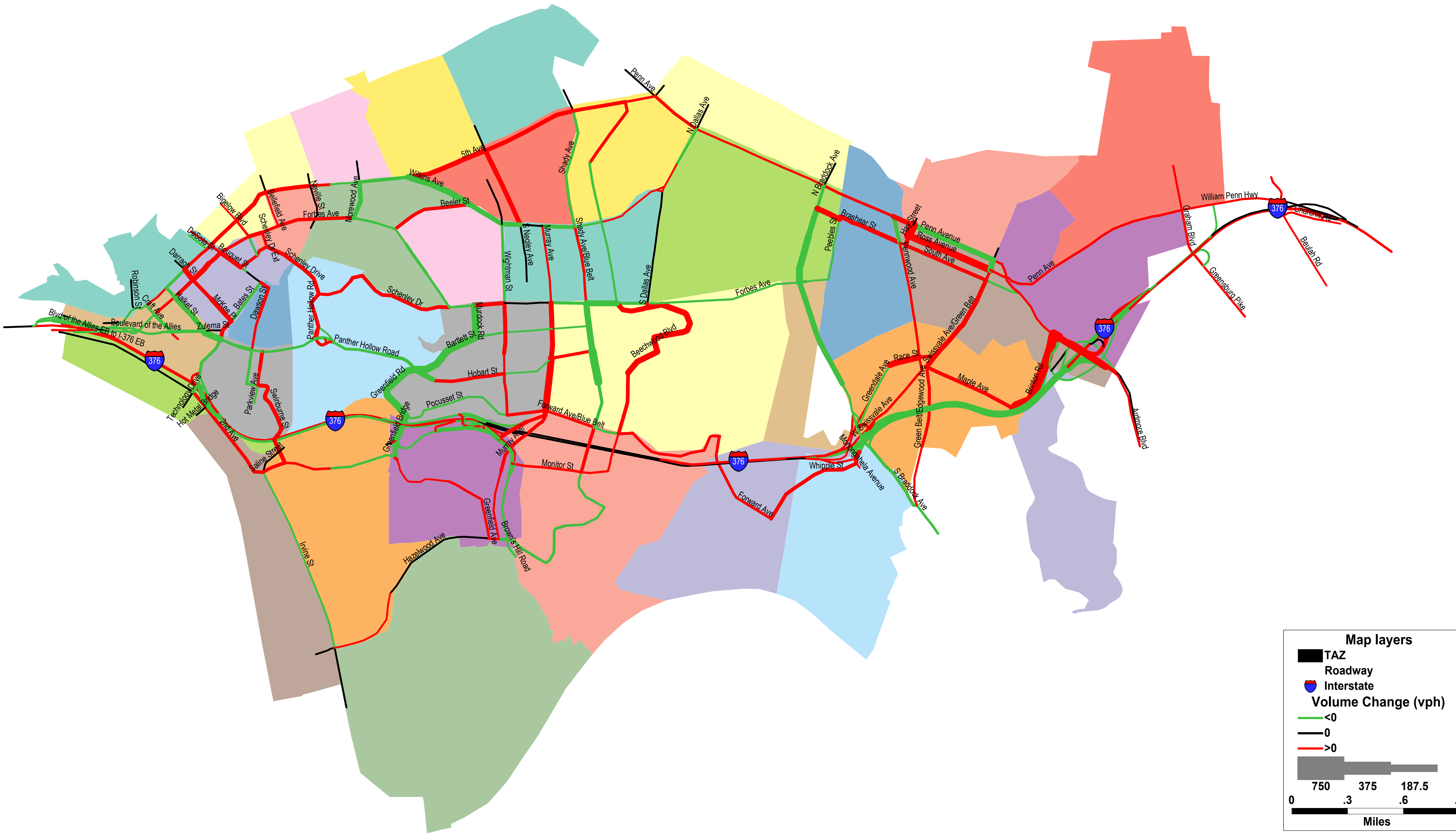
Traffic Diversions - AM Peak Hour - Option 1



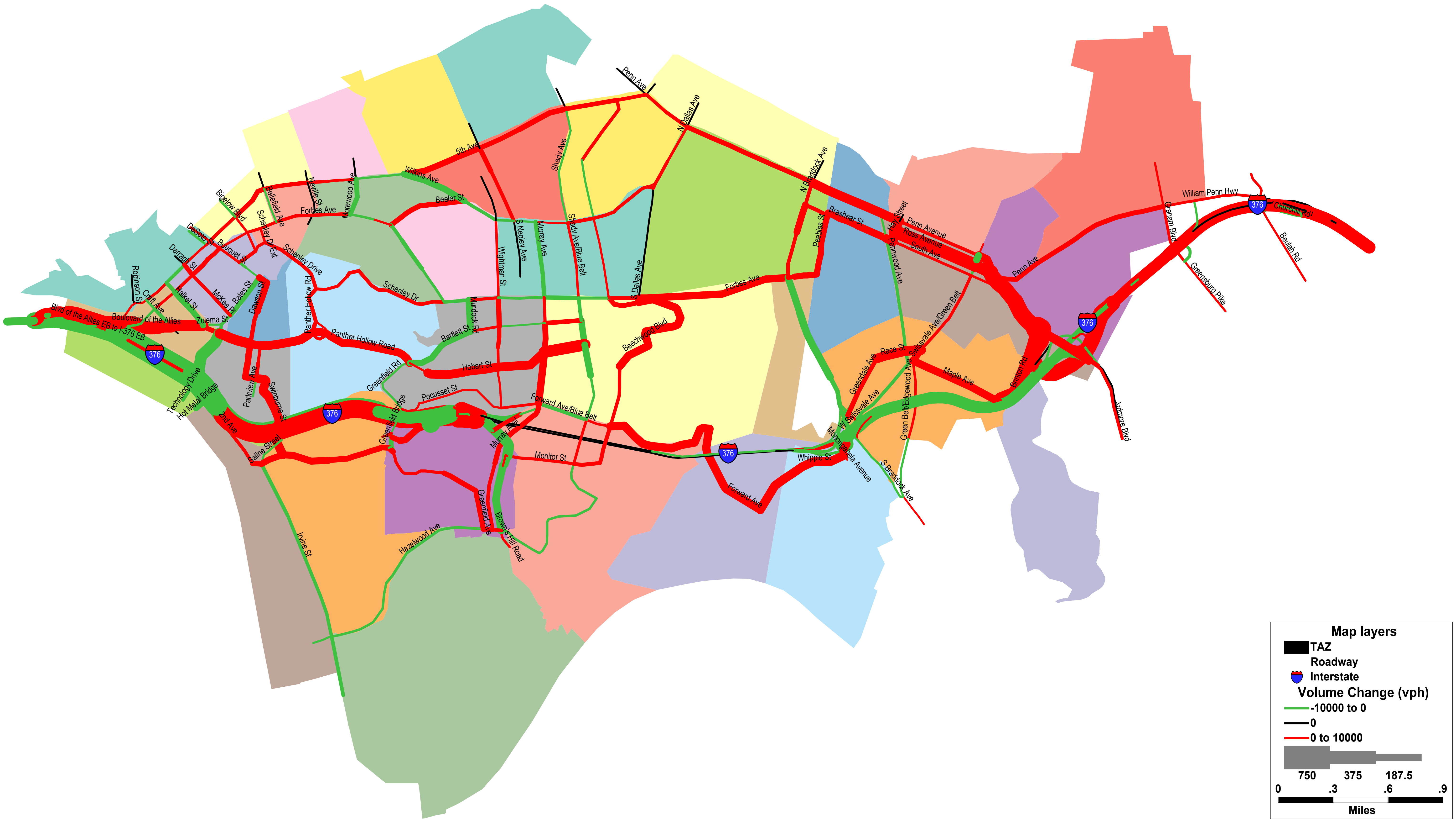
Traffic Diversions - AM Peak Hour - Option 2



