Implementation of Probe Data Performance Measures

FINAL REPORT

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TABLE OF CONTENTS

TABLE OF CONTENTS v
LIST OF FIGURES viii
LIST OF TABLES x
LIST OF ACRONYMS xi
Executive Summary xii
1. Introduction 1
2. Project Scope 2
  2.1 District/Counties overview with maps 2
  2.2 List of agency-side data elements produced 3
  2.3 Corridor List and Attributes 4
3. Inrix XD Data Overview 4
  3.1 Corridor Mapping 4
  3.2 Shape files and versioning system 5
  3.3 Real-time download process 5
  3.4 Archive backfill process 6
4. Server Overview 6
  4.1 Hardware System 7
  4.2 Software System 8
    4.2.1 Operating System 8
    4.2.2 SQL Server 9
    4.2.3 Node.js and npm 9
    4.2.4 Dashboard Software (Deliverables) 9
    4.2.5 Ingestion Process Overview 11
5. Dashboards Overview 12
  5.1 Travel Time Comparison Tool 13
  5.2 Travel Time Comparison Tool – Metric Explained 14
  5.3 Multi-criteria Arterial Ranking Tool 17
  5.4 Multi-criteria Arterial Ranking Tool – Metric Explained 18
    5.4.1 Speed Limit Travel Time Normalization 19
    5.4.2 Interquartile Range (IQR) Normalization 21
    5.4.3 Speed Limit and IQR Normalization 22

5.5 Travel Delay Monitor Tool 23
5.6 Travel Delay Monitor Tool – Metric Explained 24
6. User Benefits Methodology 25
6.1 User Cost Savings Due to Improved Travel Time 25
6.2 Carbon Dioxide Savings 26
7. Case Studies 27
7.1 Five-Corridor Before-and-After Analysis 27
7.1.1 Location 27
7.1.2 Travel time distributions for a single corridor 30
7.1.3 Arterial ranking 32
7.1.4 Hour-by-hour median and IQR evaluation 32
7.1.5 User benefits and CO_2 savings 36
7.2 Incidents 37
7.2.1 Gulph Road 37
7.2.2 Belmont Avenue 39
7.3 List of Application Uses 41
8. Engagement 41
8.1 Webinars 41
8.2 TRB 2017 42
8.3 PennDOT Workshop 42
8.4 Implementation of User Feedback 42
9. Implementation Plan 46
9.1 Server Delivery 46
9.2 Server Operating System (OS) Licensing 46
9.3 Maintaining Production and Beta Sites 47
9.4 User Logins 47
9.5 INRIX XD Map Updates 47
10. Summary 47
References 49
Appendix I – How To Use Dashboards 51
Appendix II – Mapping Corridors, Timing Plans and Database Management (Webinar Topic) 87
Appendix III – Updating Shapefile Versions 103

Appendix IV – Archived Speed Data Import 111
Appendix V – Corridor List and Attributes 119
Appendix VI – List of Participants 124

LIST OF FIGURES

Figure 1. Overview of engineering districts in Pennsylvania 2
Figure 2. The five counties comprising District 6 3
Figure 3. Data extracted from corridor mapping 4
Figure 4. C# .NET function to initially retrieve a token and URI from the INRIX API. 6
Figure 5. View of the Windows Task Manager on server. 7
Figure 6. Windows Server System panel on server. 8
Figure 7. The INRIX XD speeds ingester installed as a Windows Service. 10
Figure 8. Log of ingester service. Fetch and ingest times are provided in milliseconds. 11
Figure 9. Overview of the real-time ingestion process 12
Figure 10. Splash screen of Probe Data Performance Measures Dashboard. 13
Figure 11. Travel time comparison tool 14
Figure 12. Before and after CFDs 15
Figure 13. Travel times on a corridor during a 24-hour period 15
Figure 14. Plotting CFDs from Timing Plan 4 16
Figure 15. CFDs comparing before and after retiming 16
Figure 16. Median travel time improvement of 1 minute after signal retiming 17
Figure 17. Multi-criteria arterial ranking tool 18
Figure 18. Median travel time and speed limit travel time on Newtown Bypass (shown in black) and US-1 (shown in red) for the study period 12/5/2016 to 12/10/2016 19
Figure 19. Normalized travel time, with Newtown Bypass (shown in red) and US-1 (shown in black) 20
Figure 20. Ranking the corridors based on the speed limit travel time 21
Figure 21. 25^{th} and 75^{th} percentiles 21
Figure 22. Ranking the corridors based on the interquartile range 22
Figure 23. Arterial ranking using both speed limit travel time and IQR 23
Figure 24. Travel Delay Monitor 24
Figure 25. Travel delay monitor graph over a 1-week period 24
Figure 26. A 15-minute slice of the graph generated by the Travel Delay Monitor Tool, and its respective speed breakdown over the entire length of the corridor 25
Figure 27. Selected corridors in Greater Philadelphia area 28
Figure 28. Corridor maps of intersections running adaptive control 29
Figure 29. Corridor A3 31
Figure 30. Corridor A3, Weekdays, 17:00-18:00 Travel Times Before and After Installation of Adaptive Signal Control. 31
Figure 31. Travel Time and Reliability Trends for Adaptive Installations. Data is shown for Weekdays, 17:00-18:00, for before and after periods indicated in Table 2. 32
Figure 32. Weekday Median Travel Times and Interquartile Ranges by Hour 34
Figure 33. Weekend Median & IQR by hour 35
Figure 34. Summary of annual user cost/benefits for the five study corridors 36
Figure 35. I-76 West accident impact (red) and expected Gulph Rd detour (blue) 37
Figure 36. Travel time impacts on Westbound Gulph Rd 38

Figure 37. Congestion heat map of Westbound Gulph Rd 38
Figure 38. I-76 East accident impact (red) and Belmont Ave. detour (blue)................................ 39
Figure 39. Travel time impacts on Belmont Ave... 40
Figure 40. Congestion heat map on Southbound Belmont Ave.. 40
Figure 41. PennDOT employees and Purdue researchers at the TRB Poster Session on January 9, 2017, Washington D.C.. 42
Figure 42. Howell Li and Jijo Mathew leading the workshop at PennDOT District 6 on 01.12.2017.. 46

LIST OF TABLES

Table 1. Shape file versions 5
Table 2. Corridor Information... 28
Table 3. Summary of Annual CO_2 Emission Reductions for the Adaptive Signals 36
Table 4. List of Application Uses 41
Table 5. List of Recommendations from User Feedback 43
Table 6. Bucks County Corridor Information.. 119
Table 7. Chester County Corridor Information.. 120
Table 8. Delaware County Corridor Information 121
Table 9. Montgomery County Corridor Information 122
Table 10. Philadelphia County Corridor Information 123

LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
API	Application Programming Interface
CFD	Cumulative Frequency Diagram
CSV	Comma-Separated Variable
EPA	Environmental Protection Agency
GPS	Global Positioning System
IQR	Interquartile Range
PennDOT	Pennsylvania Department of Transportation
TMC	Traffic Message Channel
TRB	Transportation Research Board
TT	Travel Time
UI	User Interface
URI	Uniform Resource Identifier

EXECUTIVE SUMMARY

In recent years, highway monitoring and performance measure requirements have been increasingly emphasized for federal transportation funding mandates such as MAP-21. The provisions in these mandates have led to an increased need for the reporting of system performance at both state and local levels. It is highly likely that future bills will trend toward requiring data-driven performance measurement. Historically, this has been a challenge due to the data collection infrastructure required for any such wide-scale deployment efforts. To meet this data need, advances in connected and probe vehicle technologies have made available an unprecedented amount of data through third-party commercial vendors for agencies to procure and use. However, this data must be transformed to adapt to the goals and objectives of the agency so to be well-suited for analyzing performance on their systems.

In May 2016, the Pennsylvania Department of Transportation sponsored a 12-month research project at Purdue University to develop, implement and assess three web dashboards and a data system that make use of the commercial probe data licensed by Pennsylvania to produce arterial performance measures for engineers and stakeholders to evaluate and monitor traffic conditions. Traffic speed data was downloaded in real-time as well as historic data from INRIX to populate roadway speeds nominally at 1-mile spatial resolution. The dashboards mapped the speeds to 138 "super-critical" corridors in the five-county region of District 6, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties, and produced travel time and reliability metrics, cross-corridor rankings, and a congestion monitoring tool on a web-enabled user platform. The three dashboards are summarized below:

- **Arterial Travel Time Comparison Tool.** This tool allows the user to perform a comparison of travel times on a selected corridor for specified "before" and "after" date ranges that can be filtered by day of week and time of day. The tool produces cumulative frequency diagrams (CFDs) of the travel times that illustrate the difference between the before and after conditions. This tool is instrumental for assessing the effects of maintenance, operational changes, capital programs and adaptive deployments.

- **Arterial Ranking Tool.** This tool enables the user to view performance of several corridors for a specified date range, and to rank the corridors according to their travel time characteristics, including both the median travel time and the interquartile range (IQR), a measure of the travel time variability. The tool produces sorted bar charts based on either performance measure, or a scatter-plot using both criteria axes.

- **Arterial Congestion Ticker.** This tool produces a chart of speed distributions on selected arterial routes over time. Users can interact with the chart to focus-in on specific instances in time and display on a map the segments where the speeds are observed.

These web dashboards were accompanied by a research paper that assessed over $30 million in user travel time and emissions benefits derived from a combination of signal retiming and adaptive system deployments. That paper was presented at the Transportation Research Board 96th Annual Meeting. Looking ahead, the groundwork laid by this project will aid the development of new business processes for assessing road network performance using emerging data sources to align with requirements of upcoming government mandates on performance measures.

1. INTRODUCTION

A central concept of system engineering is to define the goals and objectives of the system, then measure the outcomes of the system performance to determine whether those goals and objectives are being adequately met. In the operation of coordinated traffic signal systems, these are determined by the operating environment of the system and the needs of the stakeholders.

Corridor progression is a common objective of traffic signal system operations, particularly for arterial highways. Travel time is perhaps the most common performance measure used to evaluate the quality of progression. This can be measured by a number of techniques, such as GPS travel time runs *(1)* or vehicle re-identification *(2, 3)*; or estimated by the analysis of segment speed data sampled from connected vehicles from private-sector data providers *(4–7)*. Several researchers have recently explored the viability of private sector speed data for analysis of arterial travel times *(4–6)*. While results have varied, the growing consensus is that such data is viable on corridors with higher traffic volumes. A recent study demonstrated the scalability of this data set by applying the method to a large inventory of corridors on a state-wide level, ranking them by travel time and travel time reliability metrics for multiple times of day *(7)*.

Adaptive signal control is one application where such analysis tools are essential to evaluate the return on investment. In 2013, the University of California, Berkley evaluated adaptive signals based on field data collected through Bluetooth detectors *(8)*. For this particular corridor, the implementation of adaptive signals had a detrimental effect, which was attributed to suboptimal splits and offsets for specific intersections. A recent study by the Virginia Department of Transportation *(9)* explored six adaptive control deployments and observed reductions in travel time averaging about 25%, with a 16% improvement in travel time reliability, using private-sector speed data spatially segmented using the Traffic Message Channel (TMC) scheme.

There is clear consensus that outcome assessment is an important part of any traffic signal modernization or adaptive control project. However, the techniques used in past studies are relatively labor intensive. To address the need for an assessment tool, the Pennsylvania Department of Transportation (PennDOT) initiated a project to adapt the corridor ranking tool *(7)* to a district-wide level web tool incorporating 138 corridors. That ranking methodology was further extended to visualize before and after effects in terms of both travel time and travel time reliability. Of these corridors, five recently incorporated adaptive deployments that varied from full-corridor to partial-corridor deployments, are evaluated. In this study, the more spatially detailed “XD” segmentation scheme is used. Results are examined for each hour of the day from 6:00 a.m. to 8:00 p.m. for all five corridors, and the annualized user benefits are calculated.

2. PROJECT SCOPE

2.1 District/Counties overview with maps

The location of this analysis was determined by the Pennsylvania Department of Transportation (PennDOT), concentrating on analyzing and ranking high-volume signalized arterial corridors around the Philadelphia area. This region is defined as District 6 and consists of 5 counties: Bucks, Chester, Delaware, Montgomery, and Philadelphia. Figure 1 shows a map of the eleven districts in Pennsylvania, while Figure 2 shows District 6 in more detail. Within District 6, there are 138 corridors, stretching along 766 miles, and totaling 2,184 signals. In the past few years, Pennsylvania has accelerated its investments in signal infrastructure with its "Green Light Go" program, which has led to a number of improvements including several signal retiming projects and adaptive control deployments *(10)*.

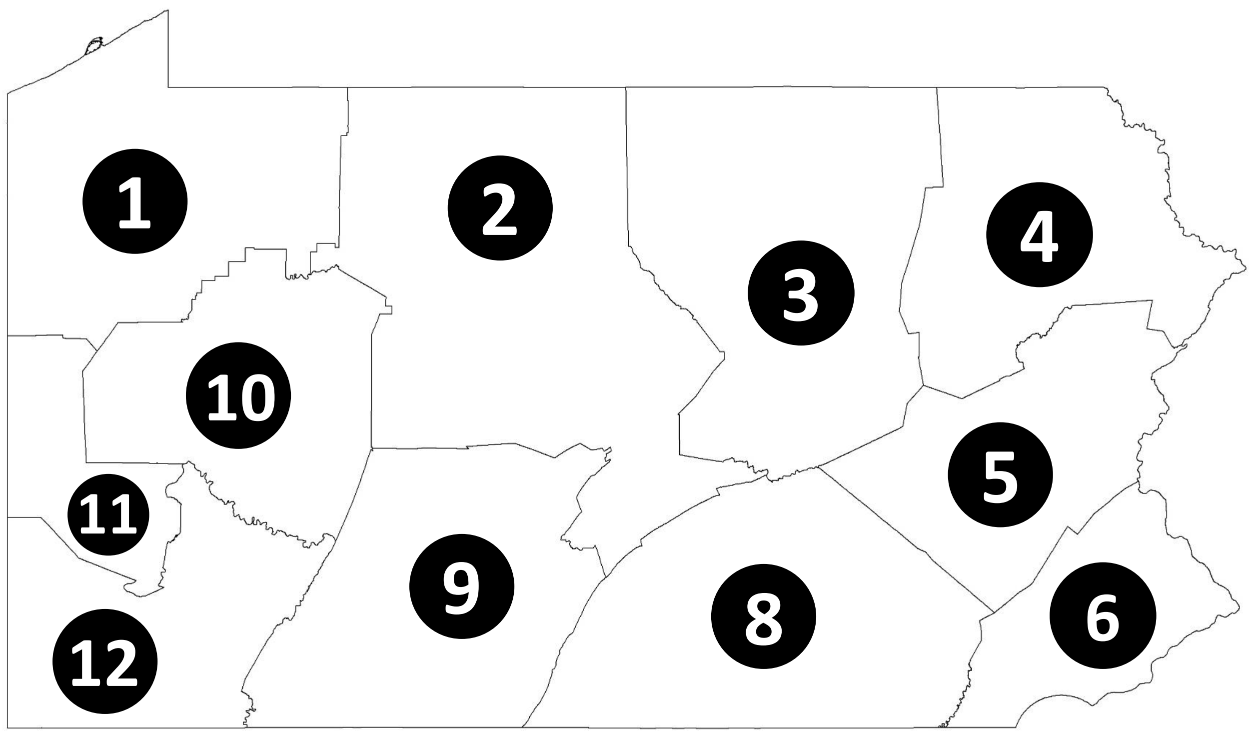


Figure 1. Overview of engineering districts in Pennsylvania

Figure 2. The five counties comprising District 6

2.2 List of agency-side data elements produced

The Purdue team acquired necessary data elements from PennDOT at the beginning of the project. This data included various GIS files, corridor information files, and signal timing plans. The comprehensive list is below.

- GIS Files
  - Supercritical Corridors Shapefile
  - Pennsylvania Shapefile Version 14.2
  - Pennsylvania Shapefile Version 15.1
  - Pennsylvania Shapefile Version 15.2
  - Pennsylvania Shapefile Version 16.1
  - Pennsylvania Shapefile Version 16.2
  - Pennsylvania Shapefile Version 17.5
  - Spat Int Speed Limit Data shapefile
- Corridor Information Files
  - District 6 Supercritical Corridor PDF
    - Number signals, corridor length, AADT
  - All District Supercritical Corridors Excel File
    - Number signals, corridor length, AADT
- Signal Timing Plans
  - Bucks County
    - 9 corridors
  - Chester County
    - 2 corridors
  - Delaware County
    - 2 corridors
  - Montgomery County
    - 4 corridors

2.3 Corridor List and Attributes

From the files listed above, corridor information was aggregated for the 138 corridors. Data used most frequently in the analysis was corridor length, AADT, speed limits, and number of signals. The complete list of data from all 138 corridors can be found in Appendix V – Corridor List and Attributes

3. INRIX XD DATA OVERVIEW

3.1 Corridor Mapping

Travel times were evaluated using private-sector probe vehicle speeds. These speeds are obtained on a minute-by-minute basis from an aggregation of individual vehicle speeds determined from timestamped positions of GPS-enabled devices, including fleet telematics and cellular phones. For this study, segment definitions from the data provider were used, each approximately 0.3 mile in length for evaluating arterials known as "XD segments."

Corridor analysis requires the mapping of XD segments to match individual corridors. This was accomplished using a manual mapping process using ArcMap 10.3.1. In this process, two shape files (PennDOT super-critical corridors and INRIX XD) are superimposed as separate layers and manually matched to obtain the appropriate XD segments. The XD segments are sorted by position along the roadway for the two different directions of travel. In some cases, the endpoints of the corridors might not align with the endpoints of the XD segments. In such cases, the XD segments were trimmed to match the corridor end points. Figure 3 shows a snippet of the CSV data file produced from the mapping process.

1	county	corr_no	corr_name	xdsegid	bearing	xd_pos	trim_first	trim_final
2	Bucks	46004	PA63/Welsh Rd	3934216	W	1	4205	
3	Bucks	46004	PA63/Welsh Rd	3934204	W	2		
4	Bucks	46004	PA63/Welsh Rd	3934205	W	3		
5	Bucks	46004	PA63/Welsh Rd	3934206	W	4		
6	Bucks	46004	PA63/Welsh Rd	3934207	W	5		
7	Bucks	46004	PA63/Welsh Rd	3934208	W	6		
8	Bucks	46004	PA63/Welsh Rd	3934209	W	7		
9	Bucks	46004	PA63/Welsh Rd	3934210	W	8		
10	Bucks	46004	PA63/Welsh Rd	3934211	W	9		
11	Bucks	46004	PA63/Welsh Rd	3934212	W	10		
12	Bucks	46004	PA63/Welsh Rd	3934882	W	11		
13	Bucks	46004	PA63/Welsh Rd	3934883	W	12		
14	Bucks	46004	PA63/Welsh Rd	3934884	W	13		
15	Bucks	46004	PA63/Welsh Rd	3934885	W	14		
16	Bucks	46004	PA63/Welsh Rd	28301857	W	15		

Figure 3. Data extracted from corridor mapping

The manual mapping was performed for each direction of travel on the 138 super-critical corridors. The time consumed for manually mapping a corridor took between 10 to 20 minutes. A detailed step-by-step procedure of the mapping process can be found in Appendix II – Mapping Corridors, Timing Plans and Database Management.

3.2 Shape files and versioning system

INRIX releases a new shape file every six months to incorporate new roads and segments. The XD segments have some variation across the shape files in terms of where the endpoints terminate and numbering of the segments. As a result, the XD segments that comprise a corridor may not be consistent over a study period that spans multiple shape file versions. To overcome this, multiple mappings of each corridor were maintained across all the shape file versions within the current project timeline. The shape file update process requires version management within the SQL Server database in the [__version] table and corresponding [version] columns in the [__xd] and [xdpaths] tables with the effective starting date of the shape file version as the version identifier. These data structures maintain the specific XD segment definition sets needed to represent the corridors over time. A tutorial of the shapefile update process is in Appendix III – Updating Shapefile Versions.

Six XD segment shape file versions were used through the course of this project, as shown in Table 1. The nomenclature for the versioning was based on the year and the month during which the release took place. If the user queried for a date range within a particular shapefile, the XD segments belonging to the respective shape file for the appropriate time period would be returned for analysis.

Table 1. Shape file versions

Shape File Name	Start Date	End Date
v14_09	01/01/1900	03/20/2015
v15_03	03/20/2015	09/20/2015
v15_09	09/20/2015	03/20/2016
v16_03	03/20/2016	09/20/2016
v16_09	09/20/2016	05/09/2017
v17_05	05/09/2017	09/20/2017 (estimated)

3.3 Real-time download process

The INRIX web Application Programming Interface (API) is used to retrieve real-time speed data for the segments pertaining to corridors defined by the mapping process. A Windows service application called INRIX XML Ingester Multithreaded automates the process on the server and performs the data retrieval once-per-minute. The API is first called at the endpoint http://api.inrix.com/Traffic/Inrix.ashx to retrieve a token for accessing INRIX data as well as the Uniform Resource Identifier (URI) for the subsequent calls.