Traffic Diversions - PM Peak Hour - Option 1



Traffic Diversions - PM Peak Hour - Option 2



APPENDIX J

I-376 Internal and External Zone Travel Time Comparisons

TRAVEL TIME COMPARISON, AM PEAK HOUR

ZONE ID	ZONE TYPE	Average Travel Time (min)				
		Base	Option 1	Change	Option 2	Change
1	Internal	3.04	3.05	0.01	3.05	0.01
2	Internal	5.07	5.13	0.06	5.16	0.09
3	Internal	6.39	6.44	0.05	6.50	0.11
4	Internal	5.61	5.57	-0.04	5.57	-0.03
5	Internal	5.82	5.84	0.01	5.94	0.11
6	Internal	8.55	8.34	-0.21	8.34	-0.20
7	Internal	5.20	5.35	0.15	6.35	1.15
8	Internal	8.22	7.88	-0.34	8.00	-0.22
9	Internal	9.15	9.18	0.03	8.98	-0.17
10	Internal	8.70	8.11	-0.60	8.81	0.11
11	Internal	6.04	6.12	0.08	6.04	0.00
12	Internal	9.24	9.11	-0.13	9.15	-0.09
13	Internal	7.03	7.09	0.05	7.14	0.11
14	Internal	9.55	9.56	0.01	9.72	0.17
15	Internal	9.63	8.84	-0.79	9.10	-0.53
16	Internal	6.59	6.54	-0.06	6.60	0.01
17	Internal	7.97	7.67	-0.31	7.83	-0.15
18	Internal	13.26	11.30	-1.95	11.66	-1.60
19	Internal	12.06	8.97	-3.09	10.35	-1.72
20	Internal	13.13	9.47	-3.66	9.55	-3.58
21	Internal	13.38	16.17	2.79	15.06	1.68
22	Internal	7.33	7.57	0.23	7.45	0.11
23	Internal	11.55	13.40	1.84	13.10	1.55
24	Internal	8.09	8.15	0.06	7.95	-0.14
25	Internal	9.08	9.01	-0.07	9.82	0.74
26	Internal	12.03	12.88	0.85	13.24	1.21
27	Internal	8.49	8.17	-0.32	8.45	-0.03
28	Internal	11.73	11.61	-0.12	11.98	0.25
29	Internal	5.99	5.95	-0.04	6.17	0.18
30	Internal	14.27	13.02	-1.25	12.61	-1.66
31	Internal	9.64	9.70	0.06	9.68	0.03
32	Internal	9.77	9.31	-0.46	9.81	0.04
33	Cordon	8.40	8.37	-0.03	8.43	0.04
34	Cordon	8.79	8.72	-0.08	8.92	0.13
35	Cordon	11.35	10.95	-0.40	10.92	-0.42
36	Cordon	19.92	17.18	-2.74	16.60	-3.32
37	Cordon	10.47	11.05	0.59	10.88	0.41
38	Cordon	10.40	10.42	0.02	10.41	0.00
39	Cordon	19.85	17.71	-2.14	17.45	-2.40
41	Cordon	6.48	6.68	0.20	6.78	0.30
42	Cordon	4.64	4.59	-0.06	4.72	0.08
43	Cordon	12.42	12.07	-0.35	12.11	-0.30
44	Cordon	18.96	16.31	-2.65	15.33	-3.63
45	Cordon	8.82	8.86	0.04	8.84	0.02
46	Internal	8.48	8.54	0.06	8.88	0.39
47	Cordon	12.14	11.64	-0.49	12.46	0.32
48	Internal	8.91	8.67	-0.24	9.31	0.40

TRAVEL TIME COMPARISON, AM PEAK HOUR

ZONE ID	ZONE TYPE	Average Travel Time (min)				
		Base	Option 1	Change	Option 2	Change
49	Cordon	12.14	10.66	-1.48	10.87	-1.27
50	Cordon	8.53	8.41	-0.12	8.76	0.23
51	Cordon	7.56	7.64	0.07	7.86	0.29
52	Internal	6.53	6.43	-0.10	6.69	0.16
53	Cordon	9.29	9.29	0.00	9.56	0.28
56	Cordon	12.48	12.47	0.00	12.48	0.01
57	Internal	8.46	8.21	-0.25	7.99	-0.46
58	Cordon	15.63	17.25	1.62	16.42	0.79
59	Cordon	11.88	11.35	-0.52	11.40	-0.48
60	Cordon	16.05	16.72	0.67	17.02	0.97
61	Cordon	9.11	8.96	-0.15	9.11	0.00
62	Internal	7.20	7.02	-0.18	7.12	-0.07
63	Cordon	18.91	15.44	-3.47	15.30	-3.61
64	Cordon	15.79	15.41	-0.38	15.48	-0.32
65	Cordon	2.81	2.80	-0.01	2.79	-0.02
66	Cordon	12.15	12.09	-0.06	12.16	0.01
67	Cordon	15.40	14.65	-0.75	14.70	-0.70
68	Cordon	13.66	13.48	-0.18	13.60	-0.06
69	Cordon	14.23	13.65	-0.58	13.68	-0.54
70	Cordon	13.54	12.66	-0.87	12.60	-0.94
71	Cordon	10.60	10.28	-0.32	10.39	-0.21
1006	Cordon	8.05	8.06	0.02	8.02	-0.03
1008	Cordon	10.76	10.82	0.07	10.88	0.12
1025	Cordon	14.18	13.53	-0.65	13.15	-1.03
1026	Internal	7.94	7.16	-0.78	7.30	-0.64
1027	Internal	4.02	4.01	-0.01	4.04	0.02
1028	Internal	12.24	10.45	-1.79	10.37	-1.87
1029	Internal	15.11	14.38	-0.73	14.54	-0.56
1030	Internal	5.68	5.73	0.05	5.78	0.10
1031	Internal	6.41	5.89	-0.51	5.77	-0.64
1032	Internal	7.49	7.49	0.00	9.50	2.01
1033	Internal	8.40	7.21	-1.19	7.49	-0.91
1035	Internal	8.15	7.99	-0.15	8.13	-0.01
TOTAL		**10.64**	**10.00**	**-0.64**	**10.02**	**-0.62**
CHANGE	MAX		2.79		2.01	
	# of Zones > 1 min		3		5	
	# of Zones > 2 min		1		1	
ZONE TYPE	Internal-Internal	6.86	6.49	-0.36	6.69	-0.17
	Internal-External	11.33	10.89	-0.44	11.19	-0.14
	External-Internal	6.08	6.05	-0.03	6.11	0.03
	External-External	18.38	16.56	-1.82	16.20	-2.18

TRAVEL TIME COMPARISON, PM PEAK HOUR

ZONE ID	ZONE TYPE	Average Travel Time (min)						
		Base	Option 1	Change	Option 2	Change	Option 3	Change
1	Internal	3.30	3.29	-0.01	3.32	0.02	3.26	-0.04
2	Internal	4.92	4.96	0.04	5.03	0.11	4.85	-0.07
3	Internal	5.14	5.08	-0.06	5.12	-0.02	5.06	-0.08
4	Internal	5.66	5.71	0.06	6.04	0.38	5.83	0.17
5	Internal	7.54	7.12	-0.42	7.82	0.28	6.87	-0.67
6	Internal	8.89	8.85	-0.04	11.70	2.81	9.27	0.38
7	Internal	9.96	10.25	0.29	10.64	0.68	9.58	-0.37
8	Internal	8.36	8.72	0.36	8.79	0.43	8.42	0.06
9	Internal	9.79	10.02	0.23	10.93	1.14	10.22	0.43
10	Internal	7.85	7.93	0.09	9.59	1.74	7.64	-0.21
11	Internal	9.04	8.73	-0.31	8.44	-0.59	7.90	-1.13
12	Internal	8.78	8.16	-0.62	8.71	-0.07	8.02	-0.77
13	Internal	7.01	7.07	0.06	7.14	0.13	7.03	0.02
14	Internal	7.68	7.57	-0.10	7.84	0.16	7.48	-0.20
15	Internal	7.11	6.97	-0.14	7.17	0.06	6.99	-0.12
16	Internal	7.92	7.82	-0.10	7.94	0.02	7.92	0.00
17	Internal	6.93	7.05	0.12	7.42	0.49	7.01	0.08
18	Internal	7.86	7.83	-0.03	8.44	0.59	7.94	0.08
19	Internal	7.44	7.52	0.08	7.66	0.22	7.40	-0.04
20	Internal	8.64	8.56	-0.08	8.78	0.14	8.47	-0.17
21	Internal	8.43	8.20	-0.24	8.35	-0.08	8.23	-0.20
22	Internal	7.65	7.60	-0.05	8.17	0.52	7.62	-0.03
23	Internal	8.22	7.99	-0.23	8.83	0.61	8.00	-0.21
24	Internal	7.73	7.75	0.03	8.02	0.29	7.80	0.07
25	Internal	7.28	7.49	0.22	8.99	1.71	7.14	-0.13
26	Internal	7.08	7.10	0.02	8.10	1.02	6.92	-0.16
27	Internal	8.03	7.80	-0.24	7.83	-0.20	7.82	-0.22
28	Internal	9.18	8.66	-0.52	9.19	0.01	8.98	-0.20
29	Internal	7.85	7.21	-0.64	7.81	-0.04	7.18	-0.67
30	Internal	9.71	9.83	0.11	10.61	0.90	10.40	0.69
31	Internal	8.80	8.92	0.12	9.09	0.29	8.81	0.01
32	Internal	9.92	9.51	-0.40	11.11	1.19	9.37	-0.55
33	Cordon	18.38	17.55	-0.82	14.22	-4.16	16.97	-1.40
34	Cordon	11.18	10.44	-0.74	9.35	-1.83	10.20	-0.98
35	Cordon	12.31	11.82	-0.49	16.26	3.94	12.35	0.04
36	Cordon	10.05	10.05	0.00	13.51	3.46	10.06	0.01
37	Cordon	7.26	7.25	-0.01	7.27	0.01	7.24	-0.02
38	Cordon	11.93	11.42	-0.52	11.96	0.02	11.23	-0.70
39	Cordon	11.97	11.91	-0.06	14.42	2.45	11.91	-0.06
41	Cordon	6.70	6.63	-0.07	6.63	-0.07	6.55	-0.15
42	Cordon	3.70	3.72	0.02	3.83	0.13	3.64	-0.06
43	Cordon	11.29	11.22	-0.06	13.47	2.18	11.32	0.04
44	Cordon	14.75	14.76	0.02	15.55	0.81	14.95	0.21
45	Cordon	9.89	10.58	0.69	10.46	0.58	10.33	0.44
46	Internal	6.68	6.74	0.06	6.84	0.16	6.74	0.07
47	Cordon	10.80	10.50	-0.30	11.02	0.22	10.58	-0.22

TRAVEL TIME COMPARISON, PM PEAK HOUR

ZONE ID	ZONE TYPE	Average Travel Time (min)						
		Base	**Option 1**	**Change**	**Option 2**	**Change**	**Option 3**	**Change**
48	Internal	8.21	8.03	-0.19	8.50	0.29	8.06	-0.15
49	Cordon	8.33	8.45	0.12	8.45	0.12	8.41	0.08
50	Cordon	10.11	9.91	-0.21	11.06	0.94	9.88	-0.23
51	Cordon	7.19	7.08	-0.11	7.27	0.08	7.09	-0.10
52	Internal	6.57	6.42	-0.15	6.95	0.38	6.45	-0.12
53	Cordon	8.55	8.36	-0.19	8.59	0.04	8.38	-0.17
56	Cordon	15.58	15.90	0.31	15.89	0.30	15.83	0.25
57	Internal	5.32	6.06	0.74	6.81	1.49	5.56	0.24
58	Cordon	8.54	8.77	0.24	9.42	0.89	8.59	0.06
59	Cordon	12.43	12.30	-0.12	12.22	-0.21	12.33	-0.09
60	Cordon	11.65	11.13	-0.52	11.77	0.12	11.51	-0.14
61	Cordon	7.53	7.43	-0.10	7.45	-0.08	7.48	-0.05
62	Internal	6.63	6.55	-0.08	7.08	0.45	6.23	-0.40
63	Cordon	12.48	12.60	0.12	15.29	2.81	12.59	0.11
64	Cordon	20.86	20.40	-0.45	19.01	-1.84	20.57	-0.29
65	Cordon	2.62	2.62	0.00	2.62	0.00	2.62	0.00
66	Cordon	10.14	10.11	-0.03	10.86	0.72	10.14	0.00
67	Cordon	14.87	15.16	0.29	17.09	2.22	16.83	1.96
68	Cordon	14.39	13.95	-0.44	14.12	-0.27	13.96	-0.43
69	Cordon	14.29	14.34	0.05	14.82	0.53	14.37	0.09
70	Cordon	14.69	14.56	-0.12	16.07	1.38	14.47	-0.22
71	Cordon	11.22	11.26	0.04	11.36	0.14	11.38	0.16
1006	Cordon	11.94	11.82	-0.12	12.15	0.22	11.31	-0.63
1008	Cordon	10.48	10.32	-0.16	10.70	0.21	10.21	-0.27
1025	Cordon	13.01	12.62	-0.38	13.60	0.59	13.23	0.22
1026	Internal	6.85	6.89	0.05	7.70	0.85	6.88	0.03
1027	Internal	1.60	1.60	0.00	1.60	0.00	1.60	0.00
1028	Internal	9.13	9.01	-0.12	10.39	1.26	9.00	-0.13
1029	Internal	7.03	6.91	-0.12	7.19	0.16	6.85	-0.17
1030	Internal	4.32	4.33	0.01	4.89	0.57	5.18	0.85
1031	Internal	7.36	7.16	-0.21	7.50	0.14	6.82	-0.54
1032	Internal	6.60	6.53	-0.07	7.13	0.53	6.04	-0.56
1033	Internal	14.64	14.38	-0.26	14.22	-0.42	13.30	-1.34
1035	Internal	8.49	8.30	-0.19	12.22	3.73	8.82	0.33
TOTAL		**9.56**	**9.43**	**-0.13**	**9.93**	**0.36**	**9.41**	**-0.15**
CHANGE	MAX		0.74		3.94		1.96	
	# of Zones > 1 min		0		16		1	
	# of Zones > 2 min		0		8		0	
ZONE TYPE	Internal-Internal	6.30	6.19	-0.11	6.55	0.24	6.11	-0.19
	Internal-External	7.53	7.53	0.00	8.22	0.69	7.47	-0.06
	External-Internal	7.20	7.08	-0.12	7.46	0.26	7.00	-0.20
	External-External	16.39	16.08	-0.31	16.56	0.16	16.22	-0.17

APPENDIX K

Suggested Intersection Improvements for Ramp Management Option 2

1. Hazelwood/Murray – Revise pavement markings to provide a SB right-turn lane on Murray.

On-street parking exists on the southbound lane of Murray Ave. In order to create a right-turn lane, some of the parking would need to be removed.

2. Greenfield/Saline – Remove NB left-turn phase. Construct WB left-turn lane.

Currently, there is only one westbound lane on Greenfield Ave. However, there appears to be enough room to re-stripe for two westbound lanes (one left-turn and one thru/right). Below is a photo of westbound approach to the intersection (On Greenfield Ave).

3. Greenfield/Hazelwood – Construct traffic signal.

There do not appear to be any problems with constructing a traffic signal at this intersection.

4. Swissvale/Race – Revise pavement markings to provide EB right-turn lane on Race St. Construct traffic signal.

This is a picture looking Eastbound on Race St. Currently, there already are two lanes designated by pavement markings (one thru/left and one right-turn).

There do not appear to be any problems with constructing a traffic signal at this intersection.

5. Swissvale/Ross – Construct NB right-turn lane on Swissvale.

There appears to be enough room to re-stripe the northbound Swissvale Ave approach to include a thru/left-turn lane and a right-turn lane. Below is a photo of the northbound approach on Swissvale Ave.

6. Ardmore/Brinton – Construct NB right-turn lane on Brinton.

There appears to be enough room with the wide shoulder at the northbound approach on Brinton Rd to construct an additional right-turn lane. Below is a photo of the northbound intersection approach on Brinton Rd.

7. Hobart/Shady – Construct traffic signal.

There do not appear to be any problems with constructing a traffic signal at this intersection.

8. Ardmore/Swissvale – Revise pavement markings to provide WB thru lane and WB thru- right-lane on Ardmore.

Currently, there is only one lane on westbound Admore Blvd. On the other side of the intersection, there are two receiving lanes (although they are not striped).

However, there is some parking on this street, which reduces it to one lane. Parking may have to be restricted along Ardmore Blvd westbound. There appears to be enough room at the westbound approach to stripe two lanes. Below is a photo of the intersection, looking eastbound along Ardmore Blvd.

10. Boulevard of the Allies/Dawson – Revise pavement markings to provide NB right-turn lane on Dawson.

The northbound approach on Dawson St is a one-way street with parking on both sides of the street. There appears to be enough room to re-stripe to allow for a thru/left lane and a right-turn lane. Some parking may have to be removed. Below is a picture of the northbound approach to the intersection on Dawson St.

10. Brashear/Braddock – Construct traffic signal.

There do not seem to be any problems with constructing a traffic signal at this intersection.

11. Fifth/Bellefield – Revise pavement markings to provide three WB lanes and one egress lane on Fifth Avenue.

Currently, there are three westbound lanes and two eastbound lanes through this intersection. The photo above is looking at the westbound approach to the intersection. This section of roadway between Fifth/Bellefield and Fifth/Dithridge can be converted into four westbound lanes and one eastbound lane by re-striping.

12. Ardmore/South – sign for right-in/right-out on South with YIELD sign.

There do not seem to be any problems with adding these signs to the intersection. Below is a photo of the eastbound approach to the intersection on South Ave.