The initial call is made with three parameters: “action”, “vendorid,” and “consumerid”, and are sent as a GET request. The action value is “getsecuritytoken” and the vendorid and consumerid are provided by INRIX. Once the token and URI are retrieved, subsequent calls to the URI are made with the “getsegmentspeed” action value and the “token” parameter with the token supplied by the initial call. In addition, a separate parameter “segments” is supplied with its value of a comma-separated string of XD segment identifiers provided by the corridor mapping information in the database. Once the call is made, an XML document is returned with the list of segments and their current respective speeds. The automated service then stores the speed data into the database. Since there is also a limit on the number of segments that can be requested at once, the process also batches the requests in sets of 200 segments at a time.

```
public static TokenResponse GetTokenAndURI()
{
    TokenResponse tr = new TokenResponse();

    // this is the URL that we go to to fetch our INRIX token
    string tokenURL = "http://api.inrix.com/Traffic/Inrix.ashx?action=getsecuritytoken&Vendorid=xxxxxxxxxx&consumerid=xxxxxxx";

    // calling a web request using the URL provided
    WebRequest request = WebRequest.Create(tokenURL);

    // grabbing the response from the request object's function
    WebResponse response = request.GetResponse();

    // a placeholder for the token which will be pulled from the response's XML later
    Stream responseStream = Util.CopyAndClose(response.GetResponseStream());
    StreamReader responseStreamReader = new StreamReader(responseStream);
    tr.responseStr = responseStreamReader.ReadToEnd();
    responseStream.Position = 0;

    XmlSerializer serializer = new XmlSerializer(typeof(Inrix));
    Inrix inrix = (Inrix)(serializer.Deserialize(responseStreamReader));
    tr.token = inrix.AuthResponse.AuthToken.Value;

    foreach (InrixAuthResponseServerPath spath in inrix.AuthResponse.ServerPaths)
    {
        if (spath.type == "API" && spath.region == "NA")
        {
            tr.requestURI = spath.Value;
            break;
        }
    }

    responseStreamReader.Close();
    responseStream.Close();

    return tr;
}
```

Figure 4. C# .NET function to initially retrieve a token and URI from the INRIX API.

3.4 Archive backfill process

Every three months, INRIX makes available the archived speed data for the previous quarter. An Excel sheet with a set of links for each month is provided, or compressed CSV files are provided as links directly. In the former scenario, each link directs to a zip file on the Amazon Web Service (AWS) where the archived data is stored. There are around 60 to 70 links for a given month. A semi-automatic process was developed by the Purdue team using the .NET framework to download the zip files, extract, process, and finally bulk insert them to their respective data tables in the SQL database. The process for backfilling using CSVs is detailed in Appendix IV – Archived Speed Data Import.

4. SERVER OVERVIEW

One blade server and one license of Microsoft SQL Server Enterprise Edition was procured for this project. The server was procured by Purdue University and operated within the Purdue network for the duration of the project. The platform hosted software for data retrieval and storage, application development and testing, and web production interfaces for Pennsylvania stakeholders, and was the vehicle for product delivery by the Purdue team. The server was delivered with the aforementioned software packages to the PennDOT Harrisburg server farm on April 19, 2017.

4.1 Hardware System

The hardware procured for this project is a Dell PowerEdge R730 chassis with an Intel Xeon E5-2637 v3 processor running at 3.5 GHz. There are 15 megabytes of L3 cache on the processor, running at 9.6 giga-transfers per second (GT/s) with QuickPath Interconnect (QPI) and Hyper-Threading (HT) technology. There are four physical cores on the processor with eight total threads. The system operates at 135 watts.

There are 128 gigabytes (GB) of memory installed on the system in the configuration of four 32 GB modules. The disk configuration consists of two 400 GB solid-state (SSD) 2.5 inch SAS drives alongside six 1.8 TB 10,000 RPM 12 gigabits-per-second (Gb/s) SAS mechanical drives. The disk array operates on a Dell PERC H730P RAID controller with 2 GB of NV cache. The mechanical disks are configured as RAID 10 with 5.4 TB usable space, split between the operating system C: drive and the data store D: drive. The two SSDs are configured as RAID 1 and holds the database transaction log data.

The network daughter card for the system is an Intel Ethernet X540 module that can operate up to 10 Gb/s.

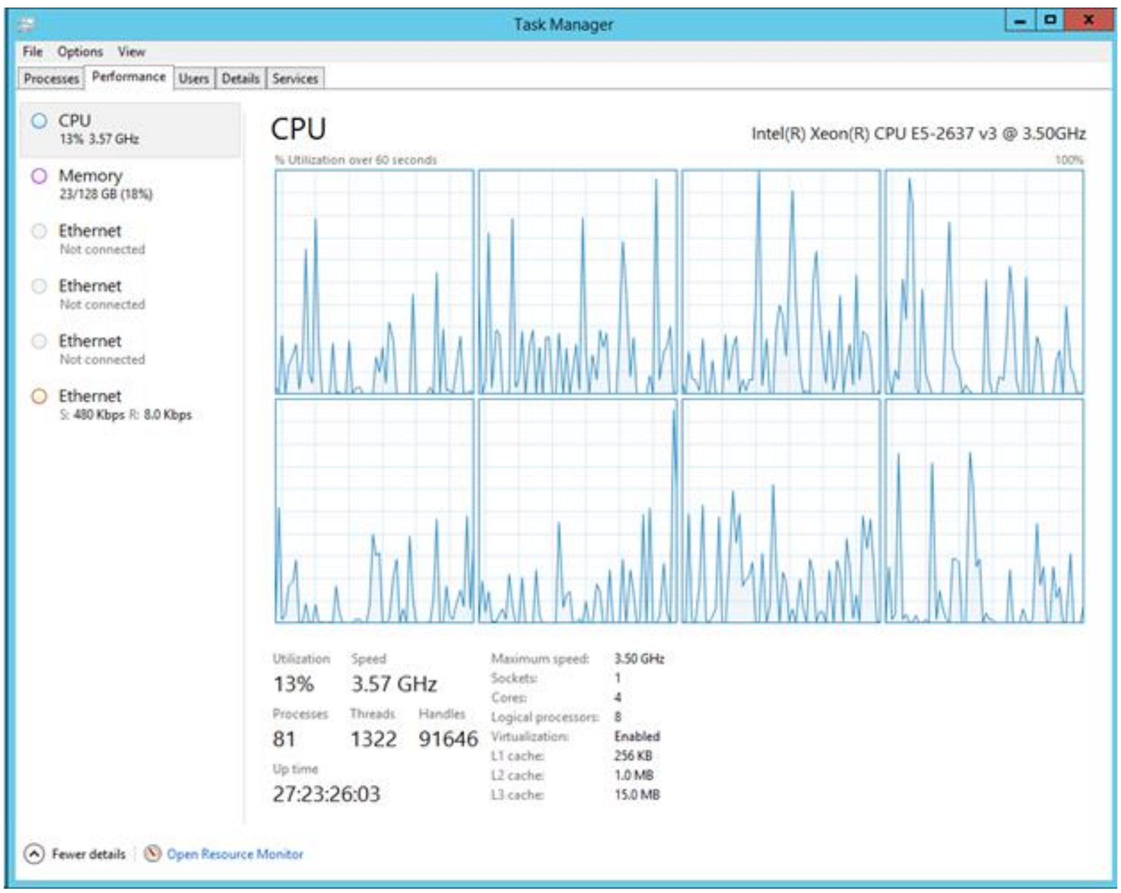


Figure 5. View of the Windows Task Manager on server.

4.2 Software System

4.2.1 Operating System

The operating system (OS) installed is Windows Server 2012 R2 Standard edition. For the duration of the project, the OS operated on a Purdue-wide license and has since been transferred to a Pennsylvania license after the delivery and installation of the server on PennDOT premises.

Guest accounts are disabled on the operating system and the remote desktop feature is enabled. The administrator group on the OS contains three users at the time of delivery.

Internet Information Services (IIS) module version 8.5 is installed for the OS, with the web applications bound to port 80 for HTTP. Simple anonymous authentication is enabled to allow for password protecting the web dashboards. The physical path of the web applications is located at C:\inetpub\wwwroot. The front-end modules are in the Apps subfolder while the server-side .NET modules are in the net subfolder.

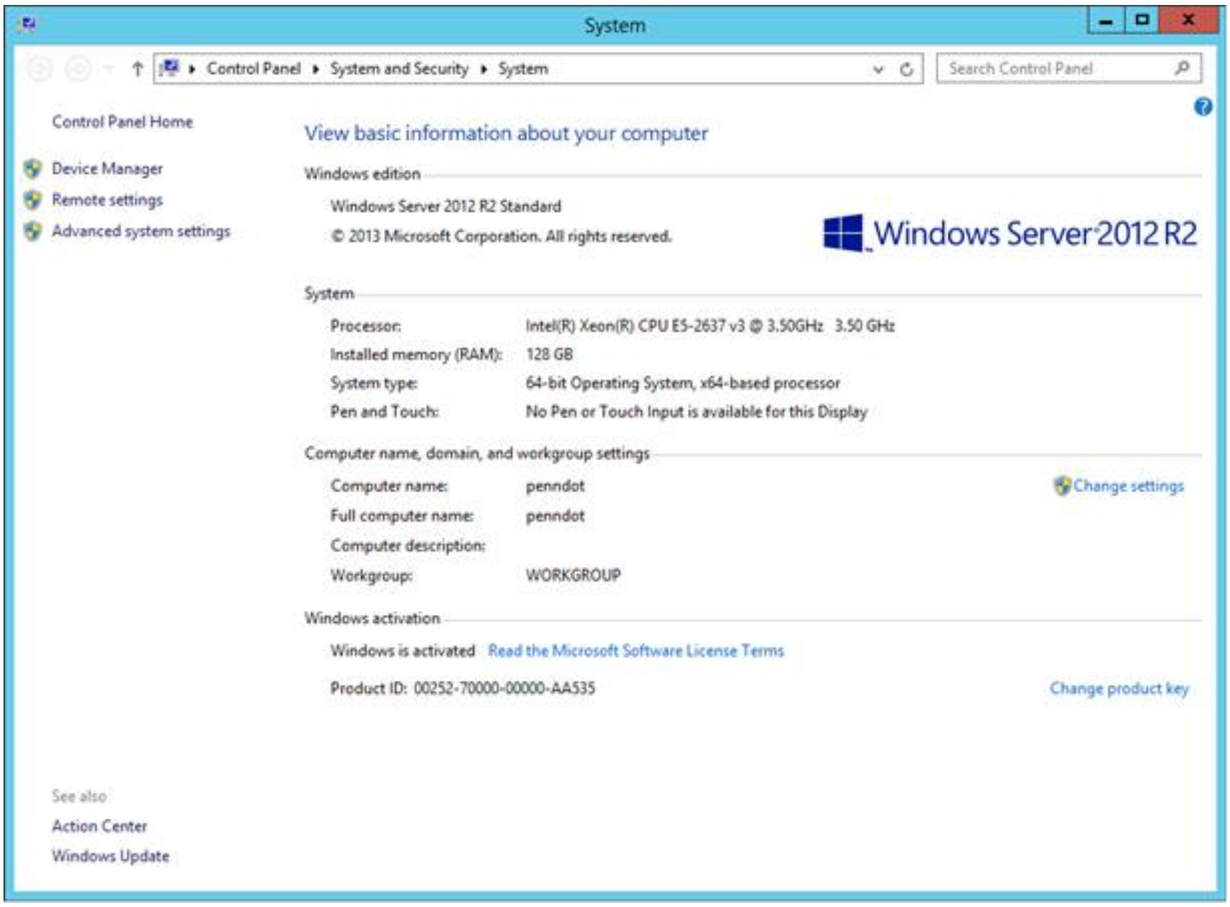


Figure 6. Windows Server System panel on server.

4.2.2 SQL Server

The server is running Microsoft SQL Server 2014 64-bit Enterprise Edition for the relational database management system (RDBMS). The licensing method is core-based and the memory configuration is set to consume a maximum of 124,000 MB. Services of the RDBMS includes the SQL Server service, SQL Server Agent, SQL Server VSS Writer, and SQL Full-text Filter Daemon Launcher.

Both SQL Server and Windows Authentication is enabled for the RDBMS. All users in the Administrator group in the OS are enabled for accesses, as well as SQL application users.

The primary database that stores the data is inrix_xd_penndot. There is also a testing database inrix_xd_penndot_beta. The data files are located in the folder D:\USER_DB and the log files are located in the folder E:\Microsoft SQL Server\MSSQL12.MSSQLSERVER\MSSQL\DATA. Simple recovery model is used.

4.2.3 Node.js and npm

In addition to the IIS HTTP web service and corresponding .NET services, the server also has Node.js installed, which is an event-based, server-side JavaScript environment. This environment is for operating the *highcharts-export-server* software used deliver client-side chart graphics, generated from each application, to be savable by the user on his or her local PC.

Node.js comes with npm, which is a package manager application. The package manager is used for the setup and installation of the highchart-export-server package into Node.js. The package was installed using the command *npm install highcharts-export-server –g* from the command prompt running as an administrator. The installed package then resides in the C:\Users\<user account>\AppData\Roaming folder to be usable by other applications.

4.2.4 Dashboard Software (Deliverables)

The set of software deliverables are installed on the server as either front-end modules, e.g. HTML, CSS, and Javascript files, or server-side .NET applications. All client-facing application files are stored in C:\inetpub\wwwroot for the production interface. The database connection information is stored in the Web.config file in the C:\inetpub\wwwroot\net subfolder. Similarly, all client-facing application files for the development/beta site are stored in C:\inetpub\wwwroot\dev. The database connection information is stored in the Web.config file in the C:\inetpub\wwwroot\dev\net subfolder.

Additionally, a set of service modules are installed on the server to facilitate the real-time retrieval and processing of the data. The services are located in the C:\inetpub\services folder and operates on a scheduled basis. The services start with Windows automatically, running as the Local System account, and logs daily activity in the folder C:\inetpub\logs\<service name> as flat files.

Three services are the *ingest* service, the *agg15* service and the *Highcharts export server* service. The *ingest* service is a minute-by-minute automation application that fetches current speeds for the active set of XD segments defined in the server database ([xdpaths] table), from the INRIX API.

The *agg15* service is a service that runs every 15-minutes to generate aggregated statistics for each XD segment's speeds for the data retrieved over the previous 15-minute interval. The dashboards currently run on the aggregated 15-minute statistics data for improved performance. Finally, the *Highcharts export server* service is a wrapper service for the *highcharts-export-server* Node.js application, installed under the li895 user account. The service launches and keeps alive the application to listen on port 7801 for incoming requests for generating client-side chart graphics.

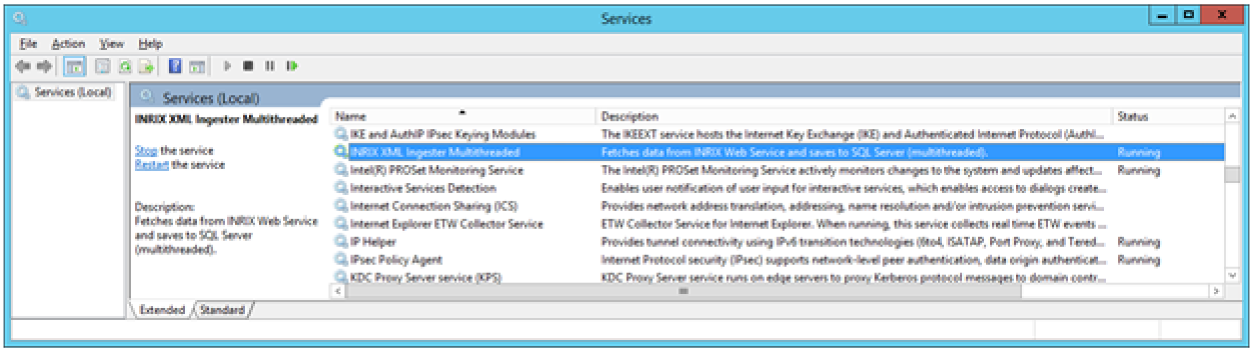


Figure 7. The INRIX XD speeds ingester installed as a Windows Service.

The configuration file for the *ingest* service, including database connectivity, is located at *C:\inetpub\services\penndot.net.ingest.service\penndot.net.ingest.service.exe.xml*.

The configuration file for the *agg15* service, including database connectivity, is located at *C:\inetpub\services\penndot.net.agg15.service\penndot.net.agg15.service.exe.xml*.

The configuration file for the *Highcharts export server* service is located at *C:\inetpub\services\penndot.net.highchartsexportserver\penndot.net.highchartsexportserver.exe.xml*.

```
2016_10_17.log
Starting job >>> 2016_10_17 00:00:19
Last thread completed at 00:00:25 with a runtime of 6.4843681
Average Fetch: 0, Max Fetch: 6250, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:01:19
Last thread completed at 00:01:25 with a runtime of 6.1874926
Average Fetch: 0, Max Fetch: 6062, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:02:19
Last thread completed at 00:02:24 with a runtime of 5.1406194
Average Fetch: 0, Max Fetch: 5000, Average Ingest: 0, Max Ingest: 31
Starting job >>> 2016_10_17 00:03:19
Last thread completed at 00:03:26 with a runtime of 6.5781173
Average Fetch: 0, Max Fetch: 6453, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:04:19
Last thread completed at 00:04:26 with a runtime of 7.0624919
Average Fetch: 0, Max Fetch: 6953, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:05:19
Last thread completed at 00:05:24 with a runtime of 5.0781194
Average Fetch: 0, Max Fetch: 4953, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:06:19
Last thread completed at 00:06:26 with a runtime of 6.5312426
Average Fetch: 0, Max Fetch: 6406, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:07:19
Last thread completed at 00:07:23 with a runtime of 4.4218702
Average Fetch: 0, Max Fetch: 4297, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:08:19
Last thread completed at 00:08:24 with a runtime of 4.7812455
Average Fetch: 0, Max Fetch: 4625, Average Ingest: 0, Max Ingest: 31
Starting job >>> 2016_10_17 00:09:19
Last thread completed at 00:09:30 with a runtime of 10.6718619
Average Fetch: 0, Max Fetch: 10437, Average Ingest: 0, Max Ingest: 31
Starting job >>> 2016_10_17 00:10:19
Last thread completed at 00:10:31 with a runtime of 12.32811
Average Fetch: 0, Max Fetch: 12187, Average Ingest: 0, Max Ingest: 31
Starting job >>> 2016_10_17 00:11:19
Last thread completed at 00:11:24 with a runtime of 5.265619
Average Fetch: 0, Max Fetch: 5109, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:12:19
Last thread completed at 00:12:27 with a runtime of 8.1718658
Average Fetch: 0, Max Fetch: 8016, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:13:19
Last thread completed at 00:13:26 with a runtime of 6.4374926
Average Fetch: 0, Max Fetch: 6203, Average Ingest: 0, Max Ingest: 31
Starting job >>> 2016_10_17 00:14:19
Last thread completed at 00:14:26 with a runtime of 6.7187419
Average Fetch: 0, Max Fetch: 6531, Average Ingest: 0, Max Ingest: 31
Starting job >>> 2016_10_17 00:15:19
Last thread completed at 00:15:26 with a runtime of 6.6562428
Average Fetch: 0, Max Fetch: 6500, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:16:19
Last thread completed at 00:16:25 with a runtime of 5.4062439
Average Fetch: 0, Max Fetch: 5187, Average Ingest: 0, Max Ingest: 47
Starting job >>> 2016_10_17 00:17:19
Last thread completed at 00:17:25 with a runtime of 5.8437429
Average Fetch: 0, Max Fetch: 5703, Average Ingest: 0, Max Ingest: 31
```

Figure 8. Log of ingester service. Fetch and ingest times are provided in milliseconds.

4.2.5 Ingestion Process Overview

Figure 9 shows an overview of the workflow of the real-time Windows services to bring in minute-by-minute INRIX XD speed data. First, a connection to the INRIX API is established with the PennDOT credentials, from where a token is received. The token is then used to make subsequent calls to the API. Speeds for XD segments defined in the [xdpaths] table for the current version at the time of ingestion is retrieved in batches of 150 segments, sent to INRIX in 16 parallel threads, and the resulting speeds are saved in the database in the [xdspeeds] table. In addition, every 15 minutes a service is run to aggregate statistics within the previous 15-minute period for each segment. This process generates the median speeds used for the client-facing applications.