APPENDIX L

Cost Assumptions for Ramp Management System

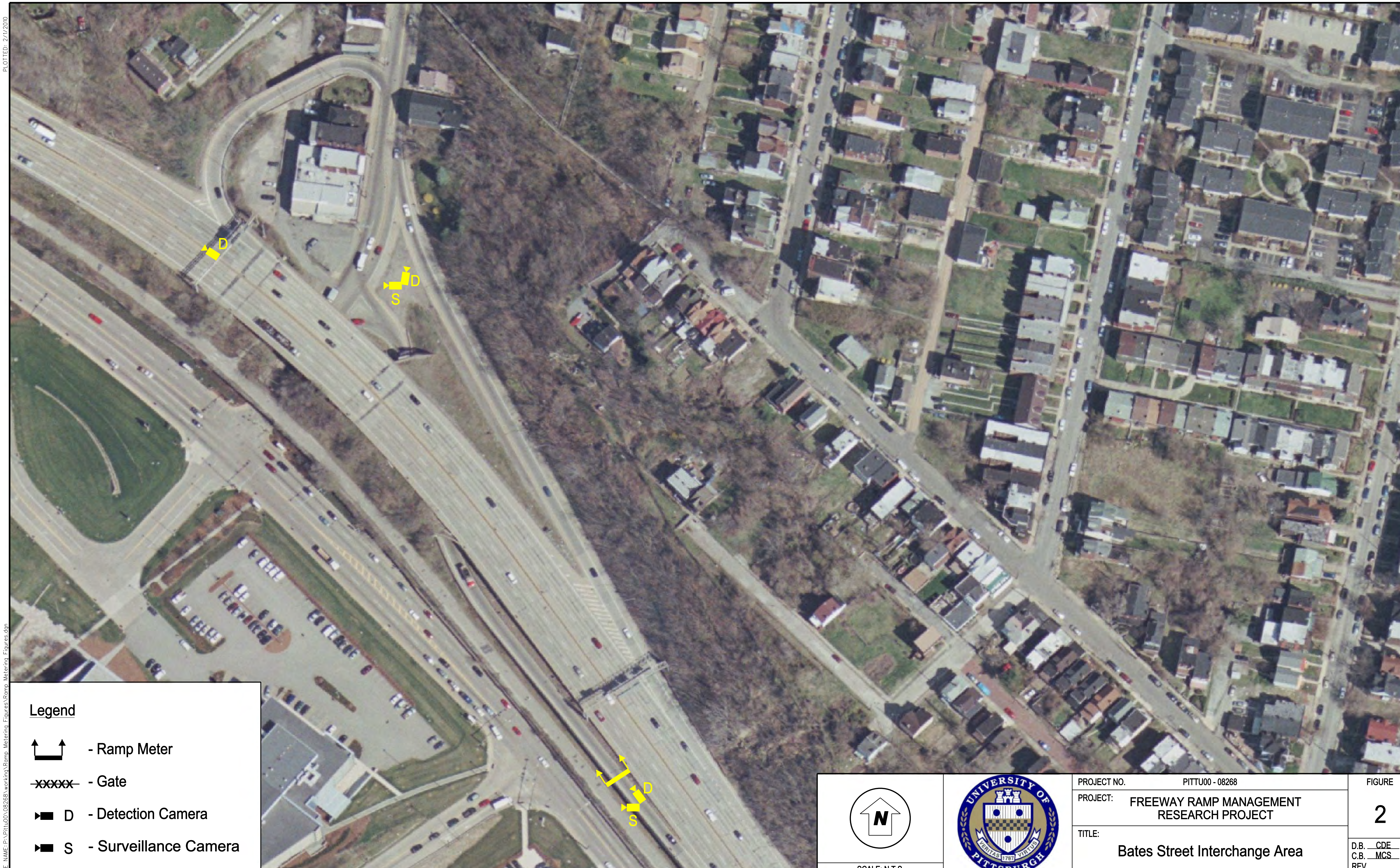
SCALE: N.T.S.

PROJECT NO.	PITTU00 - 08268
PROJECT:	FREEWAY RAMP MANAGEMENT RESEARCH PROJECT
TITLE:	Traffic Signal Locations and Fiber Optic Cable Run

FIGURE 1

D.B. CDE
C.B. MCS
REV.

PLOTTED: 2/1/2010



PROJECT NO. PITTU00 - 08268

PROJECT: FREEWAY RAMP MANAGEMENT RESEARCH PROJECT

TITLE: Bates Street Interchange Area

FIGURE 2

D.B. CDE
C.B. MCS
REV.

FILE NAME: P:\Pittu00\08268\working\Ramp Metering Figures\Ramp Metering Figures.dgn

Legend

- Ramp Meter
- Gate
- D - Detection Camera
- S - Surveillance Camera

SCALE: N.T.S.

PROJECT NO.	PITTU00 - 08268
PROJECT:	FREEWAY RAMP MANAGEMENT RESEARCH PROJECT
TITLE:	Squirrel Hill Interchange Area
FIGURE	3
D.B.	CDE
C.B.	MCS
REV.	

PLOTTED: 2/1/2010

FILE NAME: P:\Pittu00\08268\working\Ramp Metering Figures\Ramp Metering Figures.dgn

PROJECT NO. PITTU00 - 08268

PROJECT: FREEWAY RAMP MANAGEMENT RESEARCH PROJECT

TITLE: Swissvale Interchange Area

FIGURE 4

D.B. CDE
C.B. MCS
REV.

Legend

- Ramp Meter
- Gate
- D - Detection Camera
- S - Surveillance Camera

PROJECT NO.	PITTU00 - 08268
PROJECT:	FREEWAY RAMP MANAGEMENT RESEARCH PROJECT
TITLE:	Forest Hills Interchange Area
FIGURE	5
D.B.	CDE
C.B.	MCS
REV.	

PLOTTED: 2/1/2010

FILE NAME: P:\Pittu00\08268\working\Ramp Metering Figures\Ramp Metering Figures.dgn

PROJECT NO. PITTU00 - 08268

PROJECT: FREEWAY RAMP MANAGEMENT RESEARCH PROJECT

TITLE: Churchill Area

FIGURE 6

D.B. CDE
C.B. MCS
REV.

PLOTTED: 2/1/2010

FILE NAME: P:\Pittu00\08268\working\Ramp Metering Figures\Ramp Metering Figures.dgn

Cost Assumptions for Ramp Management System

Interchange Ramp Meters and Closures Assumptions
Bates Street Interchange
Ramp meter system - $75,000 (includes controller, signals and all signal supports)
Cable and Conduit to connect to existing PennDOT system - $10,000 (assumes exiting fiber optic trunk line exists in the area. Cost reflects trench and cable to connect to existing trunk line)
Detection system - $30,000 (cameras and supports)

Squirrel Hill Interchange
Ramp meter and closure system - $125,000 (includes controller, gates, signals and all signal supports)
Cable and Conduit to connect to existing PennDOT system - $5,000 (assumes exiting fiber optic trunk line exists in the area. Cost reflects trench and cable to connect to existing trunk line
Detection system - $25,000 (cameras and supports)

Swissvale/Edgewood Interchange
Ramp meter and closure system - $325,000 (includes controller, signals, gates and all signal supports)
Cable and Conduit to connect to existing PennDOT system - $15,000 (assumes exiting fiber optic trunk line exists in the area. Cost reflects trench and cable to connect to existing trunk line)
Detection system - $45,000 (cameras and supports)

Forest Hills Interchange
Ramp meter and closure system - $200,000 (includes controller, signals, gates and all signal supports)
Cable and Conduit to connect to existing PennDOT system - $10,000 (assumes exiting fiber optic trunk line exists in the area. Cost reflects trench and cable to connect to existing trunk line)
Detection system - $45,000 (cameras and supports)

Churchill Interchange
Ramp meter system - $75,000 (includes controller, signals and all signal supports)
Cable and Conduit to connect to existing PennDOT system - $10,000 (assumes exiting fiber optic trunk line exists in the area. Cost reflects trench and cable to connect to existing trunk line)
Detection system - $25,000 (cameras and supports)

Total cost for ramp/closure systems at interchanges = $1,020,000 20% contingencies = $1,224,000.*

PennDOT TMC Upgrade Assumptions
Ramp metering/closure software and system integration = $200,000 (includes all hardware, software and training required for complete system)

Area traffic signal control software and system integration = $140,000 (includes all hardware, software and training for complete system)

*Total cost for TMC upgrades = $340,000*20% contingencies = $408,000*

Offline Costs

Assume that all traffic signals along local roadways that experience diverted traffic must be in communication with PennDOT TMC so timings can be changed by operator at TMC. This will require the installation of approximately 20 miles of new fiber optic cable. Assume that 80 percent of this cable can be installed overhead.

- Installation of fiber optic cable = 16 miles overhead * $18,000 per mile = $288,000
- Installation of fiber optic cable = 4 miles underground *$32,000 per mile = $128,000
- Total cost for fiber installation = $416,000

Assume that on the local roadway network, 72 signalized intersections will need to be upgraded or at a minimum retimed for optimal efficiency. Using the SPC percentages contained in their signal retiming project, 24% of the existing area traffic signals will only need retimed, while 76% will also require controller upgrades.

- Retiming costs – 18 intersections *$1,000 = $18,000
- Retiming and controller upgrades – 54 intersections*$10,000 = $540,000
- Total cost for signalized upgrades = $558,000

Surveillance system (installation of cameras along major arterials) - $75,000

New traffic signal/intersection restriping
For 4 new traffic signals, assuming $150,000 per installation, budget $600,000. Add 50,000 for intersection restriping at 12 locations. Total cost of $650,000 for offline improvements.

1. Hazelwood/Murray – Revise pavement markings and remove parking to provide a SB right-turn lane on Murray.
2. Greenfield/Saline – Remove NB left-turn phase and construct WB left-turn lane.
3. Greenfield/Hazelwood – Construct traffic signal.
4. Swissvale/Race – Construct traffic signal
5. Swissvale/Ross – Stripe a NB right-turn lane on Swissvale.
6. Ardmore/Brinton – Stripe shoulder to provide a NB right-turn lane on Brinton.
7. Hobart/Shady – Construct traffic signal.
8. Penn/Swissvale – Revise pavement markings to provide WB thru lane and WB thru- right-lane on Penn. Parking may have to be restricted along Penn Avenue westbound.
9. Boulevard of the Allies/Dawson – Revise pavement markings to provide NB right-turn lane on Dawson. Some parking may have to be removed.
10. Brashear/Braddock – Construct traffic signal.
11. Fifth/Bellefield – Revise pavement markings to provide four WB lanes and one egress lane on Fifth Avenue.
12. Ardmore/South – sign for right-in/right-out on South with YIELD sign.

*Total cost for local traffic signal upgrades = $416,000 (fiber installation) + $558,000 (signalized upgrades)+ $75,000 (surveillance system) + $650,000 (offline improvements) =$1,699,000*20% contingencies = $2,038,800.*

APPENDIX M

Benefit Cost Analysis Worksheets

Known Data

AM DATA for I-376				
	Base	Option 1	Option 2	Option 3
Avg Delay EB (sec)	125.78	134.18	135.24	125.78
Avg Delay WB (sec)	520.46	443.76	186.3	520.46
Total Delay (sec)	646.24	577.94	321.54	646.24
Throughput EB (veh)	316.8	316.8	316.8	316.8
Throughput WB (veh)	1731.2	1731.2	1995.2	1731.2
Total Throughput (veh)	2048	2048	2312	2048
AM Avg Change in Delay		68.3	324.7	0

PM DATA for I-376				
	Base	Option 1	Option 2	Option 3
Avg Delay EB (sec)	670	670	417.6	558.2
Avg Delay WB (sec)	75	75	75	75
Total Delay (sec)	745	745	492.6	633.2
Throughput EB (veh)	1612	1612	1840	1724
Throughput WB (veh)	1296	1296	1296	1296
Total Throughput (veh)	2908	2908	3136	3020
PM Avg Change in Delay		0	252.4	111.8

% Trucks = 9% (from PennDOT iTMS data, base year 2010)

Value of Time Savings Due to Delay Reduction (Eq 5-2)

H(D) = (D0-D1)/3600*(V0+V1)/2*M*O

O (Avg Vehicle Occupancy)*** =	1.12	(assumed)	Census Data***	
			Drove alone to Work:	410840
			Carpooled to Work:	56556

Inflation** 30.46%

M = Value of Time

	Cars	Trucks
% of Wage/Comp*:	50%	100%
Wage/Comp in 2000*:	$18.56	$20.23
Wage/Comp in 2011*:	$24.21	$26.39
M (Value of Time):	$12.11	$26.39

* Wage and Compensation info taken from Table 5-1 and Table 5-2 in the AASHTO User Benefit Analysis for Highways Handbook.

** Based on data obtained from www.inflationdata.com, an inflation rate was used to bring the 2000 data found in Table 5-17 of AASHTO User Benefit Analysis for Highways up to a 2011 value. The inflation rate was calculated from Jan 2000 to Jan 2011.

*** Average Vehicle Occupancy was determined through Census (2005-2009 Average) data. According to the data, 410,840 workers commuted to work alone and 56,556 worked commuted in a carpool. Information was not given on the average number of people per carpool, so it was assumed to be 2.

	Change in Delay (sec)	Throughput (base)	Throughput	Value of Time	Total Value of Time Savings per Peak Hour
AM Option 1 Car	68.30	1863.68	1863.68	$12.11	$479.87
AM Option 1 Truck	68.30	184.32	184.32	$26.39	$103.46
PM Option 1 Car	0.00	2646.28	2646.28	$12.11	$0.00
PM Option 1 Truck	0.00	261.72	261.72	$26.39	$0.00
AM Option 2 Car	324.70	1863.68	2103.92	$12.11	$2,428.34
AM Option 2 Truck	324.70	184.32	208.08	$26.39	$523.55
PM Option 2 Car	252.40	2646.28	2853.76	$12.11	$2,616.70
PM Option 2 Truck	252.40	261.72	282.24	$26.39	$564.16
AM Option 3 Car	0.00	1863.68	1863.68	$12.11	$0.00
AM Option 3 Truck	0.00	184.32	184.32	$26.39	$0.00
PM Option 3 Car	111.80	2646.28	2748.2	$12.11	$1,136.82
PM Option 3 Truck	111.80	261.72	271.8	$26.39	$245.10

Total Value of Time Savings per Peak Hour

	(A)	(B)	(A)+(B)
	Cars	Trucks	Total
AM Option 1	$479.87	$103.46	$583.33
PM Option 1	$0.00	$0.00	$0.00
AM Option 2	$2,428.34	$523.55	$2,951.89
PM Option 2	$2,616.70	$564.16	$3,180.87
AM Option 3	$0.00	$0.00	$0.00
PM Option 3	$1,136.82	$245.10	$1,381.92

Total Value of Time Savings per Day

	% of Peak*	Option 1	Option 2	Option 3
1 hour before AM Peak	73.37%	$427.99	$2,165.80	$0.00
AM Peak Hour	100.00%	$583.33	$2,951.89	$0.00
1 hour after AM Peak	92.80%	$541.33	$2,739.35	$0.00
2nd hour after AM Peak	77.44%	$451.73	$2,285.94	$0.00
2 hours before PM Peak	98.21%	$0.00	$3,123.93	$1,357.18
1 hour before PM Peak	95.97%	$0.00	$3,052.68	$1,326.22
PM Peak Hour	100.00%	$0.00	$3,180.87	$1,381.92
1 hour after PM Peak	88.61%	$0.00	$2,818.56	$1,224.52
	SUM ($/day):	$2,004.37	$22,319.03	$5,289.83

* % of Peak is derived from PennDOT ATR counts

Total Value of Time Savings per Year

	Option 1	Option 2	Option 3
$ per Weekday	$2,004.37	$22,319.03	$5,289.83
$ per Week	$10,021.85	$111,595.13	$26,449.17
$ per Year**	$501,092.56	$5,579,756.65	$1,322,458.61
25 additional peak AM hours	$14,583.18	$73,797.27	$0.00
25 additional peak PM hours	$0.00	$79,521.64	$34,547.89
Total Travel Time Savings per Year ($)	$515,675.73	$5,733,075.56	$1,357,006.49

** 5 days a week, 52 weeks a year. Minus 10 assumed federal holidays per year.

Fuel Cost Savings Due to Delay Reduction (Eq 5-5)

C(D) = gal/min * (D0-D1) *Pgas

Fuel Consumption Cars (Table 5-6) =	0.054		
Fuel Consumption Trucks (Table 5-6) =	0.578		
Fuel Price per Gallon Cars ($) =	$3.50	(C)	(Pittsburgh average price from fueleconomy.gov on 3/6/11)
Fuel Price per Gallon Trucks ($) =	$4.07	(C)	(Pittsburgh average price from fueleconomy.gov on 3/6/11)

	(A)	(B)	(D) = (A)*(B)*(C)	(E)	(D)*(E)
	Change in Delay (min)	Fuel Consumption (gal/min)	Savings per veh ($)	Throughput	Total Savings per peak hour ($)
AM Option 1 Car	1.14	0.054	$0.22	1863.68	$400.96
AM Option 1 Truck	1.14	0.578	$2.68	184.32	$493.59
PM Option 1 Car	0.00	0.054	$0.00	2646.28	$0.00
PM Option 1 Truck	0.00	0.578	$0.00	261.72	$0.00
AM Option 2 Car	5.41	0.054	$1.02	2103.92	$2,151.90
AM Option 2 Truck	5.41	0.578	$12.73	208.08	$2,649.01
PM Option 2 Car	4.21	0.054	$0.80	2853.76	$2,268.91
PM Option 2 Truck	4.21	0.578	$9.90	282.24	$2,793.05
AM Option 3 Car	0.00	0.054	$0.00	1863.68	$0.00
AM Option 3 Truck	0.00	0.578	$0.00	184.32	$0.00
PM Option 3 Car	1.86	0.054	$0.35	2748.2	$967.83
PM Option 3 Truck	1.86	0.578	$4.38	271.8	$1,191.41

Inventory Savings Due to Delay Reduction (Eq 5-13)

I(D) = 100 * r/8760/60*Pcargo*(D0-D1)
r= 5% (B)
Pcargo = $200,000 (C)

	(A)	(D) = (A)*(B)*(C)	(E)	(D)*(E)
	Change in Delay (min)	Savings per veh (cents)	Throughput	Total Savings per peak hour ($)
AM Option 1	1.14	2.17	2048	$44.36
PM Option 1	0.00	0.00	2908	$0.00
AM Option 2	5.41	10.30	2312	$238.05
PM Option 2	4.21	8.00	3136	$250.99
AM Option 3	0.00	0.00	2048	$0.00
PM Option 3	1.86	3.55	3020	$107.06