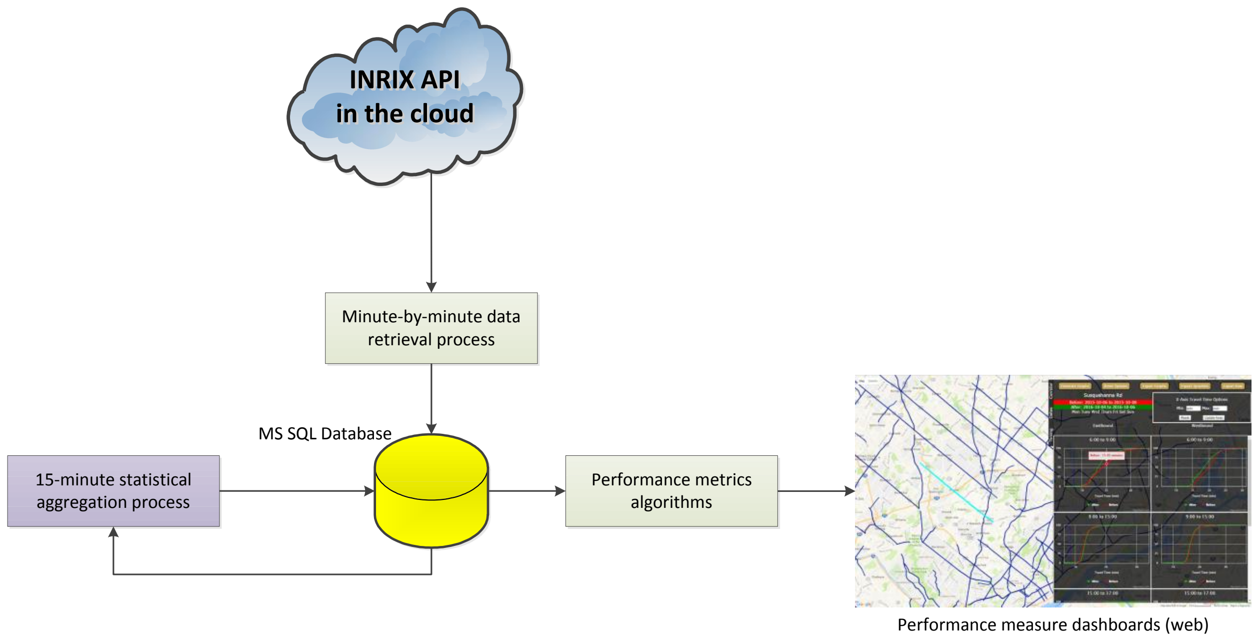


Figure 9. Overview of the real-time ingestion process

5. DASHBOARDS OVERVIEW

A splash page linking to the three web applications and supporting documents that were developed for PennDOT provides a gateway for the monitoring of the performance of the super-critical corridors. A screen shot of the splash screen is shown in Figure 10 with the Executive Summary. In addition, links to guides on dashboard use and technical processes, PDFs of two Purdue-hosted webinars, publications, posters, code, and final report is provided on this page. The below section gives a high-level view of the applications and their intended purpose. Details on usage of the web applications can be found in Appendix I – How To Use Dashboards.

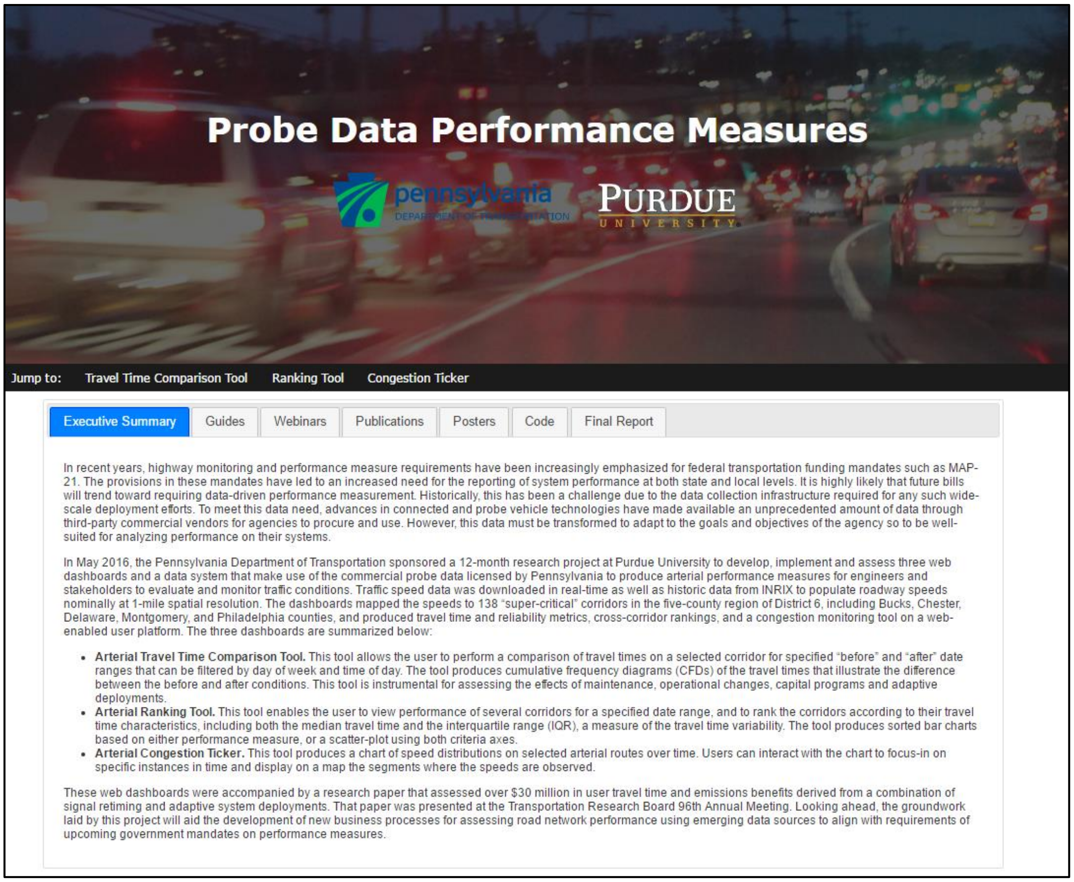


Figure 10. Splash screen of Probe Data Performance Measures Dashboard.

5.1 Travel Time Comparison Tool

The travel time comparison tool compares samples of travel times on any of the 138 super-critical corridors during a user-specified before-and-after time range. The performance metric used in this dashboard is the cumulative frequency diagram (CFD) of all estimated travel times within the selected periods, typically shown as two before-and-after curves on a single chart. A screenshot of the application screen is shown in Figure 11. Corridors can be selected from the interactive map, or using the dropdown menu. A selected corridor will become highlighted on the map to verify the selection choice.

After a single corridor has been selected, the user can then customize parameters including date ranges, the days-of-week, hour ranges, and travel time axis bounds. The "Dates" tab menu includes before-and-after calendars to choose the desired ranges. The "Timing" tab menu allows for the toggling of any day-of-week to be included in the analysis. In the hour section of the "Timing" menu, users can customize the hours to be included, such as the entire 24-hour period, hourly, generic rush hour, and custom hour range sliders. Any timing plans defined in the [signal_time_plans] table in the database is automatically loaded into the "Timing" menu when a participating corridor is selected. Finally, the axes section allows for the customization of the travel time limits on the horizontal axis (x-axis) of the generated graphs.

After the user has set all of his or her customization choices, clicking on the “Generate Graphs” button will generate a series of travel time charts based on the user-defined parameters. One column of graphs will be produced for each direction of travel associated with that corridor. In addition, each column will contain one graph for each timing period selected. Each graph will contain a red line to represent the before date range, and a green line to represent the after range. Improvements are represented by a leftward shift of travel time in the before line to the after line. Users can also export the graphs as an image, or the CSV data in quartiles or raw format. The interpretation of these charts is explained in the next section in more detail.

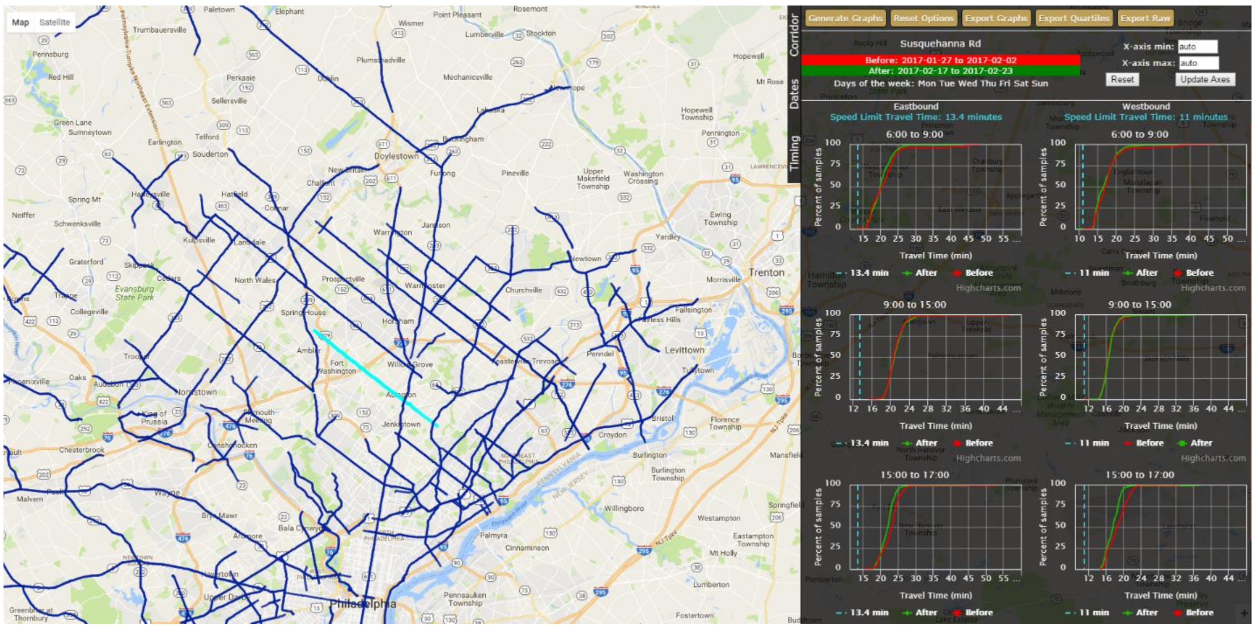


Figure 11. Travel time comparison tool

5.2 Travel Time Comparison Tool – Metric Explained

The CFDs can be used to perform a quick before-and-after assessment of the travel times on a corridor. This could be used, for example, to evaluate the impact of a signal retiming project, comparing the travel time samples for a period before the retiming and a period after the retiming. The CFDs are plotted with the travel time along the x-axis and the cumulative frequency percentage, i.e. the percentage of travel time samples taken within the evaluation period sorted by fastest to slowest travel time, along the y-axis. A near-vertical curve suggests the range of travel times are narrow, and therefore more consistent throughout the analysis period, whereas a wider curve suggests a higher range of travel times across the samples. The latter indicates a less reliable travel time experienced by users during the period.

Figure 12 shows a set of hypothetical before-and-after curves plotted on a CFD graph depicting a study before and after a signal retiming. The figure suggests an improvement in the travel time of the system, with the after (green) curve shifting to the left.

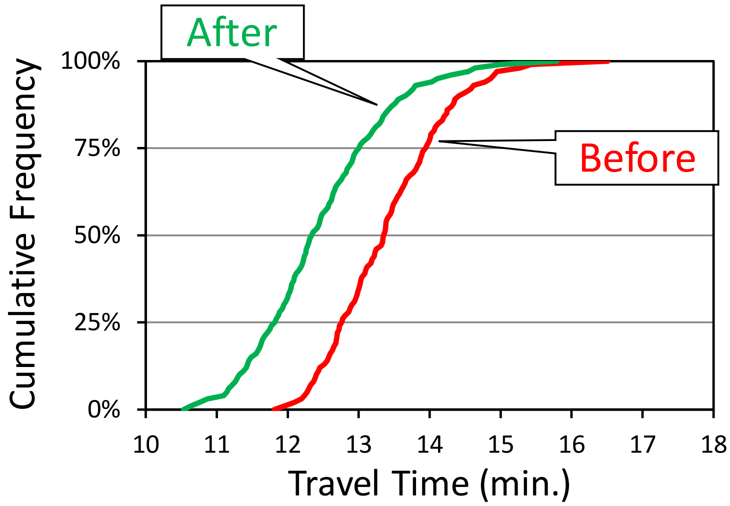


Figure 12. Before and after CFDs

To produce the CFD, travel time samples converted from speeds obtained from the INRIX API for the before and after analysis periods must be available in the SQL database. A typical analysis uses travel time samples at 1-minute intervals. However, for a better user experience and performance, the dashboard applications developed for this project uses a 15-minute median value. In other words, for every 15 speed samples within a 15-minute period, only one median value is used to construct the CFD. Figure 13 shows the 1-minute travel time samples observed on a corridor from Monday to Friday, with all sampled points across the five days combined together and displayed on a single 24-hour chart. The color-coded boxes represent the durations of the timing plans operating during the day, which reflects different traffic signal control parameters that were in effect during each period. For example, Timing Plan 5 operates between 15:00 and 19:00, which represent the "PM Peak" for this particular corridor.

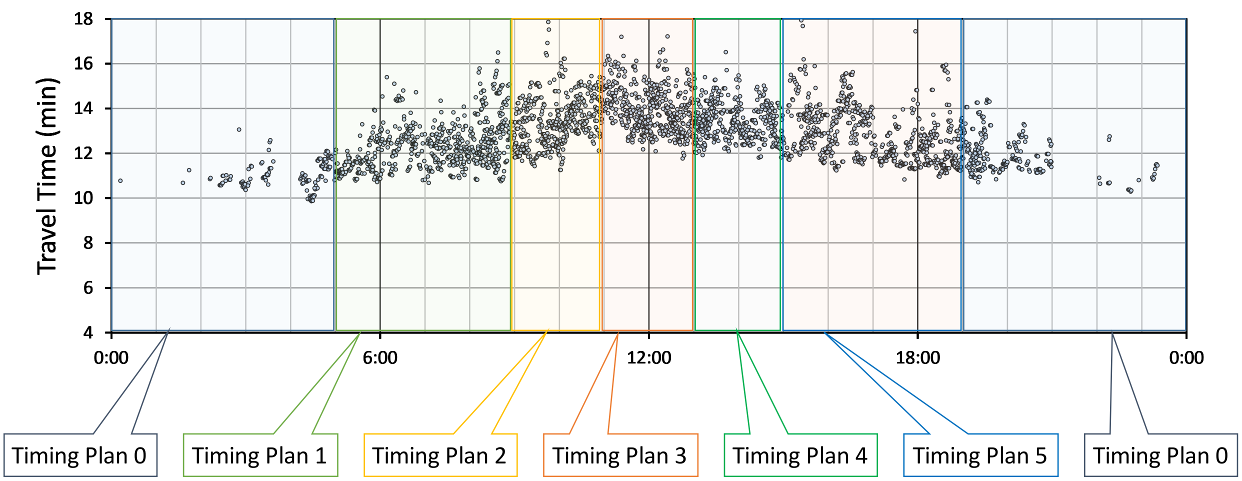


Figure 13. Travel times on a corridor during a 24-hour period

The cumulative frequency diagram for Timing Plan 5 can be produced by taking all travel time samples during the defined time-of-day over the five weekdays, and sorting the samples by fastest to slowest travel time. Each of the sorted travel time values are then assigned a percentage value that represents its position in the travel time ordering, relative to the rest of the samples in the period. With the travel time representing the x-axis value and the percentage representing the y-axis value, the data are plotted as a curve, such as that shown in Figure 14. In this chart, a distribution of the individual travel time measurements binned in one-minute intervals are also presented as green bars to show how the data would be represented as a histogram, in additional to the cumulative frequency curve (shown as a black line).

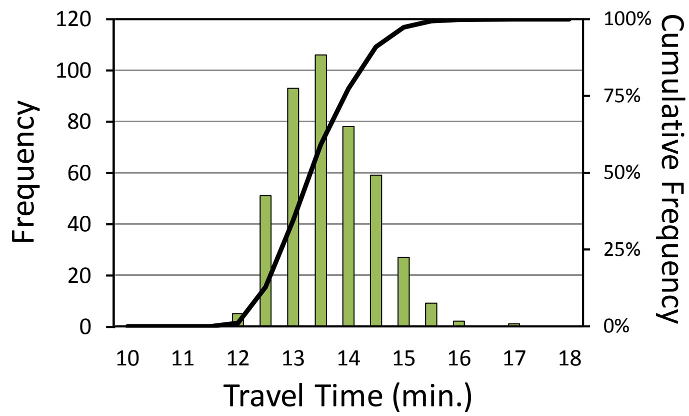
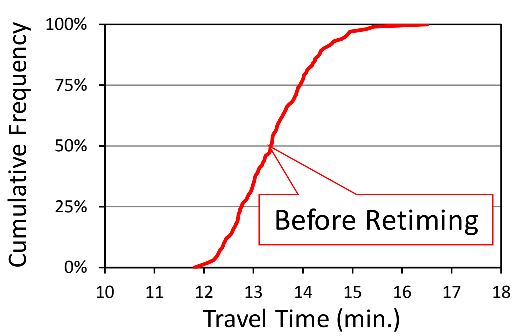
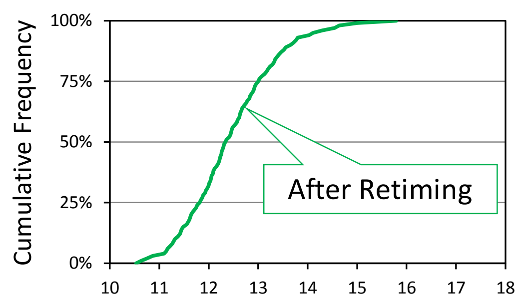


Figure 14. Plotting CFDs from Timing Plan 4

In a common scenario, PennDOT would need to evaluate the impacts of signal retiming on a specific corridor for each of the timing plans that were retimed. The CFDs can be generated for the before and after period (Figure 15) to quantify the impacts. The before and after diagrams can then be superimposed to determine how travel times changed (Figure 16). In this case, there was a median travel time reduction of nearly 1 minute after the signal retiming, which is demonstrated by the green "after" curve being positioned to the left of the red "before" curve with a separation of 1 minute along the x-axis, at the median (50%) line indicated by the green arrow in Figure 16. This is the type of figure generated by the Travel Time Comparison Tool.



(a) Before



(b) After

Figure 15. CFDs comparing before and after retiming

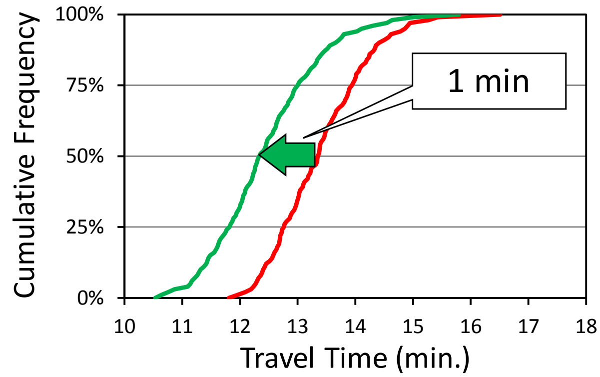


Figure 16. Median travel time improvement of 1 minute after signal retiming

5.3 Multi-criteria Arterial Ranking Tool

The Multi-criteria Arterial Ranking Tool graphs the median and interquartile range (IQR) of normalized travel times for one or more corridors of the 138 super-critical corridors identified in District 6. A screen shot of the application is shown in Figure 17. This application is geared towards users who would like to evaluate the performance of multiple corridors in a county or region at once, and compare corridors to each other objectively by using posted speed limits in each corridor. This dashboard ranks corridors by both the central tendency of travel time, using the median value, and the reliability of travel time, using the IQR, which is defined as the difference between the 75^{th} and 25^{th} percentiles. A larger IQR indicates more variable and less reliable travel time. The travel times in this tool are normalized to the speed limit travel time to facilitate comparison among multiple corridors.

The Multi-criteria Arterial Ranking Tool allows the user to select one or more corridors from the "Corridor" menu or directly from the map. The "Corridor" menu lists corridors in submenus defined by each of the counties that comprise District 6. Buttons in each county submenu allows the user to select the top 10 highest ADT corridors, or all corridors at once. In addition, the "Dates" menu allows the user to identify the date range of analysis, days-of-week, and hour of day to analyze.

One date range can be selected for a single analysis, or an additional date range can be added for a before-and-after analysis by checking the "Compare Two Date Ranges" option. In single date range analysis, corridor travel times in the scatter plot are represented by individual points, one for each direction. The included corridors are also identified in the map with the same color. In multiple date range analysis, the resulting scatterplot shows data for each corridor-direction with two connected points. The circular point represents the before value, and the triangular point represents the after value. A corridor that has improved median and IQR travel time is colored in green, while a corridor that has deteriorated median and IQR travel time is colored in red. Corridors where one axis shows improvement while the other has deteriorated is shown in yellow. The same coloration is used on the map for the corridors analyzed after the "Generate Graphs" button is clicked.

By clicking the "Generate Graphs" button, a two-dimensional scatter plot is generated on the left-hand panel. The x-axis represents the median travel time of a corridor as a percentage of the speed limit travel time, e.g. at 100% the travel time is at the posted speed limit. The user can also plot a one-dimensional column graph by unchecking one of the "Display Axes" options to visualize only the normalized IQR or median travel time. In addition, a table that ranks corridors in terms of their normalized median and IQR travel times is produced. The ranking methodology is explained in more detail in the next section.

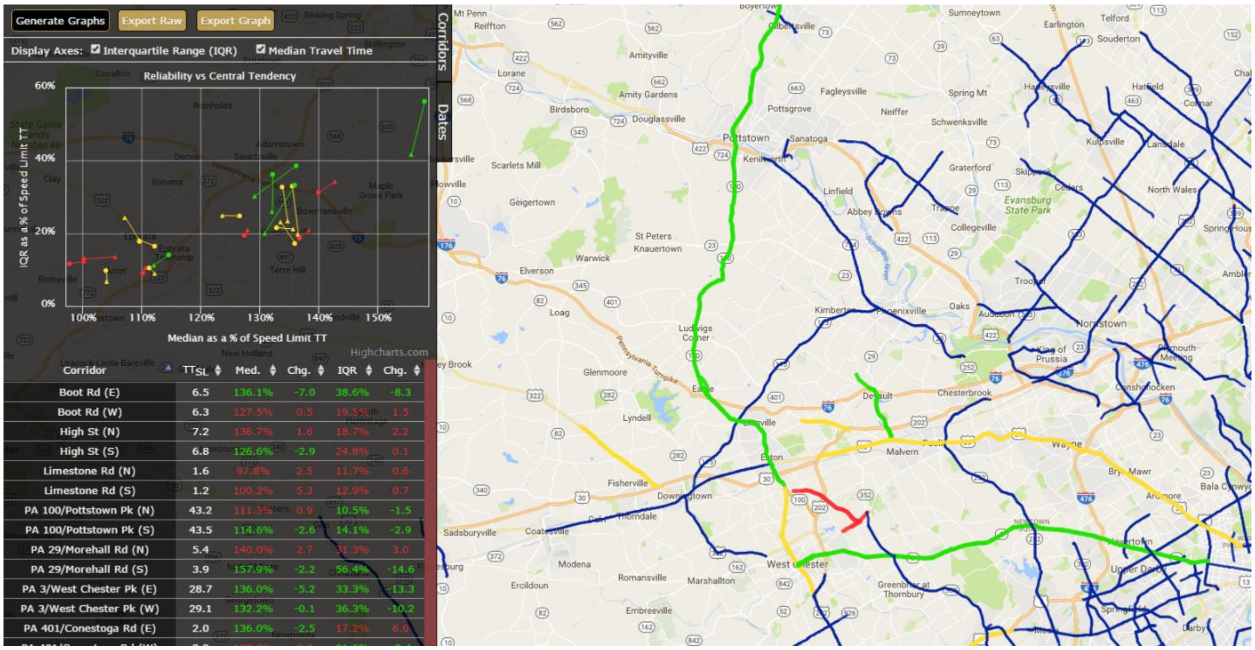


Figure 17. Multi-criteria arterial ranking tool

5.4 Multi-criteria Arterial Ranking Tool – Metric Explained

The Multi-criteria Arterial Ranking Tool uses posted speed limit values stored in the SQL database to normalize travel times of each corridor. Typically, corridor travel time performance can be evaluated by developing distributions of measured travel speeds and extracting metrics from percentiles of the distribution or other statistical properties *(12)*, as used in the before-and-after CFDs of the Travel Time Comparison Tool. However, because the speed limits and the lengths of individual corridors vary, comparisons between different corridors require that the travel times be normalized. In this tool, the normalization is done by expressing the travel times as a percentage of the speed limit travel time. In the case that a corridor has multiple posted speed limits along its route, a distance-weighted average of all posted speed limits is used. The speed limit travel time is not necessarily equivalent to a "free flow" travel time, since free flow may occur at faster (or slower) speeds than the posted speed limits. Instead, it represents the ideal travel time for a vehicle traveling at the legal maximum speed, if unimpeded by delays due to traffic control, road work, congestion, weather, geometry, or other causes.

Another normalization method is to divide the travel times by route distance in order to derive a metric such as "minutes per mile" for individual corridors. This type of metric is helpful for use cases such as deciding between alternative travel routes. This method was not selected for the corridor ranking tool because of the degree to which speed limits vary among corridors in the region. A distance-weighted metric would necessarily have higher (worse) values for corridors with lower speed limits, which might have resulted in a corridor exhibiting poor performance even though vehicle speeds may have been near the posted speed limits.

5.4.1 Speed Limit Travel Time Normalization

Consider the travel times on two separate corridors over a study period. The days-of-week analyzed are Monday through Friday. The first corridor, Newton Bypass, runs over a length of 4.2 miles with 11 signals and an AADT of 35,015. The second corridor, US-1/State Rd/Township Line Road/City Ave, runs over a length of 10 miles with 40 signals and an AADT of 35,628. The speed limits on Newtown Bypass and US-1 are 45 mph and 55 mph respectively. Figure 18 shows their median measured travel times and speed limit travel time over a 24-hour analysis period on both directions of travel. Because of the different lengths and speed limits of the corridors, without normalization the two corridors are difficult to compare.

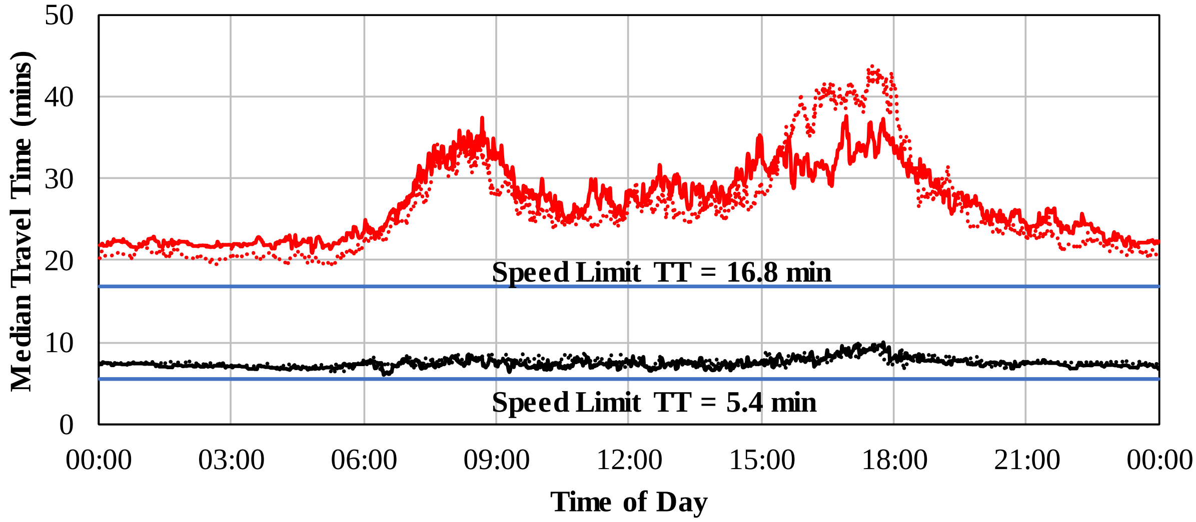


Figure 18. Median travel time and speed limit travel time on Newtown Bypass (shown in black) and US-1 (shown in red) for the study period 12/5/2016 to 12/10/2016

To rank their performance irrespective of their distances and posted speeds, it is necessary to convert the travel times to a normalized metric. As mentioned earlier, one way to do this that allows for an objective comparison of corridors with different posted speed limits is to divide each travel time sample by the speed limit travel time. The normalized travel time (TT) is computed as follows:

$$\text{Normalized TT} = \frac{\text{Median TT}}{\text{Speed limit TT}} \tag{1}$$

Figure 19 shows the normalized travel times of the two corridors from Figure 18. The blue line signifies the travel time at the speed limit at 100%, after normalizing for each corridor’s distance and speed limit.

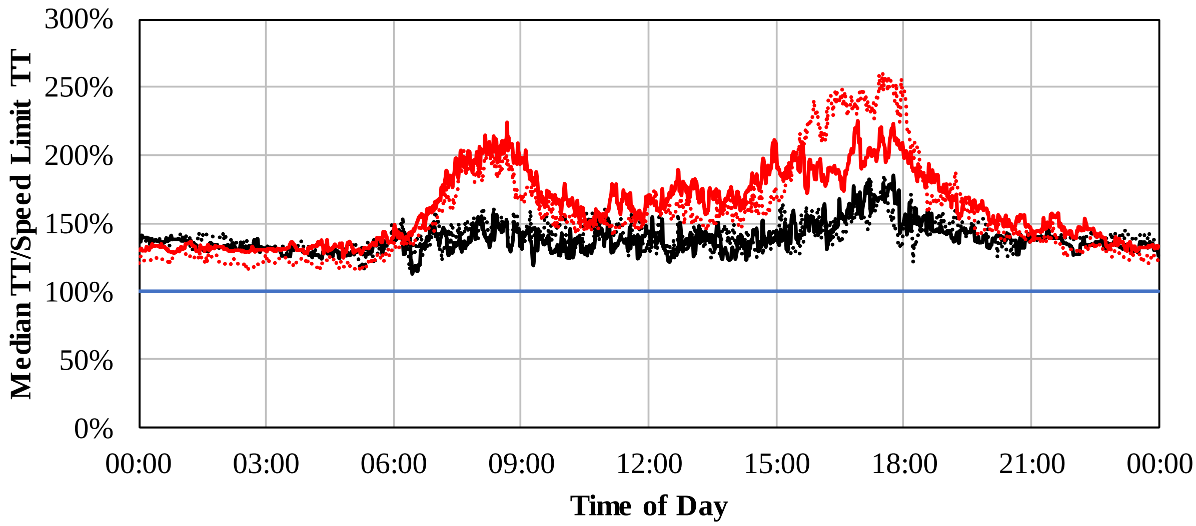


Figure 19. Normalized travel time, with Newtown Bypass (shown in red) and US-1 (shown in black)

The travel time over any study period for a particular corridor can then be expressed as a percentage of the speed limit travel time. For example, a value of 100% represents travel time that would be equivalent to that of a vehicle traveling at the posted speed from end to end, while a value of 150% would indicate that the travel time is 50% longer than that of a vehicle traveling at the posted speed. This perspective enables several corridors to be ranked, providing a means of prioritizing corridors for allocation of resources. Figure 20 shows an example where the top 10 AADT corridors in Philadelphia County were ranked on the basis of the speed limit travel time, using weekday AM (0600-0900) data between March 27 and March 31. In this case, travel time on the southbound direction of the 52nd St. southbound corridor was 292% of the speed limit travel time. This graph was generated using the "Export Graph" feature in the Multi-criteria Arterial Ranking Tool.

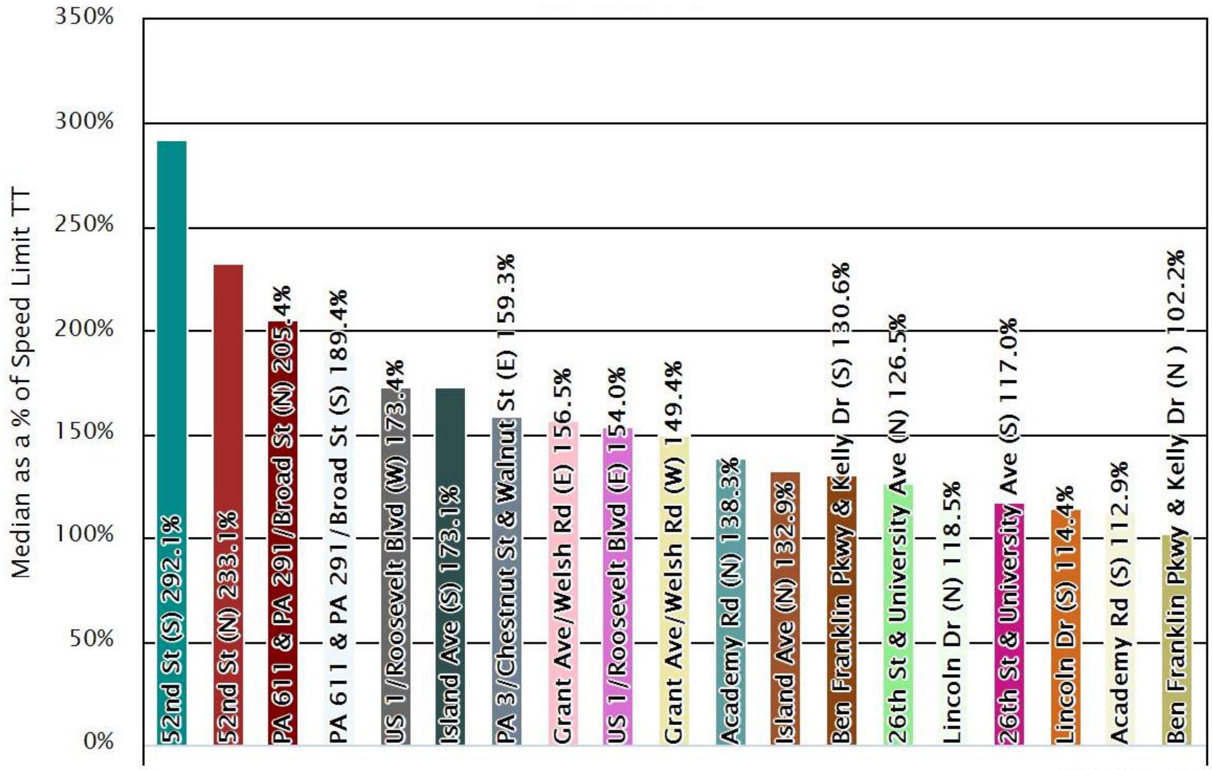


Figure 20. Ranking the corridors based on the speed limit travel time

5.4.2 Interquartile Range (IQR) Normalization

The interquartile range (IQR) is the difference between the 75th and 25th percentile travel time for a period of analysis, and can be used to quantify the reliability of travel time of each corridor. Figure 21 shows the 75th and 25th percentile values obtained from a hypothetical CFD.

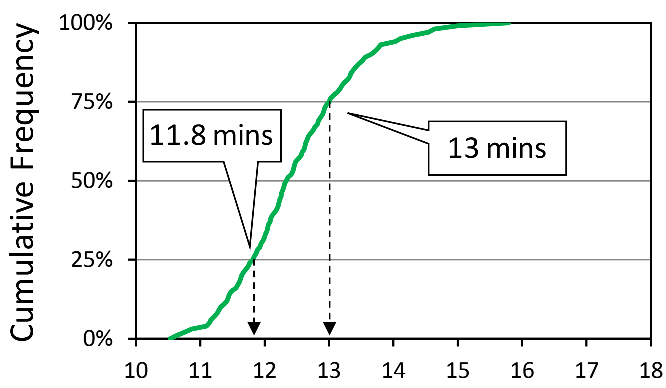


Figure 21. 25th and 75th percentiles

The posted speed limit of the corridor is then used to normalize the IQR. The normalized IQR is calculated as follows:

$$\text{Normalized IQR} = \frac{(75^{th}\ \text{percentile TT - } 25^{th}\ \text{percentile TT})}{\text{Speed Limit TT}} \tag{2}$$

IQR ranking of multiple corridors can be performed in a similar way as the normalized speed limits. Higher percentages denote lesser reliability on the corridor. In Figure 22, the IQR for the same 10 corridors in Philadelphia County are plotted for the same time period. The 52nd St. southbound corridor was found to be 120% of the speed limit travel time, indicating low reliability. In other words, the range of likely travel times varies by as much as 120% of the travel time at the speed limit.

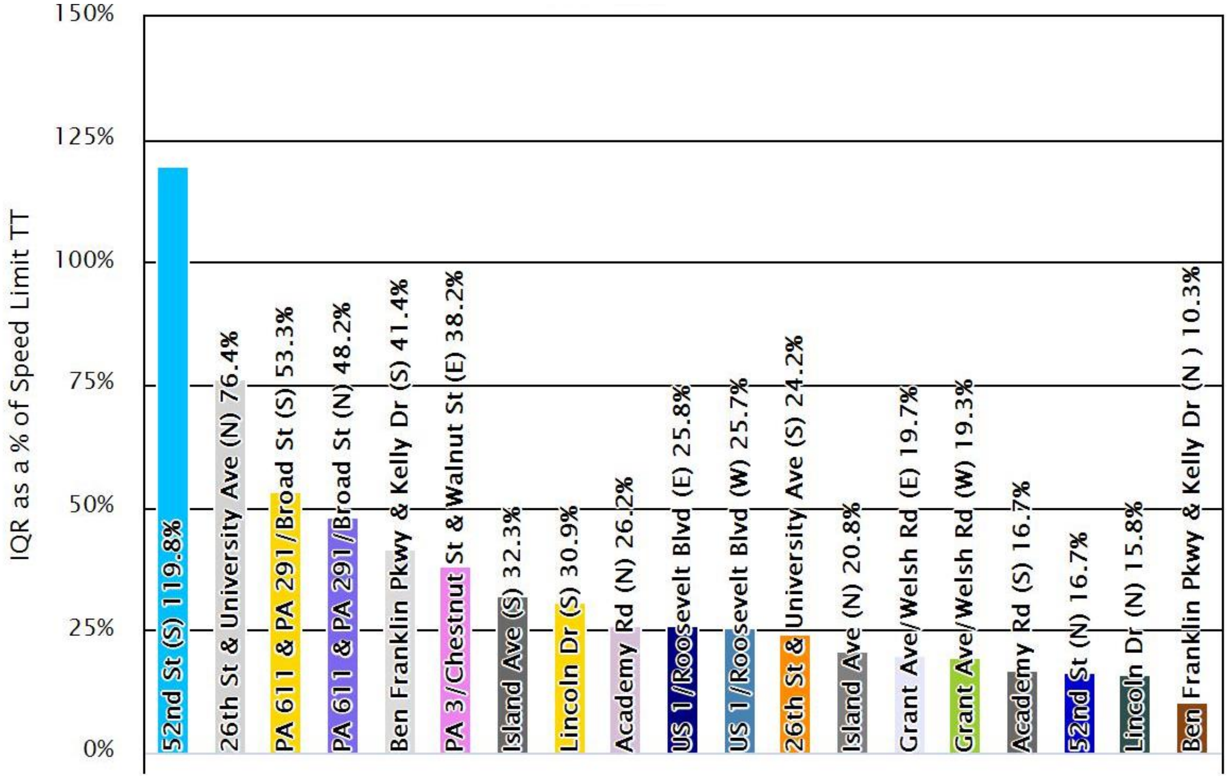


Figure 22. Ranking the corridors based on the interquartile range

5.4.3 Speed Limit and IQR Normalization

The speed limit and IQR normalization metrics can be combined together in a two-dimensional scatter plot to identify corridors with higher travel time tendencies and lower reliability. Figure 23 shows such a plot. Here, corridors in the upper-right-hand region are relatively slower and less reliable than corridors in the lower-left-hand region. The further upward the scatter point, the less reliable is the travel time of the corridor. The further to the right, the higher the central tendency of the travel time for the corridor. Note the 52nd Street southbound corridor in the upper-right hand corner of the plot, which was previously found to have both the highest median and the highest value of IQR from among this group of corridors during the weekday AM time period.