Capital Cost Savings Due to Delay Reduction (Eq 5-9)

PMT(D)= PMT*(100)/365/24/60*(D0-D1)

Pveh (Price $)=	$20,000
r (int rate) =	0.05
L (life in yrs) =	10
SV (Salvage $) =	$0

PMT = Pveh*r*[(1+r)^L-SV]/[(1+r)^L-1]

PMT = $2,590.09 (B)

	(A)	(C) = (A)*(B)*100 /365/24/60	(D)	(C)*(D)
	Change in Delay (min)	Savings per veh (cents)	Throughput	Savings per peak hour ($)
AM Option 1	1.14	0.56	2048	$11.49
PM Option 1	0.00	0.00	2908	$0.00
AM Option 2	5.41	2.67	2312	$61.66
PM Option 2	4.21	2.07	3136	$65.01
AM Option 3	0.00	0.00	2048	$0.00
PM Option 3	1.86	0.92	3020	$27.73

Total Operating and Ownership Costs per Peak Hour

	(A) Fuel ($)	(B) Inventory ($)	(C) Capital ($)	(A)+(B)+(C) Total ($)
AM Option 1	$894.55	$44.36	$11.49	$950.39
PM Option 1	$0.00	$0.00	$0.00	$0.00
AM Option 2	$4,800.91	$238.05	$61.66	$5,100.61
PM Option 2	$5,061.96	$250.99	$65.01	$5,377.96
AM Option 3	$0.00	$0.00	$0.00	$0.00
PM Option 3	$2,159.25	$107.06	$27.73	$2,294.04

Total Operating and Ownership Costs per Day

	% of Peak*	Option 1	Option 2	Option 3
1 hour before AM Peak	73.37%	$697.30	$3,742.32	$0.00
AM Peak Hour	100.00%	$950.39	$5,100.61	$0.00
1 hour after AM Peak	92.80%	$881.96	$4,733.37	$0.00
2nd hour after AM Peak	77.44%	$735.98	$3,949.92	$0.00
2 hours before PM Peak	98.21%	$0.00	$5,281.70	$2,252.98
1 hour before PM Peak	95.97%	$0.00	$5,161.23	$2,201.59
PM Peak Hour	100.00%	$0.00	$5,377.96	$2,294.04
1 hour after PM Peak	88.61%	$0.00	$4,765.41	$2,032.75
	SUM ($/day):	$3,265.64	$38,112.52	$8,781.36

* % of Peak is derived from PennDOT ATR counts

Total Operating and Ownership Costs per Year

	Option 1	Option 2	Option 3
$ per Weekday	$3,265.64	$38,112.52	$8,781.36
$ per Week	$16,328.22	$190,562.60	$43,906.79
$ per Year**	$816,410.90	$9,528,130.24	$2,195,339.42
25 additional peak AM hours	$23,759.81	$127,515.35	$0.00
25 additional peak PM hours	$0.00	$134,449.05	$57,351.01
Total $ Saved in Operating Costs per Yr	$840,170.72	$9,790,094.65	$2,252,690.43

** 5 days a week, 52 weeks a year. Minus 10 assumed federal holidays per year.

Annual Crash Cost Savings

Relevant Crash Data: Jan 1, 2006 to Dec 31, 2008

	Option 1/2	Option 3
# of Fatal Crashes:	2	0
# Injury Crashes:	146	52
# Prop Damage Crashes:	178	66

Average Relevant # of Crashes per Year (/3)

	Option 1/2	Option 3
# of Fatal Crashes:	0.67	0.00
# Injury Crashes:	48.67	17.33
# Prop Damage Crashes:	59.33	22.00

Inflation Rate* (From 2000 to 2011): 30.46%

Change in Crash Costs (Eq 5-31)

Change in Crash Costs = Vi*I + Vd*D + Vp*P

	Year 2000 $*	(E) Year 2011 $*
Vd (Value of Fatal Crashes) =	3723700.00	4857939.02
Vi (Value of Injury Crashes) =	108600.00	141679.56
Vp (Value of Prop Damage Crashes) =	200.00	260.92

Assumed that the delay cost of a crash is included in the Net Perceived User Cost.

OPTION 1 AND 2

Crash Type	(A) Relevant Crashes/year BASE (Option 1 and 2)**	(B) Expected Crash Reduction** %	(C) = (A)-(A*B) Relevant Crashes/year With Improvement (Option 1 and 2)	(D) = (A)-(C) Change in expected number of crashes	(E) Net Perceived User Cost in 2011 per crash* ($)	(D)*(E) Total Change in Crash Costs ($)
Fatal	0.67	33%	0.45	0.22	4857939.02	1068746.58
Injury	48.67	33%	32.61	16.06	141679.56	2275373.73
Prop Damage	59.33	33%	39.75	19.58	260.92	5108.81

Total Crash Savings: $3,349,229.13

OPTION 3

Crash Type	(A) Relevant Crashes/year BASE (Option 3)**	(B) Expected Crash Reduction** %	(C) = (A)-(A*B) Relevant Crashes/year With Improvement (Option 1 and 2)	(D) = (A) - (C) Change in expected number of crashes	(E) Net Perceived User Cost in 2011 per crash* ($)	(D) * (E) Total Change in Crash Costs ($)
Fatal	0.00	33%	0.00	0.00	4857939.02	0.00
Injury	17.33	33%	11.61	5.72	141679.56	810407.08
Prop Damage	22.00	33%	14.74	7.26	260.92	1894.28

Total Crash Savings: $812,301.36

* Based on data obtained from www.inflationdata.com, an inflation rate was used to bring the 2000 data found in Table 5-17 of AASHTO User Benefit Analysis for Highways up to the 2011 value of the crash data. The inflation rate was calculated from Jan 2000 to Jan 2011.

** Crash Reduction percentages based on the information found in "Intelligent Transportation Systems Benefit: 2001 Report" by AASHTO. Value used is the national average. Option 1 and Option 2 use the number of crashes within the limits of the ramp metering from the data given by PennDOT. Option 3 uses the number of crashes from the Beechwood Blvd onramp to the tunnel.

TOTAL YEARLY BENEFITS

	Option 1	Option 2	Option 3
Value of Time Savings	$515,675.73	$5,733,075.56	$1,357,006.49
Operating and Ownership Cost Savings	$840,170.72	$9,790,094.65	$2,252,690.43
Crash Cost Savings	$3,349,229.13	$3,349,229.13	$812,301.36
Total Yearly Savings	$4,705,075.58	$18,872,399.34	$4,421,998.29

Present Value Formula (Incorporating Risk Premia in the Discount Rate) Eq 6-16

PV = SUM (from t=0 to t=n) [(B-C)t/(1+d+r)^t + An/(1+d+r)^n]

(B-C)t = net benefit stream in period t
d = risk-free real discount rate
r = assumed risk premium
An = terminal asset value of the project
n = terminal year of the project

d = 0.035
r = 0.03
An = 0
n = 17

	Option 1	Option 2	Option 3
Capital Cost*	3253500	4588500	632750
Yearly Op and Maint Cost*	40000	40000	5000

*Capital Cost and Operating/Maintenance Costs taken from Freeway Ramp Management Research Project Draft Report

OPTION 1

	Year (t)	Cap Costs ($)	Op and Maint Costs ($)	Benefits ($)	B-C	PV	PV of Benefits	PV of Costs
Design / Construction Period	0	$1,084,500	$0	$0	-$1,084,500	-1084500	0	1084500
	1	$1,084,500	$0	$0	-$1,084,500	-1018309.859	0	1018309.86
	2	$1,084,500	$0	$0	-$1,084,500	-956159.4922	0	956159.492
Service Yr 1	3	$0	$40,000	$4,705,076	$4,665,076	3861978.583	3895092.55	33113.9637
Service Yr 2	4	$0	$40,000	$4,705,076	$4,665,076	3626270.97	3657363.89	31092.9236
Service Yr 3	5	$0	$40,000	$4,705,076	$4,665,076	3404949.267	3434144.5	29195.2335
Service Yr 4	6	$0	$40,000	$4,705,076	$4,665,076	3197135.462	3224548.83	27413.3648
Service Yr 5	7	$0	$40,000	$4,705,076	$4,665,076	3002005.129	3027745.38	25740.2486
Service Yr 6	8	$0	$40,000	$4,705,076	$4,665,076	2818784.159	2842953.41	24169.2475
Service Yr 7	9	$0	$40,000	$4,705,076	$4,665,076	2646745.689	2669439.82	22694.1291
Service Yr 8	10	$0	$40,000	$4,705,076	$4,665,076	2485207.219	2506516.26	21309.0414
Service Yr 9	11	$0	$40,000	$4,705,076	$4,665,076	2333527.906	2353536.4	20008.4896
Service Yr 10	12	$0	$40,000	$4,705,076	$4,665,076	2191106.015	2209893.33	18787.3142
Service Yr 11	13	$0	$40,000	$4,705,076	$4,665,076	2057376.54	2075017.21	17640.6706
Service Yr 12	14	$0	$40,000	$4,705,076	$4,665,076	1931808.957	1948372.97	16564.0099
Service Yr 13	15	$0	$40,000	$4,705,076	$4,665,076	1813905.124	1829458.19	15553.061
Service Yr 14	16	$0	$40,000	$4,705,076	$4,665,076	1703197.3	1717801.11	14603.8131
Service Yr 15	17	$0	$40,000	$4,705,076	$4,665,076	1599246.291	1612958.79	13712.5006
					Net Present Value =	$35,614,275		
						Total :	39004842.6	3390567.36
						Benefit Cost Ratio:	**12 :1**	