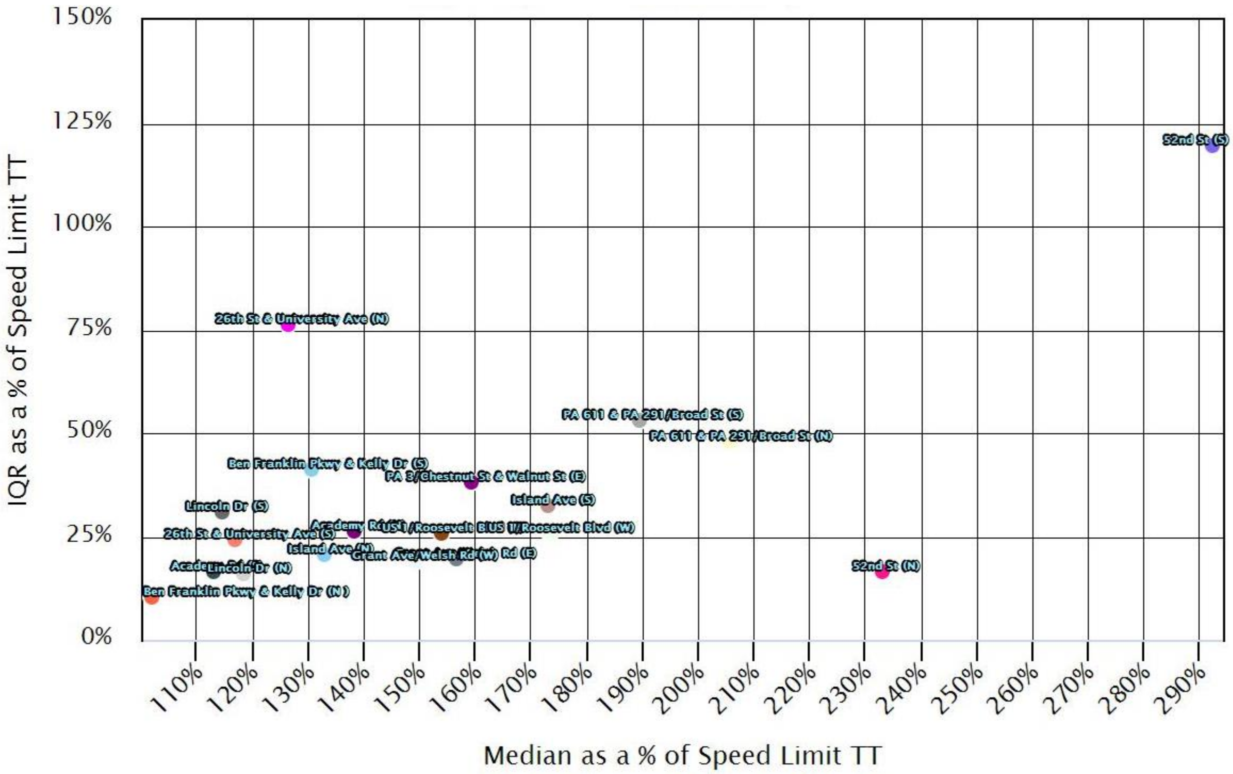


Figure 23. Arterial ranking using both speed limit travel time and IQR

5.5 Travel Delay Monitor Tool

The third web application tool is the Travel Delay Monitor Tool. It is also referred to as the “congestion ticker.” A screen shot of the tool is shown in Figure 24. The tool generates time-series plots for one or more selected corridors that show the cumulative miles of the corridor(s) proportionally colorized by the speed at which the corridor is operating over the selected period. The tool is ideal for users who would like to evaluate a corridor over a specific date range at-a-glance. The chart allows the user to visually identify trends or “spikes” in the profile that can be correlated to specific times that they occur. The tool can also display a ticker for an “after” date range, one on top of the other, to facilitate comparison of two time periods.

The color gradients represent a speed profile at each time instance, represented by eight intervals: greater than 35 MPH (dark green), 30 to 34 MPH (green), 25 to 29 MPH (lime), 20 to 24 MPH (yellow), 15 to 19 MPH (orange), 10 to 14 MPH (red), 5 to 9 MPH (pink), and less than 5 MPH (purple). This tool can be used to identify specific times of heavy congestion on a corridor over a linear time period, and how many miles of a corridor are operating at a certain speed range.

The left-hand panel allows the user to select one or more corridors from a list, or the corridors can be selected directly from the map itself. The “Date Range” menu allows the user to select the before and after date range. Clicking the “Generate Graphs” causes the ticker charts to appear. There are four graphs generated per corridor: two for each direction and two for the before-and-after analysis. The user can then click on a specific 15-minute “slice” of time on any graph to zoom in on the corridor. The corridor segments are also colorized based on the speed profile colors during the selected time slice. Finally, both the graph and the raw data can be exported using the "Export Graph" and "Export CSV" buttons on the top of the right-hand panel.

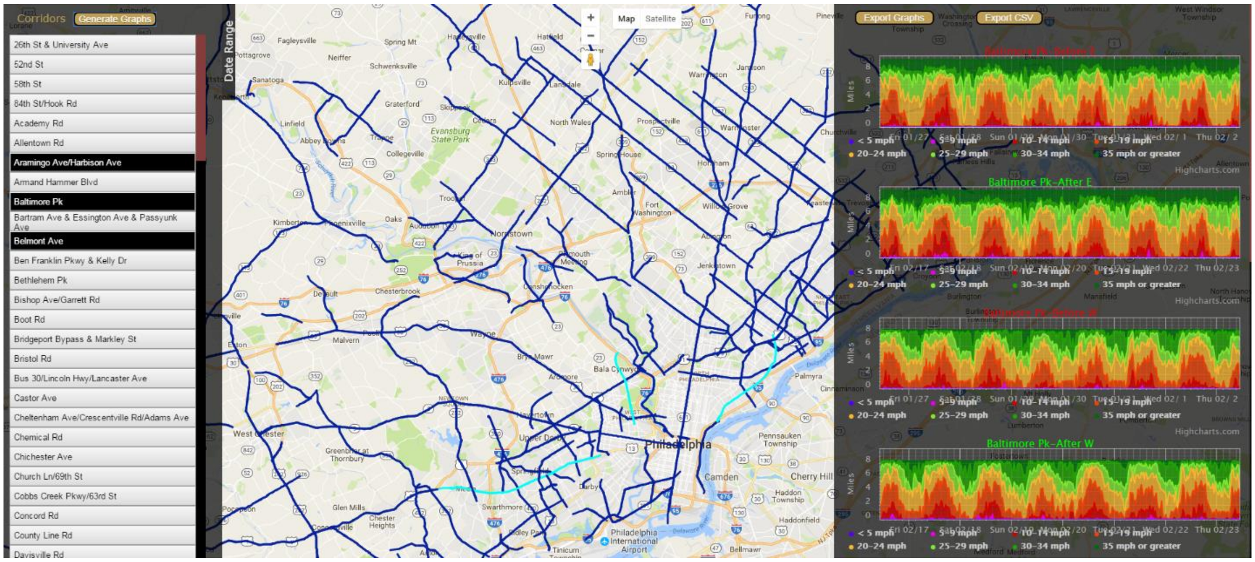


Figure 24. Travel Delay Monitor

5.6 Travel Delay Monitor Tool – Metric Explained

The stacked-area plot in the Travel Delay Monitor Tool is a visual representation of the number of miles within a corridor that fall within different speed categories. The top edge of the chart represents the total length of all the segments and is therefore representative of the length of the corridor. The order of the segments along the corridor is not relevant to this particular chart. Rather, the chart provides a visual illustration of the overall severity of congestion and delay as it varies over time.

Figure 25 shows the Travel Delay Monitor Tool for the northbound direction on Ben Franklin Parkway and Kelly Drive between Friday, January 27 and Thursday, February 2. For the majority of the period, the corridor operates above 24 MPH for about 5 out of the 6 miles. Callouts in the figure point to instances where more than two miles of the corridor had speeds under 25 MPH.

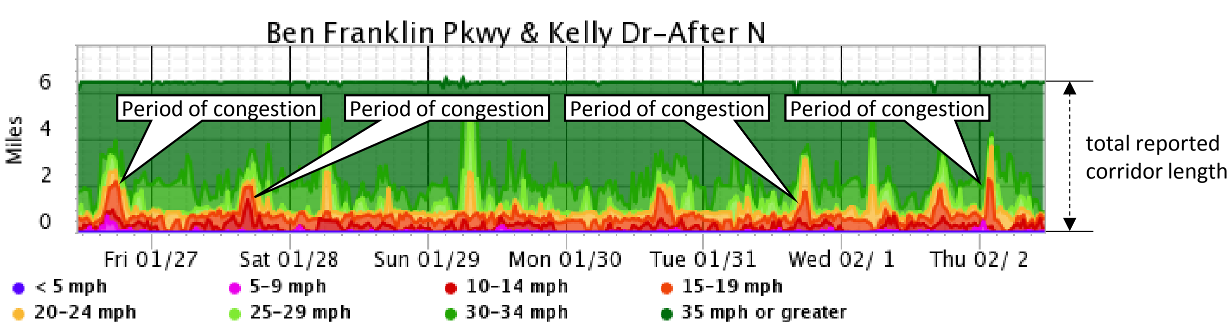


Figure 25. Travel delay monitor graph over a 1-week period

To further explain how to interpret the figure, Figure 26 shows a further breakdown of a time slice represented in the Travel Delay Monitor Tool. Here, the vertical slice from the graph is represented as a pie chart. Each slice of the pie represents the percentage of the corridor's total length that is operating at the specified speed range. The entire pie graph represents the total length of the corridor. For example, during this particular time period, 40% of the total roadway length had speeds of 35 mph or greater, and 60% of the roadway length had speeds under 35 mph.

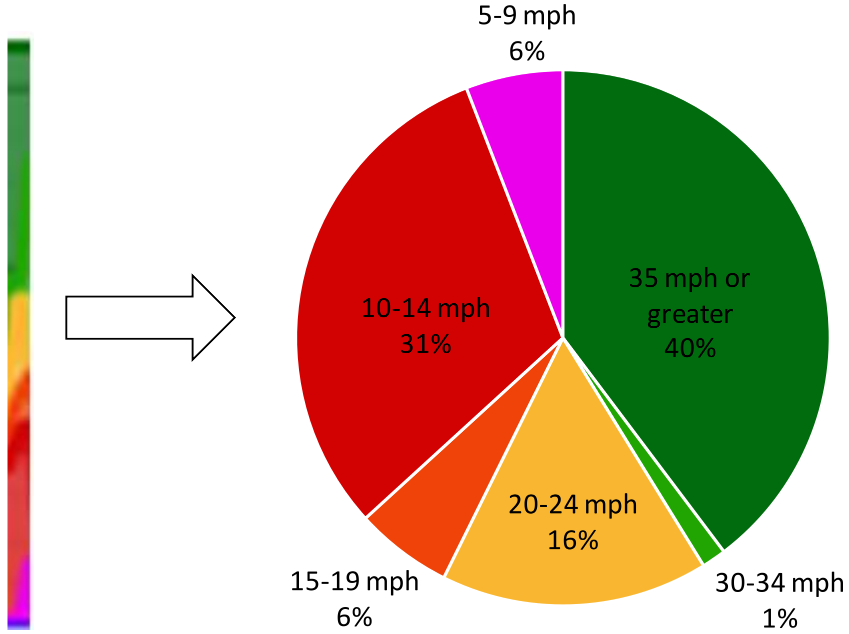


Figure 26. A 15-minute slice of the graph generated by the Travel Delay Monitor Tool, and its respective speed breakdown over the entire length of the corridor

6. USER BENEFITS METHODOLOGY

6.1 User Cost Savings Due to Improved Travel Time

The calculation of user benefits is achieved through the use of existing annual average daily traffic (AADT) data provided for the corridors in combination with information found in the 2014 Pennsylvania Traffic Data Report *(14)*.This report provided data on hourly vehicle and truck traffic percentages. These numbers are determined for 92 study locations across the state. Each of these locations are categorized into 10 traffic pattern groups. The five corridors in this study are defined as "TPG 3, Urban – Other Principle Arterials." Additional user benefit design values were adapted from the *2015 Urban Mobility Scorecard (15),* including vehicle occupancy, commercial vehicle operating cost, and average cost of time. The time period selected for the analysis is from 6:00 AM to 8:00 PM.

The hourly volumes are estimated by equation (3)

$$vol_i = AADT * k_i * d \quad (3)$$

where,

vol_i =	estimated volume for hour i
AADT =	annual average daily traffic
k_i =	hourly vehicle percentages from *(14)*
d =	directional distribution (assumed to be 0.5)

The difference in travel time for each hour, before and after the adaptive signal deployment is calculated using the following equation

$$\Delta TT_i = TT_{before,i} - TT_{after,i} \quad (4)$$

where,

$TT_{before,i}$ =	median travel time during the before period for hour i
$TT_{after,i}$ =	median travel time during the after period for hour i

The user benefit for trucks during each hour is then calculated using equation (5)

$$user_{truck,i} = vol_i * \Delta TT_i * \%T_i * PPV_t * VOT_t \quad (5)$$

where,

$\%T_i$ =	percentage of truck traffic for hour i, from *(14)*
PPV_t =	number of passengers for commercial vehicles (1 for trucks)
VOT_t =	time value of money for commercial vehicles, $94.04/vehicle-hr from *(15)*

Similarly, the user benefits for passenger cars were computed using equation (6)

$$user_{car,i} = vol_i * \Delta TT_i * \%C_i * PPV_c * VOT_c \quad (6)$$

where

$\%C_i$ =	percentage of car traffic for hour i, assumed as $(1-\%T_i)$
PPV_c =	number of passengers, 1.25 for cars from *(15)*
VOT_c =	time value of money for passenger cars, $17.67/person-hr from *(15)*

6.2 Carbon Dioxide Savings

In addition to the user costs, changes in carbon dioxide (CO_2) emissions are computed using the method adopted by Day *et al*. *(16)*. Using conversion factors from the Argonne National Laboratory, a passenger car is expected to consume 0.87 gal of gasoline per hour. This number is conservatively used to determine the fuel consumption, as given by equation (7)

$$fuel = \Delta TT * vol * \frac{0.87 gal}{hour} \quad (7)$$

Equation (8) computes the CO_2 emissions in tons. According to the U.S. Environmental Protection Agency (EPA), the amount of CO_2 emitted when a gallon of gasoline burns is approximately 19.6 lb/gal *(17)*.

$$CO_{2\ emissions} = fuel * \frac{19.6\ \text{lb}}{gal} * \frac{1\ \text{ton}}{2,000\ \text{lb}} \quad (8)$$

The EPA also estimates the social cost of CO_2 as $36/ton *(18)* and the cost of CO_2 is determined using equation (9).

$$CC = CO_{2\ emissions} * \frac{\$36}{ton} \quad (9)$$

7. CASE STUDIES

7.1 Five-Corridor Before-and-After Analysis

7.1.1 Location

Five corridors where adaptive signal control was deployed within the past 12 months were selected for before-and-after analysis. Table 2 provides a listing of these corridors and their characteristics. These five arterials account for over 180,000 vehicles per day in total, and are highlighted in Figure 27. The density of signals on these five corridors is roughly 3.3 signals per mile on average. Some of these corridors are particularly long, and included a mixture of segments with conventional signal control as well as other segments with adaptive signal control. Altogether, 61 out of 186 signals had adaptive control installed on these five corridors during the study period (Figure 28).

This study analyzes the impact of these adaptive deployments on arterial travel times using minute-by-minute representative speeds from probe vehicles along pre-defined roadway segments over the targeted date ranges defined in Table 2. The before date range indicates the period prior to adaptive deployment, and the after period samples the effect of the deployment on the travel times. The speed limits of the segments were also tabulated for each segment to determine travel times in absence of congestion or control delay. The speed limits along the corridors varied between 25 and 55 mph and were accounted for in the analysis.

Table 2. Corridor Information

Corridor ID	Corridor Name	AADT	Length (mi)	Average Speed Limit (mph)	Signal Count (Adaptive Signals)	Before Date Range	After Date Range
A1	PA 132 / Street Rd	33,965	15.2	45	50 (21)	10/12/2015–11/23/2015	1/4/2016–2/15/2016
A2	PA 332 (Newtown Bypass)	35,015	4.8	53	12 (12)	2/22/2016–4/4/2016	4/25/2016–6/6/2016
A3	US 1/State Rd/Township Line Rd/City Ave	35,268	10.0	36	40 (4)	10/12/2015–11/23/2015	3/7/2016–4/18/2016
A4	US 202/Wilmington Pkwy	46,553	8.6	45	16 (9)	9/4/2015–10/26/2015	1/4/2016–2/15/2016
A5	PA 611/Old York Rd/ Easton Rd	30,919	16.3	42	68 (15)	4/27/2015–6/8/2015	1/4/2016–2/15/2016

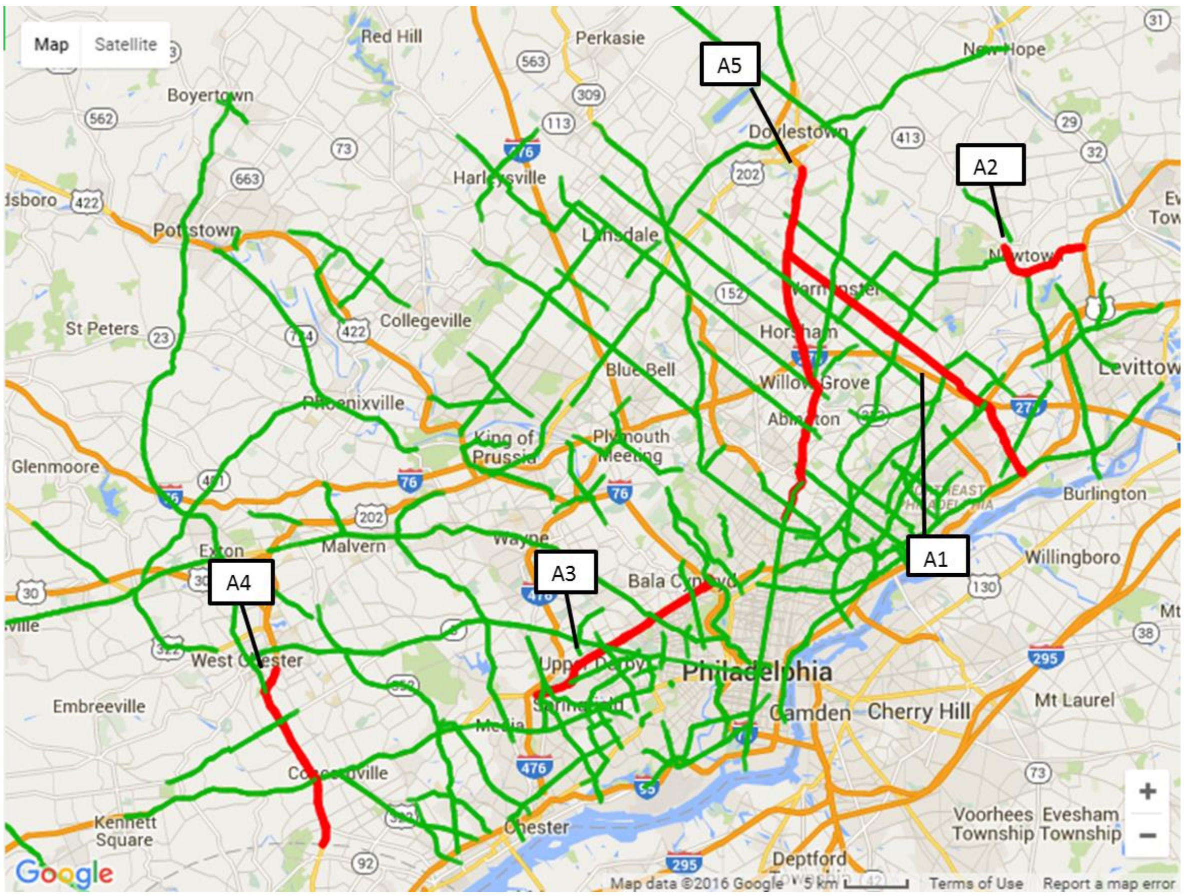
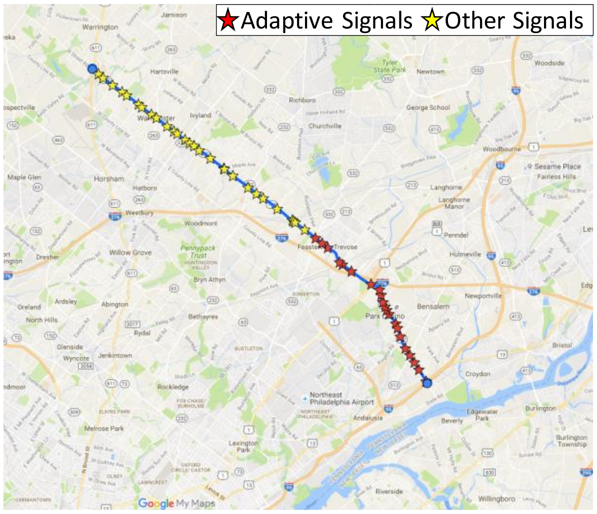
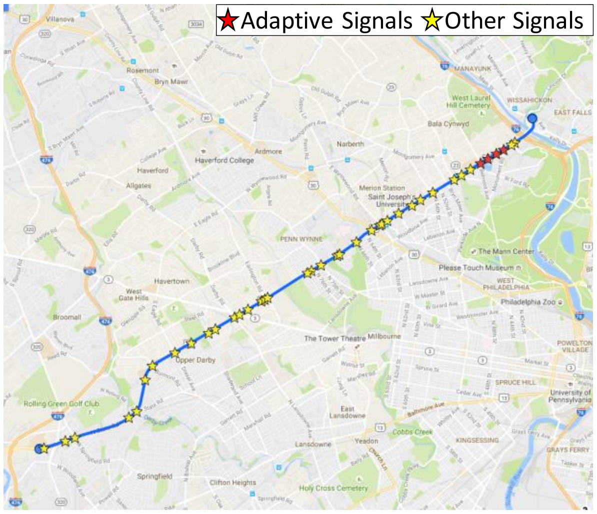


Figure 27. Selected corridors in Greater Philadelphia area

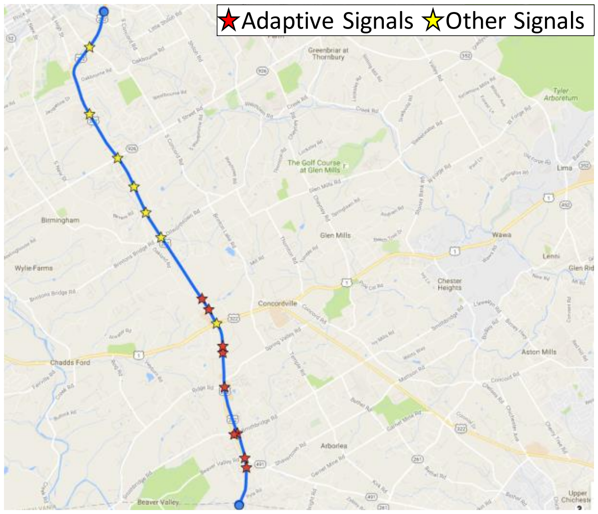


(a) A1 (15.2 miles corridor)

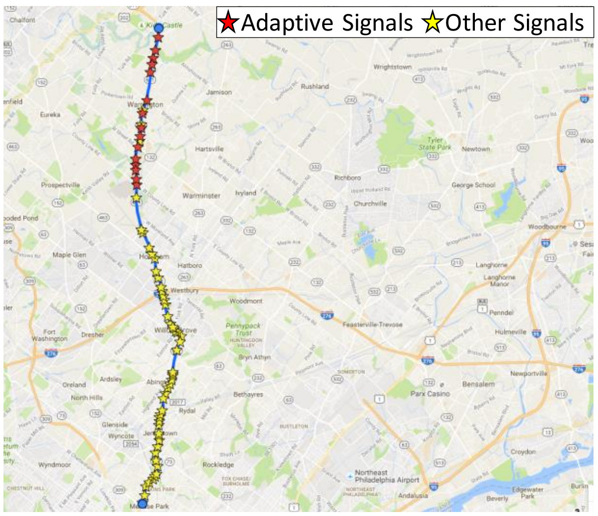
(b) A2 (4.8 miles corridor)



(c) A3 (10 miles corridor)



(d) A4 (8.6 miles corridor)



(e) A5 (16.3 miles corridor)

Figure 28. Corridor maps of intersections running adaptive control

7.1.2 Travel time distributions for a single corridor

Figure 30 illustrates two cumulative frequency diagrams (CFDs) for corridor A3 comparing a six-week period in October/November 2015 (before adaptive control deployment) and another six-week period in March/April 2016 (after deployment), for the two directions of travel. The analysis period includes weekdays during the hours of 17:00 and 18:00 representative of the PM peak period, avoiding holidays and periods where winter weather was likely to affect the operation. The eastbound and westbound sections are composed of 21 and 22 travel time segments, respectively (Figure 29). The vertical dotted line in each figure represents the travel time in each direction at the speed limit without stops, while the red and green curves represent the observed distribution of estimated travel times over the before and after periods respectively, during the specified hours.