OPTION 2

	Year (t)	Cap Costs ($)	Op and Maint Costs ($)	Benefits ($)	B-C	PV	PV of Benefits	PV of Costs
Design / Construction Period	0	$1,529,500	$0	$0	-$1,529,500	-1529500	0	1529500
	1	$1,529,500	$0	$0	-$1,529,500	-1436150.235	0	1436150.23
	2	$1,529,500	$0	$0	-$1,529,500	-1348497.873	0	1348497.87
Service Yr 1	3	$0	$40,000	$18,872,399	$18,832,399	15590384.69	15623498.7	33113.9637
Service Yr 2	4	$0	$40,000	$18,872,399	$18,832,399	14638858.86	14669951.8	31092.9236
Service Yr 3	5	$0	$40,000	$18,872,399	$18,832,399	13745407.38	13774602.6	29195.2335
Service Yr 4	6	$0	$40,000	$18,872,399	$18,832,399	12906485.81	12933899.2	27413.3648
Service Yr 5	7	$0	$40,000	$18,872,399	$18,832,399	12118766.01	12144506.3	25740.2486
Service Yr 6	8	$0	$40,000	$18,872,399	$18,832,399	11379123.02	11403292.3	24169.2475
Service Yr 7	9	$0	$40,000	$18,872,399	$18,832,399	10684622.55	10707316.7	22694.1291
Service Yr 8	10	$0	$40,000	$18,872,399	$18,832,399	10032509.44	10053818.5	21309.0414
Service Yr 9	11	$0	$40,000	$18,872,399	$18,832,399	9420196.656	9440205.15	20008.4896
Service Yr 10	12	$0	$40,000	$18,872,399	$18,832,399	8845255.076	8864042.39	18787.3142
Service Yr 11	13	$0	$40,000	$18,872,399	$18,832,399	8305403.828	8323044.5	17640.6706
Service Yr 12	14	$0	$40,000	$18,872,399	$18,832,399	7798501.247	7815065.26	16564.0099
Service Yr 13	15	$0	$40,000	$18,872,399	$18,832,399	7322536.382	7338089.44	15553.061
Service Yr 14	16	$0	$40,000	$18,872,399	$18,832,399	6875621.016	6890224.83	14603.8131
Service Yr 15	17	$0	$40,000	$18,872,399	$18,832,399	6455982.174	6469694.68	13712.5006
				Net Present Value =		$151,805,506		
						Total :	156451252	4645746.12
						Benefit Cost Ratio:	**34 :1**	

OPTION 3

	Year (t)	Cap Costs ($)	Op and Maint Costs ($)	Benefits ($)	B-C	PV	PV of Benefits	PV of Costs
Design / Construction Period	0	$210,917	$0	$0	-$210,917	-210916.6667	0	210916.667
	1	$210,917	$0	$0	-$210,917	-198043.8185	0	198043.818
	2	$210,917	$0	$0	-$210,917	-185956.6371	0	185956.637
Service Yr 1	3	$0	$5,000	$4,421,998	$4,416,998	3656608.024	3660747.27	4139.24546
Service Yr 2	4	$0	$5,000	$4,421,998	$4,416,998	3433434.764	3437321.38	3886.61545
Service Yr 3	5	$0	$5,000	$4,421,998	$4,416,998	3223882.408	3227531.81	3649.40418
Service Yr 4	6	$0	$5,000	$4,421,998	$4,416,998	3027119.632	3030546.3	3426.67059
Service Yr 5	7	$0	$5,000	$4,421,998	$4,416,998	2842365.851	2845583.38	3217.53107
Service Yr 6	8	$0	$5,000	$4,421,998	$4,416,998	2668888.123	2671909.28	3021.15594
Service Yr 7	9	$0	$5,000	$4,421,998	$4,416,998	2505998.238	2508835	2836.76614
Service Yr 8	10	$0	$5,000	$4,421,998	$4,416,998	2353049.989	2355713.62	2663.63018
Service Yr 9	11	$0	$5,000	$4,421,998	$4,416,998	2209436.609	2211937.67	2501.0612
Service Yr 10	12	$0	$5,000	$4,421,998	$4,416,998	2074588.365	2076936.78	2348.41427
Service Yr 11	13	$0	$5,000	$4,421,998	$4,416,998	1947970.296	1950175.38	2205.08382
Service Yr 12	14	$0	$5,000	$4,421,998	$4,416,998	1829080.09	1831150.59	2070.50124
Service Yr 13	15	$0	$5,000	$4,421,998	$4,416,998	1717446.094	1719390.23	1944.13262
Service Yr 14	16	$0	$5,000	$4,421,998	$4,416,998	1612625.44	1614450.92	1825.47664
Service Yr 15	17	$0	$5,000	$4,421,998	$4,416,998	1514202.291	1515916.35	1714.06257
					Net Present Value =	$36,021,779		
						Total :	36658146	636366.874

Benefit Cost Ratio: **58 :1**

Crash Data

Crash Data Dates: Jan 1, 2006 to Dec 31, 2008

Relevant Study Segments of I-376
Westbound: Squirrel Hill Tunnel to Bates St Interchange
odds 0055/0000 to 0091/0090

Eastbound: Bates St Interchange to Squirrel Hill Tunnel
evens 0030/0245 to 0055/0000

EB

Segment	Crash # Begin	Crash # End	Prop Damage	Injury	Fatal
30/0245	225	245	15	6	0
32					
34	270	285	9	7	0
36					
38					
40	292	308	12	5	0
40/2320 (Beechwood Blvd Ramp)	309	314	1	5	0
40/2536	315	320	3	3	0
42					
44	344	351	5	3	0
46					
48	358	451	54	40	0
50					
52					
54	483	486	3	1	0

WB

Segment	Crash # Begin	Crash # End	Prop Damage	Injury	Fatal
53					
55	487	502	9	7	0
57					
59					
61	533	558	17	9	0
63					
65	599	620	10	12	0
67					
69					
71	629	656	10	18	0
73					
75	665	688	11	12	1
77					
79					
81	710	724	7	8	0
83					
85	747	763	10	6	1
87					
89					
91/0090	781	786	2	4	0

Total Number of Relevant Crashes Per Option

	Prop Damage Only	Injury	Fatal
Option 1	178	146	2
Option 2	178	146	2
Option 3	66	52	0

ATR Data from Central Office

							AADT Per HR (Peak highlighted)																							
ID	Name	Comments	TMS Site #	Count Limi	Count Date	rection/La	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
33	:B, East of '	tunnel - en	38994		########	1	132	230	191	78	176	433	1500	2027	2085	2163	2105	2315	3060	2650	2351	3625	3703	3757	3080	2650	1556	1422	998	733
						2	280	41	121	198	478	801	1564	2046	2567	2166	1888	1847	2365	1681	3048	3610	3367	3610	3448	2644	2005	1403	921	682
						sum:	412	271	312	276	654	1234	3064	4073	4652	4329	3993	4162	5425	4331	5399	7235	7070	7367	6528	5294	3561	2825	1919	1415
							5.59%	3.68%	4.24%	3.75%	8.88%	16.75%	41.59%	55.29%	63.15%	58.76%	54.20%	56.50%	73.64%	58.79%	73.29%	98.21%	95.97%	100.00%	88.61%	71.86%	48.34%	38.35%	26.05%	19.21%
44	'B, West of ramps and		Traffic.Com Site #710(		2/5/2013	1	595	376	364	328	354	834	1889	2633	2476	2261	2205	2532	2544	2716	3475	4159	4335	4220	3045	2562	2171	1885	2104	1082
						2	436	293	253	360	755	2511	4471	5695	5252	4188	3197	2910	3177	2964	3269	3385	3709	3637	3497	2076	1847	1795	1424	818
						sum:	1031	669	617	688	1109	3345	6360	8328	7728	6449	5402	5442	5721	5680	6744	7544	8044	7857	6542	4638	4018	3680	3528	1900
							12.38%	8.03%	7.41%	8.26%	13.32%	40.17%	76.37%	100.00%	92.80%	77.44%	64.87%	65.35%	68.70%	68.20%	80.98%	90.59%	96.59%	94.34%	78.55%	55.69%	48.25%	44.19%	42.36%	22.81%

APPENDIX N

Intergovernmental Agreement Sample

Agreement No. ____________
SAP Vendor No. ____________
Federal ID No. ____________

COOPERATIVE MEMORANDUM OF AGREEMENT

This Cooperative Memorandum of Agreement (Agreement) entered into this ____ day of ____________, ______, by and between the Commonwealth of Pennsylvania, acting through its Department of Transportation, hereinafter referred to as the DEPARTMENT,

and

the ______________________________________, a political subdivision of the Commonwealth of Pennsylvania, with a mailing address of _________________, hereinafter referred to as MUNICIPALITY.