The CFDs in Figure 30a show an overall reduction in estimated travel times after adaptive control was deployed. For the 25th percentile, median, and 75th percentile, 3.5, 3.6, and 3.7 minutes of respective improvements are estimated in the eastbound direction. The travel times range from 22.8 to 46.9 minutes in the before period, compared to 21.0 to 38.9 in the after period, indicating that travel times were more reliable, with less variation and a slightly steeper curve. Figure 30b shows an even more significant improvement in the westbound direction, with 3.6, 5.6, and 7.7 minute reductions for the 25th percentile, median, and 75th percentile respectively. The travel time ranges from 21.9 to 61.2 minutes in the before period, compared to 18.9 and 42.2 minutes in the after period, showing a substantial improvement in reliability.

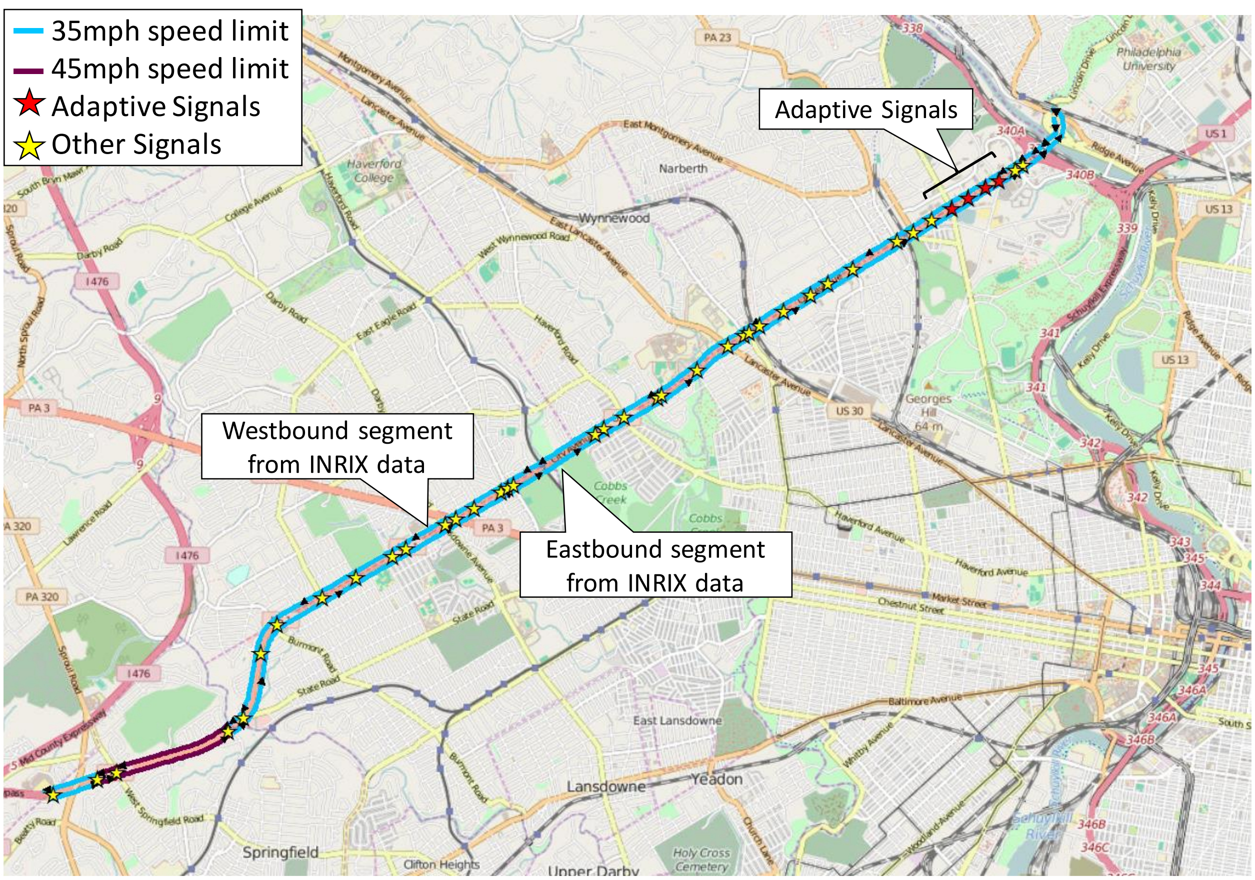
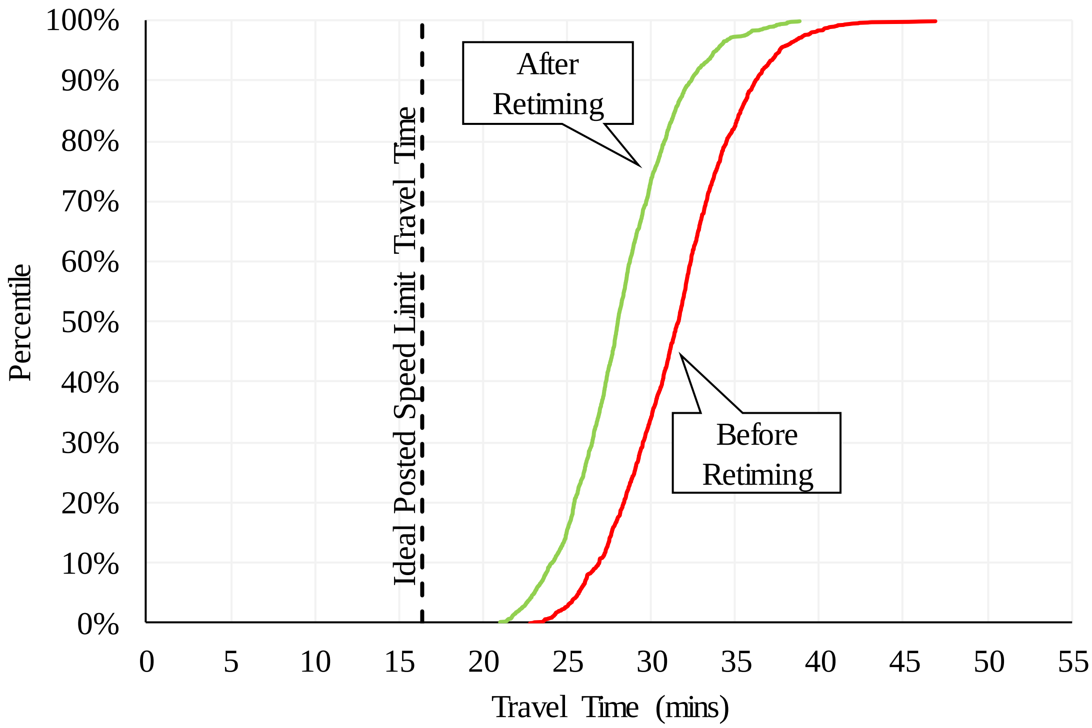
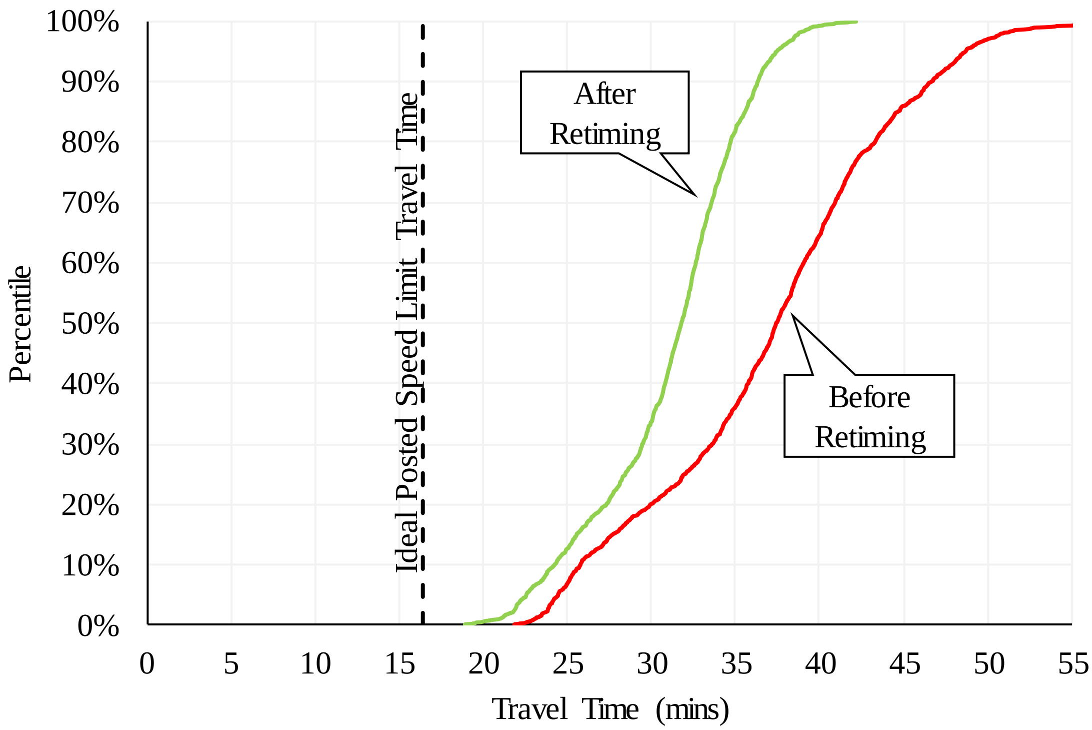


Figure 29. Corridor A3



a) Eastbound



b) Westbound

Figure 30. Corridor A3, Weekdays, 17:00-18:00
Travel Times Before and After Installation of Adaptive Signal Control.

7.1.3 Arterial ranking

Figure 31 shows the before and after change on the five study corridors based on both speed limit and IQR normalization. For each directional route, distinct 6-week "before" and 6-week "after" periods were used to assess the changes in performance associated with the deployment of the adaptive systems. The performance of the "before" period is plotted as a dot, while the "after" period is plotted as a triangle. A line is drawn connecting the two periods associated with the same route. Routes that had decreases in both the median and IQR are colored green, while routes that had increases in both median and IQR degradation are colored red. Corridors with mixed results are colored orange. The corridor with the largest improvement from an adaptive implementation was westbound A3, which had a 34.2-percentage point decrease in the normalized median travel time and a 24.9-percentage point decrease in the normalized IQR travel time. This corresponds to the CFD that was shown earlier in Figure 30b.

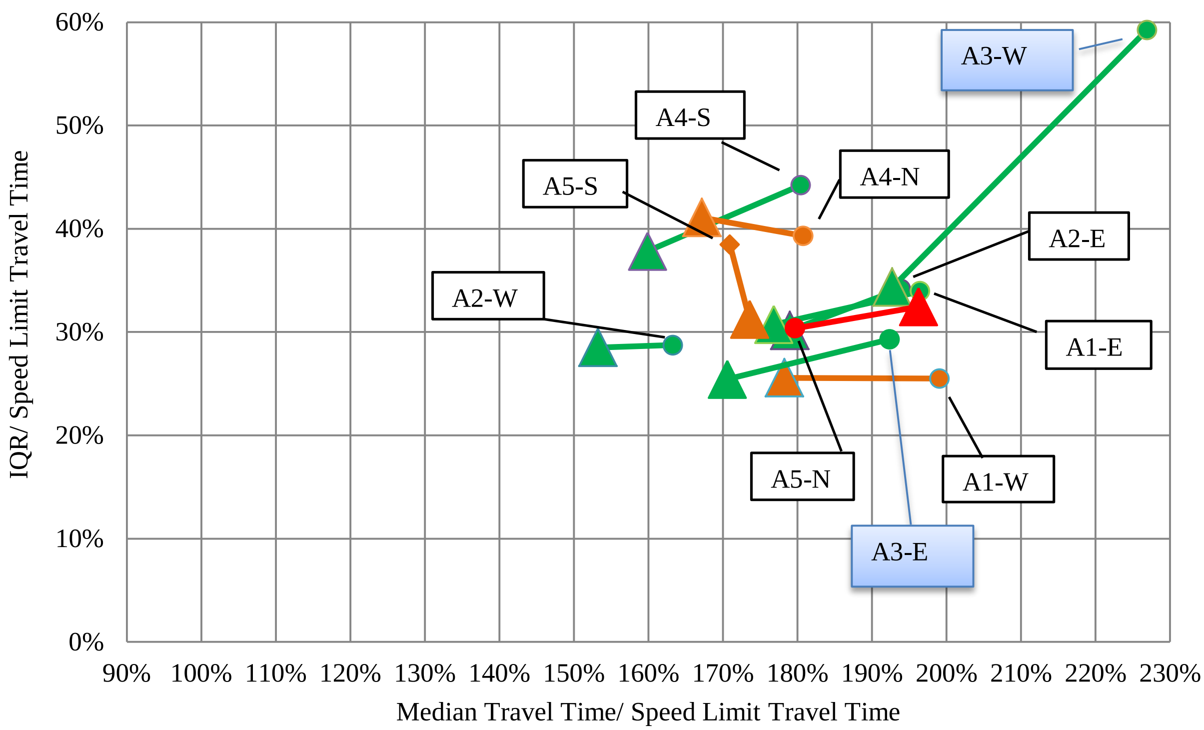


Figure 31. Travel Time and Reliability Trends for Adaptive Installations.
Data is shown for Weekdays, 17:00-18:00, for before and after periods indicated in Table 2.

7.1.4 Hour-by-hour median and IQR evaluation

To effectively characterize a corridor's change in travel performance, it must be analyzed over the entire day. For this analysis, one-hour intervals were analyzed throughout the week, including weekends, from 6:00 AM to 8:00 PM. The travel times before and after the adaptive implementation were evaluated based on median travel times and comparisons of IQR. Before and after evaluation periods were selected to be six weeks in length to compile a more consistent database for comparison. Through these evaluation metrics, a comprehensive and quantitative analysis of the travel times can be represented. However, visual representations of improved travel times can be seen in Figure 32 and Figure 33.

Figure 32 shows that, in general, the greatest improvement in adaptive signals can be made during weekday rush hour. Only corridor A1 saw major improvements during non-rush hour periods. Corridor A2 had the least amount of improvement, however, the existing condition of the signals already had a consistently uniform distribution throughout the day, even during rush hour. Corridor A3 appears to have had the biggest improvement during the weekday rush hours. In fact, for nearly every weekday hour, travel time decreased by 25%. Corridor A4 had an interesting outcome, as, throughout the corridor, the 25% travel time did not decrease. However, overall corridor performance increased with increased reliability through a reduction in the 75% travel time. The opposite is true for corridor A5 evening rush hour, which saw the greatest degradation of all the corridors. Similar increases in travel times were experienced during the morning rush hours in both directions.

Figure 33 shows that a majority of weekend improvements come in the afternoon and evening hours, as is expected. The greatest improvements for weekend traffic can be seen in corridor A1 and southbound A4. As with the weekday travel times, weekends for corridor A2 were very consistent throughout the day. Corridor A3 appears to have the largest evening impact, with travel times increasing by ten minutes when comparing 1 PM to 4 and 5 PM. Corridor A5 continued to have reliability issues throughout the weekend, especially for northbound evenings.

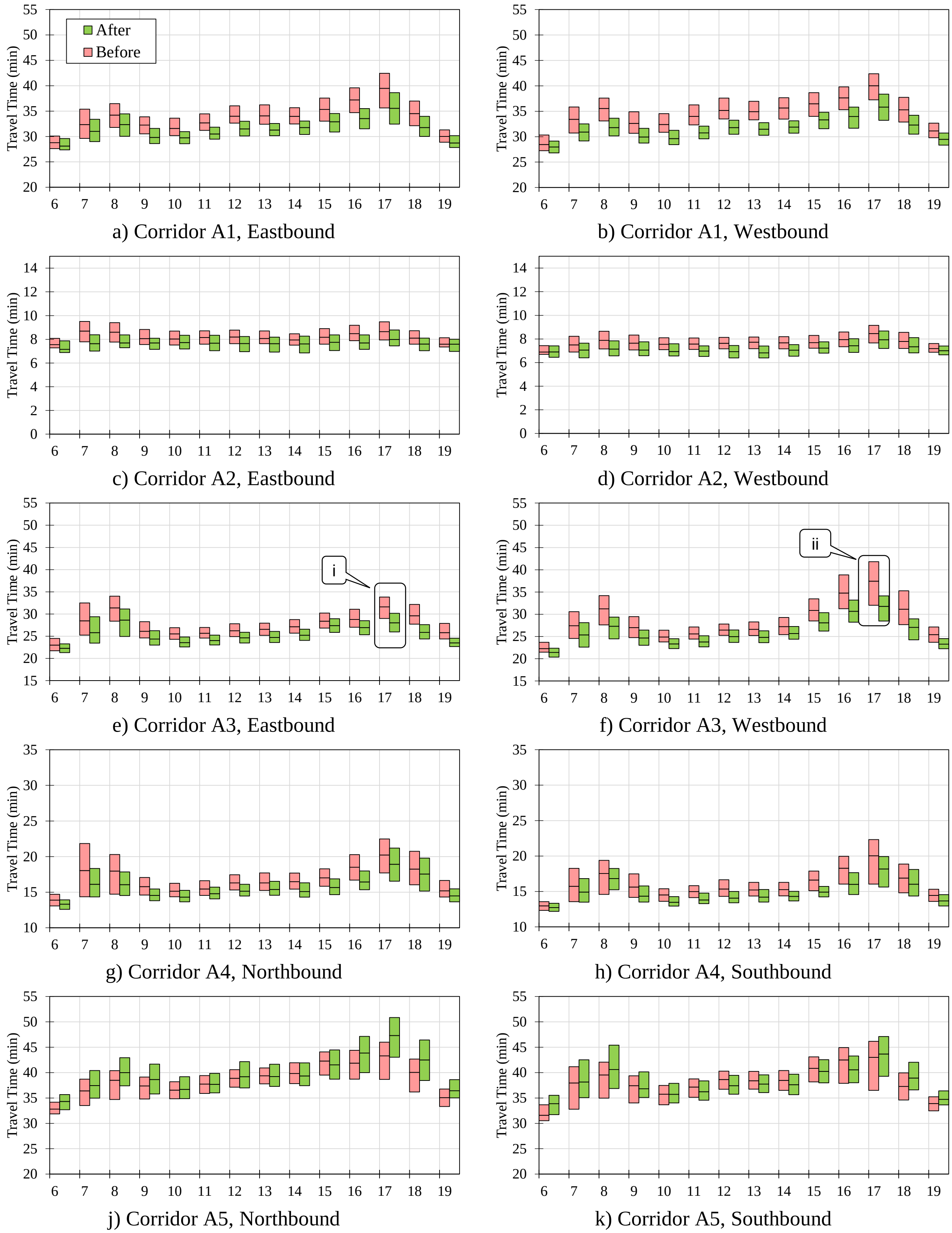
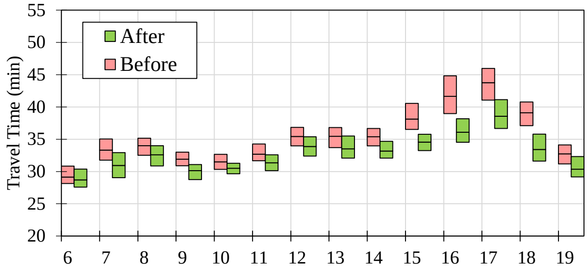
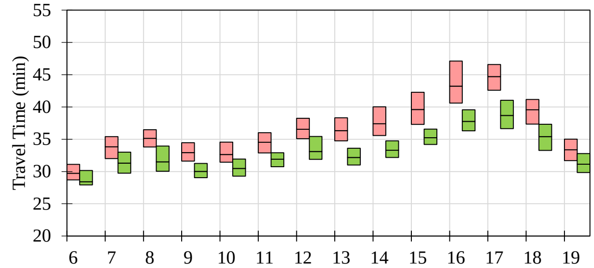


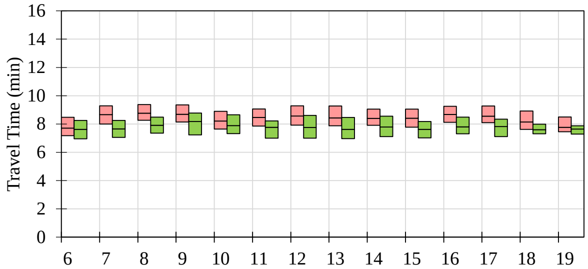
Figure 32. Weekday Median Travel Times and Interquartile Ranges by Hour



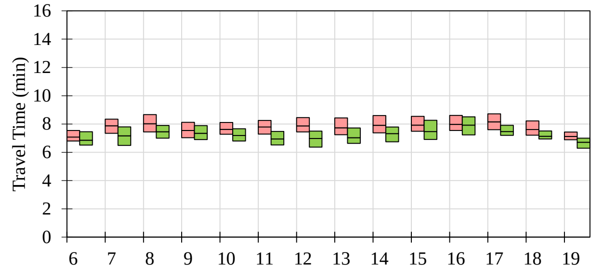
a) Corridor A1, Eastbound



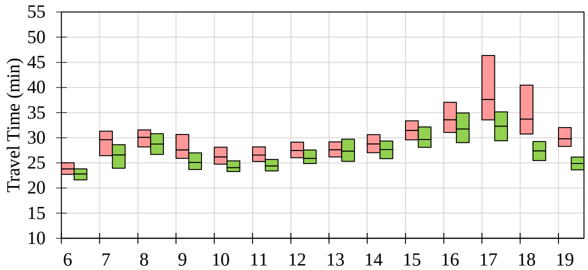
b) Corridor A1, Westbound



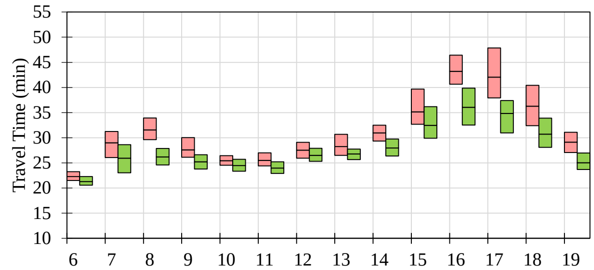
c) Corridor A2, Eastbound



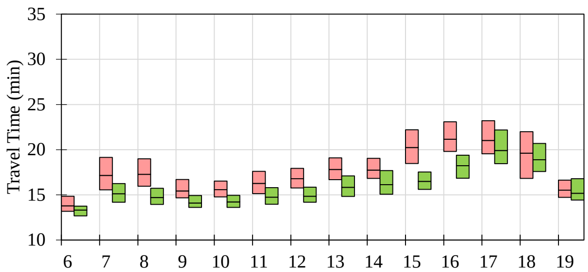
d) Corridor A2, Westbound



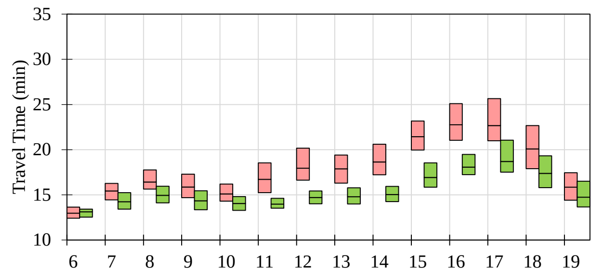
e) Corridor A3, Eastbound



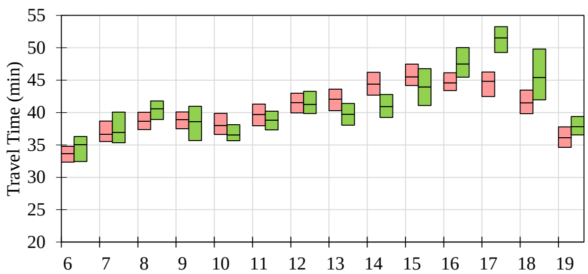
f) Corridor A3, Westbound



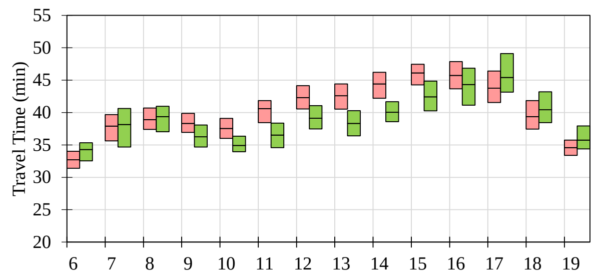
g) Corridor A4, Northbound



h) Corridor A4, Southbound



j) Corridor A5, Northbound

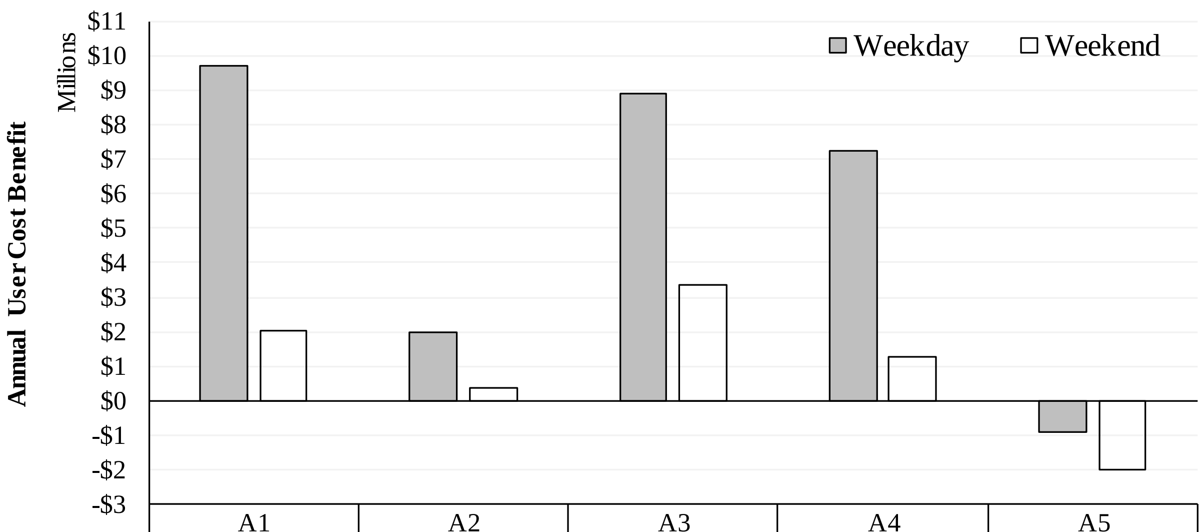


h) Corridor A5, Southbound

Figure 33. Weekend Median & IQR by hour

7.1.5 *User benefits and CO_2 savings*

Analysis was carried out separately for weekdays and weekends, and the user cost/benefits results are shown in Figure 34. Table 3 gives the weekday and weekend savings as well as emissions for CO_2. All corridors saw improvements in annual user benefits and CO_2 savings, except corridor A5. Altogether, these corridors accounted for a $32.0 million annual user benefit and a $369,000 CO_2 yearly savings. The greatest improvements are reflected by weekend totals of $5 million and $58,000, compared to weekday totals of $27 million and $312,000. Of these five corridors, A1 and A3 had the highest user benefit savings and CO_2 savings, totaling $24 million and $277,000. As mentioned previously, corridor A2 had reliable travel times before the adaptive installation and signal retiming activities, and, therefore, had the least amount of travel time impact and cost savings. Corridor A4 had a similar weekend impacts as A1 and A3, but was not as effective for weekdays. Negative user benefit and CO_2 savings from corridor A5 result from increased travel times after the changes. This may be due to unanticipated maintenance and construction activities ongoing during the "after" evaluation period. Overall, the investments showed a positive return for user benefits on four of the five selected corridors.



	A1	A2	A3	A4	A5
Weekday	$9,716,000	$1,995,000	$8,917,000	$7,238,000	-$904,000
Weekend	$2,030,000	$378,000	$3,370,000	$1,247,000	-$2,001,000

Figure 34. Summary of annual user cost/benefits for the five study corridors

Table 3. Summary of Annual CO_2 Emission Reductions for the Adaptive Signals

Corridor	**Weekday CO_2 Savings**		**Weekend CO_2 Savings**	
	Tons	Dollars	Tons	Dollars
A1	3120	$112,000	650	$23,000
A2	640	$23,000	120	$4,000
A3	2890	$104,000	1080	$39,000
A4	2320	$84,000	400	$14,000
A5	-310	-$11,000	-650	-$23,000
Total	**8660**	**$213,000**	**1610**	**$58,000**

7.2 Incidents

The Travel Time Comparison Tool and Travel Delay Monitor Tool developed as part of this project were applied for travel-time analysis following two incidents. The tools make it possible to compare "atypical" traffic patterns due to an incident or special event with a baseline "typical" travel period, and quantify the travel time and speed profile difference. The same procedure can be used to analyze the effects of scheduled maintenance and construction activities.

7.2.1 Gulph Road

Dates and times from major incidents along Philadelphia-area interstates were selected and used to compare against the same date and times of days without incidents. Corridors near the impacted interstates were selected to analyze travel time impacts on those corridors. Varying delays on the arterials were observed. One area that experienced a very extensive impact was I-76 West along the Gulph Road corridor, as shown in Figure 35.

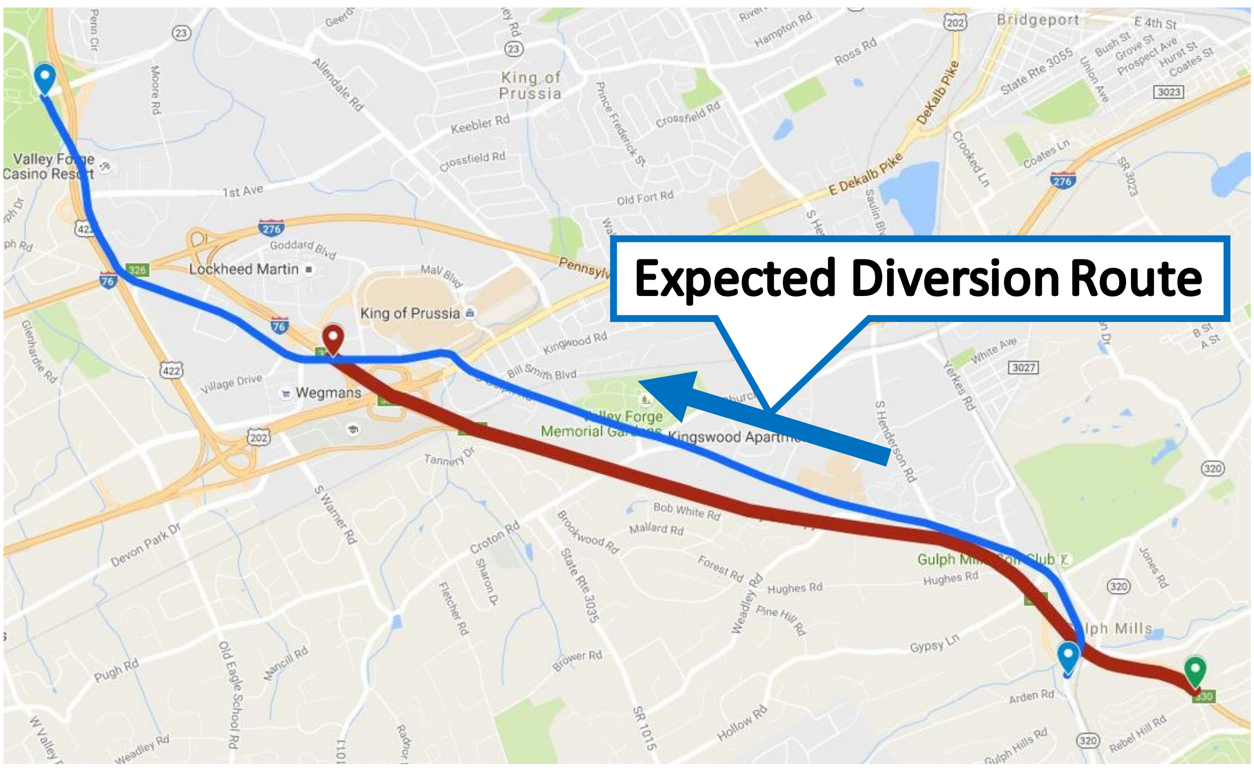


Figure 35. I-76 West accident impact (red) and expected Gulph Rd detour (blue)

The red line represents the total length of the accident impact along I-76, and the blue line is the full length of the Gulph Rd corridor. This incident was reported as a multi-vehicle accident that occurred on Tuesday, April 19, 2016. Police arrived on the scene at 16:02 and left at 20:49. The travel time impacts of this incident on the Gulph Rd corridor are highlighted in Figure 36 using the Travel Time Comparison Tool for the before and after periods.

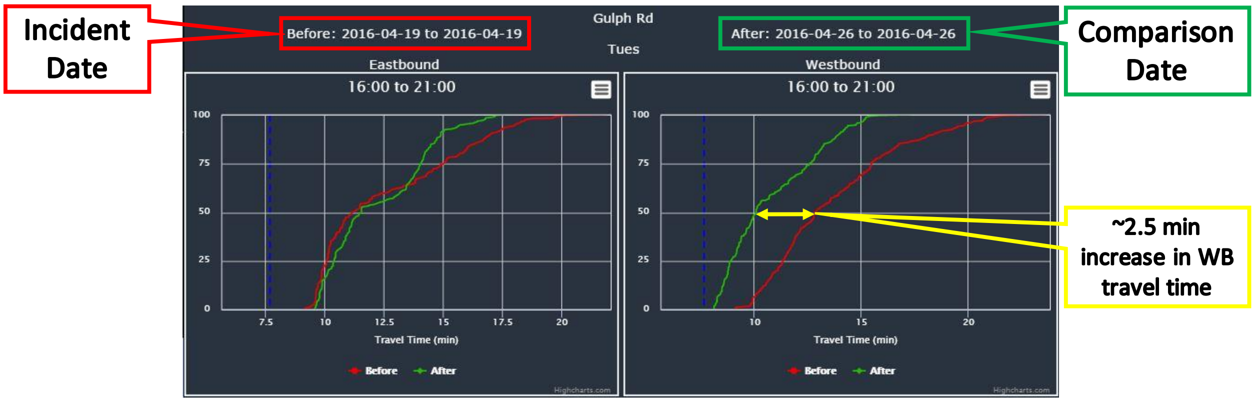


Figure 36. Travel time impacts on Westbound Gulph Rd

As illustrated by the graph, there was a 2.5 minute increase in the travel time at the median during the detour in the westbound direction. The eastbound direction also experienced greater travel times for the upper-75th percentile. Figure 37 shows the effects of the detour in the westbound direction using the Travel Delay Monitor Tool. From the graph, a much larger percentage of the corridor length was operating below 25 MPH during the time of the incident (top graph) compared to the week before the incident (bottom graph).

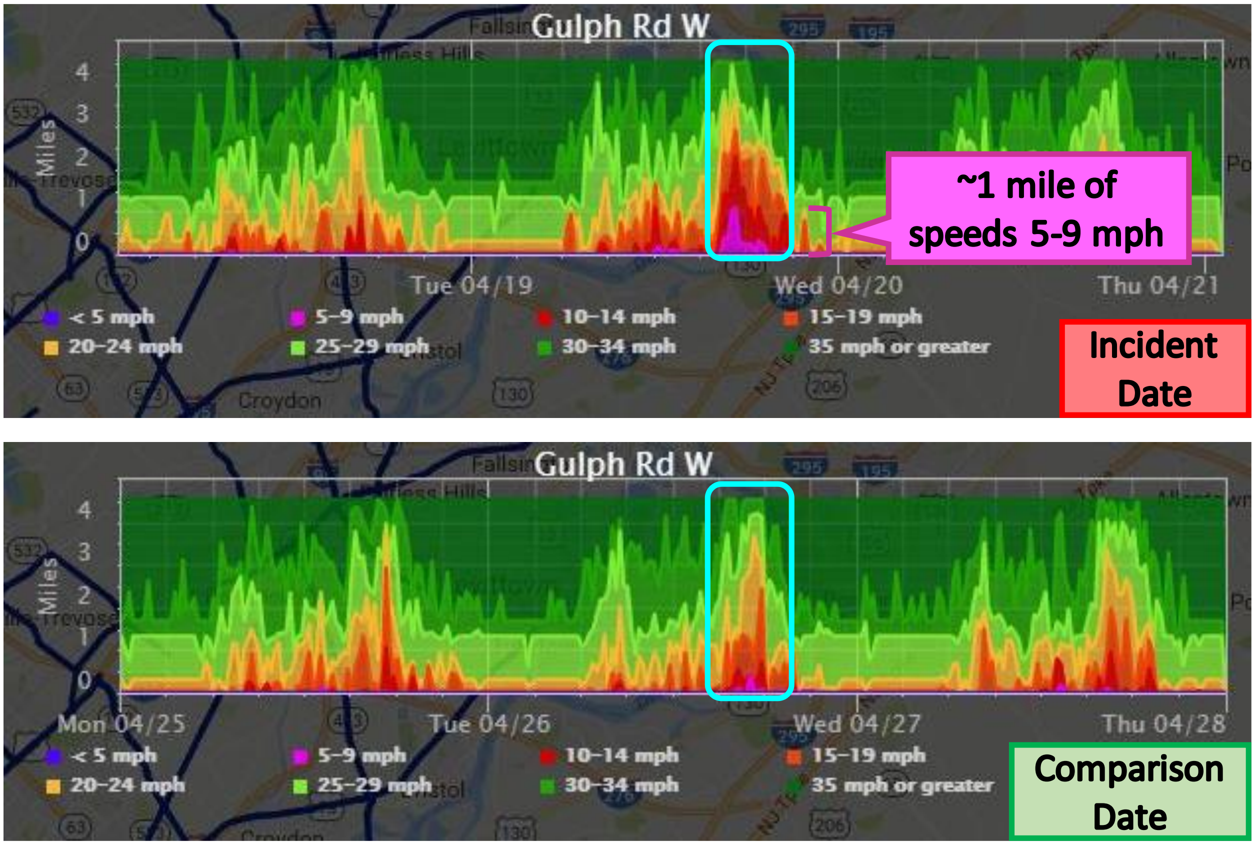


Figure 37. Congestion heat map of Westbound Gulph Rd

Figure 37 shows that, for a short period of time, there was nearly a mile of traffic having speeds in the 5 to 9 mph range. For reference, speed limits on this corridor range from 35-45 mph. This 1-mile impact affected nearly 20% of the 5.2-mile-long Gulph Road corridor.

7.2.2 Belmont Avenue

The following example shows an incident with a different degree of impact in the arterial travel times. Figure 38 shows the location of the incident.