WITNESSETH:

WHEREAS, the DEPARTMENT and the Southeastern Pennsylvania Transportation Authority previously partnered in the undertaking of a multi-staged study to improve the flow of traffic along the Schuylkill Expressway corridor by building on the previous efforts of several regional transportation agencies and to produce a final Strategic Deployment Plan; and,

WHEREAS, the study, the "Schuylkill Expressway Corridor Transportation Systems Management" ("SECTSM Study") is intended to be utilized to improve communications and technology improvements within the Schuylkill Expressway (Expressway) corridor and to better inform vehicular and public transit travelers of traffic incidents and to improve multi-agency coordination and the management of daily traffic operations; and,

WHEREAS, the SECTSM Study will be used to effectuate upgrades and interconnecting signals between King of Prussia and Philadelphia and to further improve the flow of traffic on a daily basis as well as during incidents on the Expressway; and, WHEREAS, the area of the project will include the entire Expressway corridor from the Vine Street Expressway (Interstate 676) to the Pennsylvania Turnpike (I-276) and every municipality located within these parameters, including the City of Philadelphia, the Boroughs of Conshohocken, West Conshohocken, Norristown, Narberth, Bridgeport, and Townships of Whitemarsh, Plymouth, East Norriton, Lower Merion, Upper Merion, Radnor and Haverford; and,

WHEREAS, the DEPARTMENT and the MUNICIPALITY share a common interest in facilitating the safe and efficient management of traffic flow along state, county and locally-owned roadways parallel to the Expressway in the event of an incident and wish to coordinate and disseminate accurate travel condition information to area motorists and the traveling public; and,

WHEREAS, the DEPARTMENT and the MUNICIPALITY now wish to outline their respective functions and responsibilities in this Memorandum of Agreement (Agreement).

*When referred to collectively, the DEPARTMENT and the MUNCIPALITY are referred to as the Parties.

NOW, THEREFORE, for and in consideration of the foregoing premises and of the mutual promises set forth below, the DEPARTMENT and the MUNICIPALITY agree, with the intention of being legally bound, to the following:

1. The foregoing recitals are incorporated by reference as a material part of this Agreement.

2. DEPARTMENT personnel located within the DEPARTMENT's Traffic Control Center (TCC) located within the District 6-0 Building at 7000 Geerdes Boulevard, King of Prussia, PA will serve as the point of contact during an incident along the Expressway corridor. The DEPARTMENT will provide contact information directly to the

MUNICIPALITY. Communication between the DEPARTMENT and MUNICIPALITY will be achieved via telephone, where the TCC can be reached at 610-205-6934.

3. The MUNICIPALITY will provide and identify one point of contact to the DEPARTMENT. The MUNICIPALITY's point of contact will also be responsible for ensuring that vital information is disseminated to others within the MUNCIPALITY, the content of which will be subject to the discretion of ____________________ (municipal contact) within the MUNICIPALITY.

4. In the event of an incident along the Expressway warranting the use of a parallel route traffic management plan, determined solely by the DEPARTMENT, the MUNCIPALITY agrees to allow the DEPARTMENT to implement revised traffic signal timing and phasing plans along roadways located within the boundaries of the MUNCIPALITY and to post traveler information on any Dynamic Message Sign (DMS) within the boundaries of the MUNICIPALITY to facilitate regional traffic required to be diverted from the Expressway. However, the Parties acknowledge and agree that as a condition of this arrangement, the DEPARTMENT will contact the MUNICIPALITY prior to the implementation of a traffic management plan. Upon completion of the DEPARTMENT's traffic management plan and the resumption of normal operations, the DEPARTMENT will promptly contact and notify the MUNICIPALITY. Communication between the DEPARTMENT and MUNICIPALITY will be achieved via telephone, where the TCC can be reached at 610-205-6934.

5. The MUNCIPALITY also agrees to permit the DEPARTMENT to monitor traffic conditions, via the use of video cameras to be installed along the roadways, and the traffic signals along roadways within the boundaries of the MUNICIPALITY during times of normal traffic flow and during times of an incident on the Expressway. The Parties intend that that the MUNICIPALITY will have the capability of viewing the video cameras within its borders.

6. The MUNICIPALITY agrees to continue to maintain and operate traffic signals within its jurisdiction and control in accordance with the DEPARTMENT's Publication 191 incorporated by reference as if physically attached hereto.

7. The DEPARTMENT will own, maintain, and operate video cameras, static trailblazer directional signs, and DMS locations along area roadways as well as the communication infrastructure used to operate these devices.

8. In the event of immediate danger to MUNICIPALITY operation or to the highway user, the parties hereto agree to fully cooperate with each other. The parties will notify the appropriate individuals as set forth below:

A. COMMONWEALTH contact will be the County Maintenance Manager in the appropriate Department of Transportation County Maintenance Office. A list of Counties involved with their Office location and telephone numbers is attached hereto as Attachment "A" attached to and made part of this Agreement.

B. MUNICIPALITY contact will be:

Telephone No: (xxx) xxx-xxxx

COMMONWEALTH and MUNICIPALITY will immediately notify each other under the notice provisions in paragraph concerning any change in COMMONWEALTH or MUNICIPALITY contact information.

9. The term of this Agreement shall be for two (2) years from the date of its execution, and shall automatically renew for three additional one-year terms unless cancelled by either party on written notice delivered not less than ninety (90) calendar days prior to the end of the term. Such notice of cancellation shall be by letter sent U.S. mail,

certified, return receipt requested. Notice of cancellation to COMMONWEALTH shall be addressed to the Secretary of Transportation at the then-current address of the Secretary of Transportation. Notice of cancellation to MUNICIPALITY shall be addressed to the General Manager at the then current address of MUNICIPALITY's principal offices.

10. COMMONWEALTH has the right to terminate this Agreement for reasons as stated in the following paragraphs. Termination shall be effective upon receipt of written notice from either party to the other.

A. Termination for Convenience:

COMMONWEALTH shall have the right to terminate this Agreement for its convenience if COMMONWEALTH determines termination to be in its best interest. MUNICIPALITY shall be paid for work satisfactorily completed prior to the effective date of the termination, but in no event shall MUNICIPALITY be entitled to recover loss of profits.

B. Non-Appropriation:

The COMMONWEALTH's obligations are contingent upon appropriation of funds for the Project Agreement Purpose. The COMMONWEALTH shall have the right to terminate a Project Agreement because of nonavailability of sufficient funds (state and/or federal) for the COMMONWEALTH to pay for the services to be rendered under this Agreement.

C. Termination for Cause:

COMMONWEALTH shall have the right to terminate this Agreement for MUNICIPALITY's default upon written notice to MUNICIPALITY.

COMMONWEALTH shall have the right to terminate this Agreement or any Project Agreement executed with cause upon written notice to MUNICIPALITY.

11. This Agreement may not be modified or amended except in writing signed by duly authorized representatives of both MUNICIPALITY and COMMONWEALTH. This Agreement may not be assigned by either party without the prior written authorization of the other party. This Agreement should not be construed to confer any rights upon any other persons or entities of any kind not a party hereto.

12. This Agreement shall be binding and inure to the benefit of the successors and assigns of MUNICIPALITY and COMMONWEALTH.

IN WITNESS WHEREOF, the parties have caused these presents to be executed, by their duly authorized officials, on the date first above written.

ATTEST:

By ______________________ Date

Secretary
Title

by ______________________ Date

Manager
Title

If a Corporation, the President or Vice President must sign and the Secretary, Treasurer, Assistant Secretary or Assistant Treasurer must attest; if a sole proprietorship, only the owner must sign; if a partnership, only one partner need sign; if a limited partnership, only the general partner must sign.

==

Do not write below this line – for Commonwealth use only

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

by ______________________
Gary L. Hoffman, P.E. Date
Deputy Secretary for Highway Administration

APPROVED AS TO LEGALITY AND FORM

by ______________________
Chief Counsel Date

by ______________________
Deputy Attorney General Date

by ______________________
Deputy General Counsel Date

PRELIMINARILY APPROVED

by ______________________
Assistant Counsel Date

Funds Commitment Document Number

____

Certified Funds Available under SAP Number

____

SAP Cost Center ____________
GL Account ____________
Amount ____________
SAP Vendor Number ____________

by ______________________
for Comptroller Date