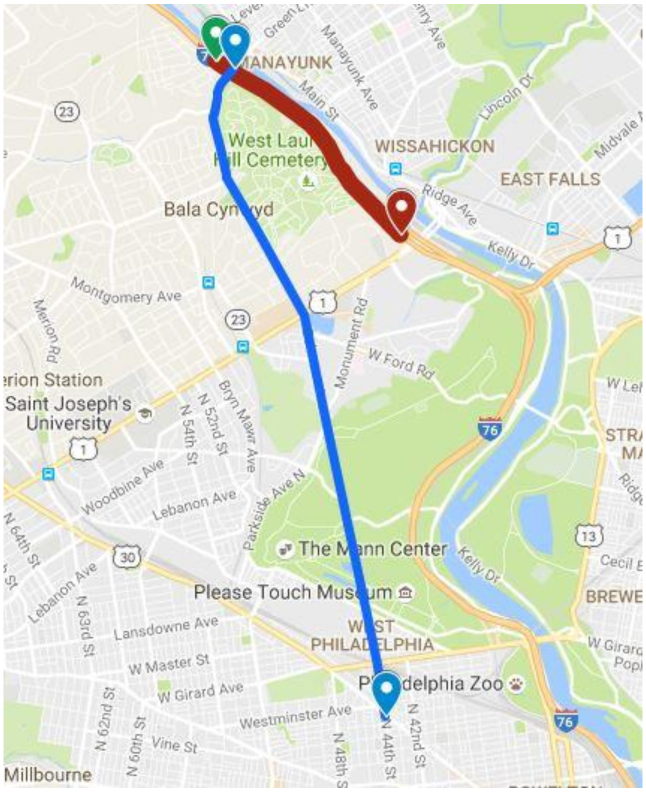


Figure 38. I-76 East accident impact (red) and Belmont Ave. detour (blue)

The incident was reported as a single-vehicle accident that occurred on Saturday, August 13, 2016. The police arrived on the scene at 09:28 and left at 11:58. Effects of this incident on the Belmont Ave corridor are shown in Figure 39 and Figure 40.

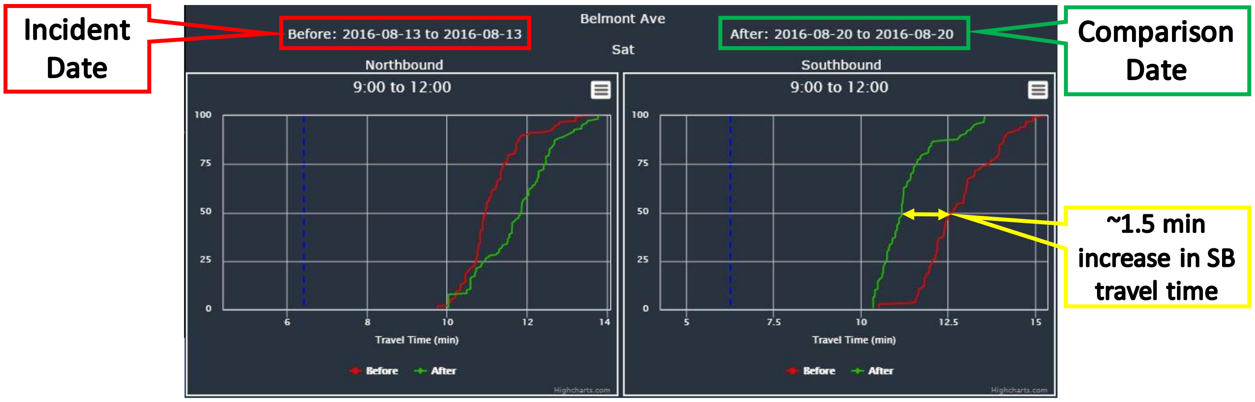


Figure 39. Travel time impacts on Belmont Ave

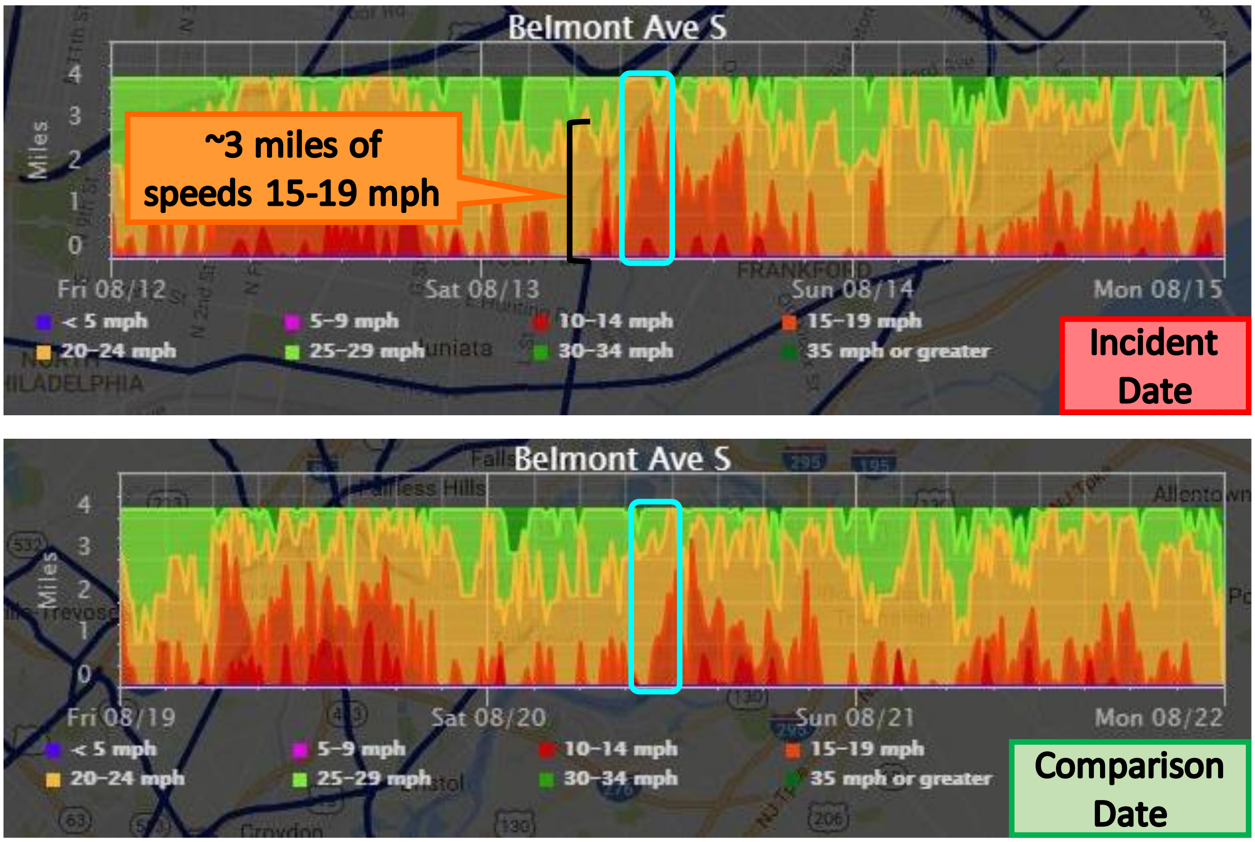


Figure 40. Congestion heat map on Southbound Belmont Ave

The CFDs (Figure 39) show that the travel times on the detour route increased by approximately 1.5 minutes in the southbound direction. The congestion heat map (Figure 40) shows a brief instance of slowed traffic at 15 to 19 mph. Though this travel time impact is not as extreme as the other corridor example provided in Figure 39, the delay is still considerable, especially for a Saturday morning. As is illustrated above, Saturday morning delays were equivalent to those of Friday morning and evening rush hours. The heat map also shows that traffic usually travels below 30 mph on this corridor, even though the speed limits range from 35 to 45 mph. Additional data, including AADT or signal timing plans could help in explaining these effects. Comparisons at different times of day, days of week, and events surround the region could also be considered in the analysis. These case studies show the various use of the web tools and also stimulate ideas to include future information to improve the analysis.

7.3 List of Application Uses

Below is a table that lists uses of the developed dashboards.

Table 4. List of Application Uses

Type of Event	Travel Time Comparison	Arterial Ranking	Travel Delay Monitor
Signal timing plan degradation	x	x	
Signal maintenance and retiming	x	x	
Adaptive installation	x	x	x
Construction activities	x	x	x
Special events	x		x
Crash	x		x
Winter storm	x		x
Land use changes	x	x	

8. ENGAGEMENT

Throughout the course of this project, the research team was actively engaged in providing technical support and maintenance of the web applications. Webinars and workshops including an introduction to the data, a conceptual overview of the analysis methodology, and a tutorial explaining how to use the dashboards, were conducted to train PennDOT personnel and other relevant users. These active engagements provided an opportunity to fine-tune the dashboards based on stakeholder input.

8.1 Webinars

Two webinars were conducted on November 15, 2016 and November 30, 2016. The materials discussed in the webinars included:

- Introduction to INRIX data
- Concepts and methodology on the data analysis
- Live demonstration of the three web applications
- Corridor mapping process
- Importing data to the SQL database

List of participants that attended the webinars can be found in Appendix V.

8.2 TRB 2017

The manuscript titled “Outcome Assessment Using Connected Vehicle Data to Justify Signal Investments to Decision Makers” (Paper #17-00314), based on preliminary analysis and results from the three web applications, was selected as a practice-ready paper and accepted for poster presentation at the 96th Annual Transportation Research Board Meeting held from January 8 to 12, 2017 at Washington D.C. The Purdue research team presented the poster on January 9, 2017, with many PennDOT personnel in attendance (Figure 41).

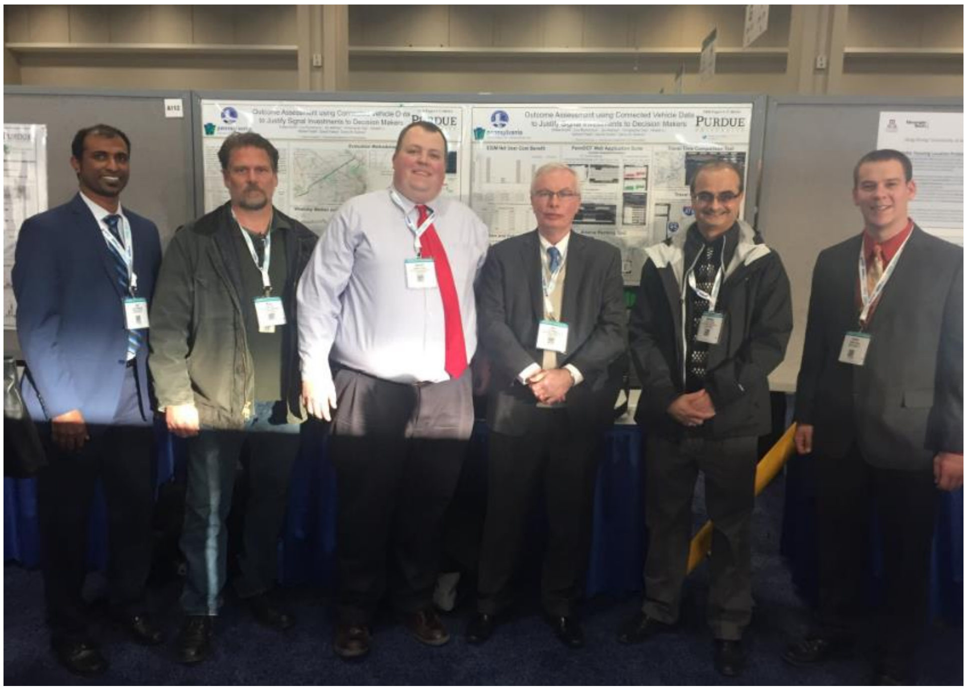


Figure 41. PennDOT employees and Purdue researchers at the TRB Poster Session on January 9, 2017, Washington D.C.

8.3 PennDOT Workshop

On January 12, 2017 researchers Howell Li and Jijo Mathew from Purdue led a workshop at the PennDOT District 6 Office at King of Prussia, PA to train the PennDOT staff and other users on the use of the dashboards. The live demonstration of the web applications was followed by an interactive question and answers sessions as well as user experience of the dashboards. Based on input from the users, a number of changes were made to the web applications, detailed in the following section. Items that were beyond the scope of the current research project was also documented.

8.4 Implementation of User Feedback

Several updates and changes were made to the three web applications as a result of user feedback following the workshop. In total, 40 suggestions for changes were documented, and 25 of those suggestions were implemented. One recommendation was not directly implemented, but the use case was accommodated in an alternate manner. The remaining 14 recommendations were classified as beyond the scope of the present project. The following table details the results of the changes. “In-scope” items were addressed as part of the maintenance and support task of the project.

Table 5. List of Recommendations from User Feedback

Recommendation	In-scope	Comments
Add US-202 Parkway corridor to the maps	Yes	The corridor has been added to the database.
Add splash page	Yes	The splash page has been added.
Add data reconciliation (Oct. 18) document to splash page	Yes	The data reconciliation document from Oct. 18 has been added.
Add executive summary document to explain dashboards to splash page	Yes	The executive summary has been added to the splash page.
Definitions of functionality in the tools with external summary document	Yes	Tooltips giving definitions and usage has been added to all of the dashboards on mouse hover.
Add example studies to the splash page	Yes	Link to publications of the case studies have been added to the splash page
Show corridor limits on map, both directions	Yes	Corridor limits have been added to the segments shown on the map overlay as solid (beginning of segment) and hollow (end of segment) circles.
Map corridor highlighting with no overlap	Yes	Corridors selected now automatically surfaces to the top layer on selection for all dashboards.
Traffic signal locations need to be identified	Yes	Traffic signals layer has been added to all dashboards for a narrow zoom level.
Use standard format for all graphics	Yes	The user interface has been updated to improve consistency and usability.
(Travel Time) Corridor identifiers to be listed to the right once selected	Yes	This has been clarified by the user interface improvements.
(Travel Time) Colorize "Before" and "After" on calendar selection to correspond to graphs	Yes	This has been implemented in the calendar selection menu.
(Travel Time) Add legend for speed limit travel time line	Yes	A legend has been added for speed limit travel time line.
(Travel Time) Export Quartiles and Export Raw buttons not functioning	Yes	The bug has been fixed.

Recommendation	In-scope	Comments
(Travel Time) Updating traffic signal plan information	Yes	Documentation covers how to update traffic signal plan information.
(Arterial Ranking) Tabularized results including road name, number, and rank	Yes	A sortable table is now generated as part of the results.
(Arterial Ranking) Colorize corridors distinctly when selected on map and graphs	Yes	Corridors are now colorized distinctly as the graph is generated.
(Arterial Ranking) No date selection (re-work UI for clarity)	Yes	The user interface has been reworked for clarity.
(Arterial Ranking) Evaluate corridors quickly to determine a % change in trend from normal	Yes	A percentage change of corridor performance has been added as a column in the tabular display.
(Arterial Ranking) Export graphs with graph points identified	Yes	Graph points are now identified in the exported chart.
(Arterial Ranking) Export data in tabular format	Yes	Data is now exportable as a CSV.
(Arterial Ranking) Add "Select by top 10 ADT" feature for district	Yes	Feature has been added.
(Arterial Ranking) No export feature	Yes	The user interface has been reworked for clarity so that the export feature can be found with ease.
(Travel Delay Monitor) Beginning and ending segments need to be identified	Yes	Corridor limits have been added to the segments shown on the map overlay as solid (beginning of segment) and hollow (end of segment) circles.
(Travel Delay Monitor) Before and after comparison similar to travel time	Yes	The dashboard now produces a before and after graph for each corridor and direction based on a set of two date ranges.
Subdividing corridors	No	Further division of corridors will require additional data reconciliation effort(s).
Incorporate Roadway Condition Reporting Information (RCRS)	No	Requires additional data automation and user interface development.
Automated reports	No	Requires new specification and metrics to be defined for the reports.

Recommendation	In-scope	Comments
Corridor identifiers in greater detail	No	Requires additional data reconciliation effort.
Corridor identifiers to include State or Local Route numbers	No	Requires additional data and data reconciliation effort.
Use consistent corridor identifiers	No	Requires additional data and data reconciliation effort.
Include sub-corridors	No	Requires additional data and data reconciliation effort.
(Travel Time) Export emissions/gas consumption, $ benefits information directly to Excel sheet	No	The automation of the TRB study requires additional integration of data and development effort.
(Arterial Ranking) Add support for multiple districts and regions	No	Requires additional data and data reconciliation effort.
(Travel Delay Monitor) Linear diagram showing relation of travel time to length and signal locations	No	This feature is similar to the University of Maryland "VPP" tool that graphs mile marker over time. Developing this dashboard will require additional effort and resources.
(Travel Delay Monitor) Show events on the map such as incidents, work zones, etc.	No	Requires additional data and data reconciliation effort.
Incorporate real-time high-resolution data from signals	No	Requires signal systems data, user interface integration, and automation.
Dashboard that provides answers to a summary of questions based on user-defined parameters within these evaluations	No	Additional specifications and development efforts need to be defined.
(Arterial Ranking) Add user-defined top corridors to select at once	Yes	This feature was not directly implemented. A performance-improvement feature was added to allow fast processing of all corridors within a county to reduce the need to specify the exact number of corridors selected at once.

Figure 42. Howell Li and Jijo Mathew leading the workshop at PennDOT District 6 on 01.12.2017

9. IMPLEMENTATION PLAN

The implementation plan will cover action items to be undertaken at and after the end of this project to sustain the Probe Data Performance Measure dashboards. This includes the delivery of the server, adjusting the Windows Server licensing, maintaining production and beta sites, user logins, bi-annual map updates, and generating user cost/benefit calculations.

9.1 Server Delivery

For the duration of the project, the server hardware was operated within the Purdue University network. Before the end of this project, the physical server hardware that operates the database software and houses the data, user-interface and backend ingestion code was delivered to PennDOT headquarters in Harrisburg, PA for installation and network connectivity.

9.2 Server Operating System (OS) Licensing

The server operated on Windows Server 2012 R2 within the Purdue University network at the time of project conclusion and used a Purdue license. After the server was delivered, it was transferred to a Pennsylvania-owned license.

9.3 Maintaining Production and Beta Sites

Two versions of the Probe Data Performance Measure dashboards are available on the server. One version is for production use, located in C:\inetpub\wwwroot\Apps, and stores the data and structures in the database inrix_xd_penndot. The beta dashboards are located in C:\inetpub\wwwroot\dev\Apps and stores the data and structures in inrix_xd_penndot_beta. Following the deployment of the server hardware to the Pennsylvania network, internal Commonwealth of Pennsylvania (CWOPA) URIs will be used as follows: *<URI>\Apps* and *<URI>\dev\Apps*, respectively. New development or testing of the data system or UI code should be performed on the beta site before publishing to the production site.

9.4 User Logins

There are two separate logins for the production and beta site. The authentication method used is the Windows Internet Information Services (IIS) Basic Authentication using the HTTP 401 Challenge on both application site directories. The separate user permissions are folder-level permissions that allow unrestricted access to each site. To implement a more sophisticated authentication system for multiple users, groups, and their respective program-level access rules, Integrated Windows Authentication can be used in conjunction with role logic that must be coded at the application level.

9.5 INRIX XD Map Updates

INRIX releases a new shapefile for Pennsylvania every six months, typically provided by an INRIX Public Sector representative. These releases implicate changes to the XD identifier set, location of XD segments, and other geometric and non-geometric attributes. The Probe Data Performance Measures system developed by Purdue is designed to house multiple versions of shapefiles in the system at once. However, the updating of any new shapefiles must be performed in conjunction with the release cycle to ensure proper operation of the applications – i.e. all segments that makeup a corridor is consistent. This update includes the following steps:

1. *Shapefile download* – retrieve shapefile from INRIX sources;
2. *Shapefile copy to SQL Server table* – import shapefile data using ArcMap software to the [__xd] table, adding version column information;
3. *Remapping corridors* – Identify any shifts in the existing corridor set by checking for corridor completeness and length consistency. Removed, adjusted or added segments introduced in the new version typically shifts corridor starting and ending positions, and total length. Adjustments to the corridor mapping, corridor summary, and speed limit mapping may be required. Additional instructions are provided in Appendix II.

10. SUMMARY

This report presented results from a 12-month project where arterial analysis tools based on probe vehicle segment speed data were developed and implemented into a web-based dashboard. Three tools were developed:

- An arterial travel time comparison tool, showing superimposed CFDs for a “before” period and an “after” period for the same corridor. This facilitates before/after comparisons of travel time and travel time reliability.

- An arterial ranking tool, where travel times for several different corridors can be ranked according to travel time metrics that are normalized to account for differences in posted speed limits, as well as varying corridor lengths.

- An interactive arterial congestion ticker showing the distribution of speeds over time for a given corridor.

The analysis tools are demonstrated by application to a study of five corridors in the Philadelphia area (District 6) where investments were made including signal retiming and deployments of adaptive control, in various combinations. The travel times along the corridors were tabulated for before and after periods, and used to estimate changes in user costs, based on traffic volumes from corridor AADTs and heavy vehicle proportions, and using basic assumptions of the value of time and other related factors. The data showed a user benefit in four of the five corridors, with a total user savings of $32 million. The report provides further discussion of use of the tools for incidents where traffic is diverted from a parallel Interstate highway to the arterial. The resulting increases in travel time can be visualized using CFDs and the congestion ticker, as demonstrated in the two examples.

With the increasing emphasis on data-driven, outcome-oriented performance analysis, tools such as these are likely to become essential for transportation agencies to align their practices with federal initiatives. The tools delivered as part of this project are one means for agencies to be prepared for future reporting needs, as well as to develop better intelligence about their operations, make well informed decisions about system investments, and independently evaluate the outcome of those investments.

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APPENDIX I – HOW TO USE DASHBOARDS

TRAVEL TIME COMPARISON TOOL

1. Link

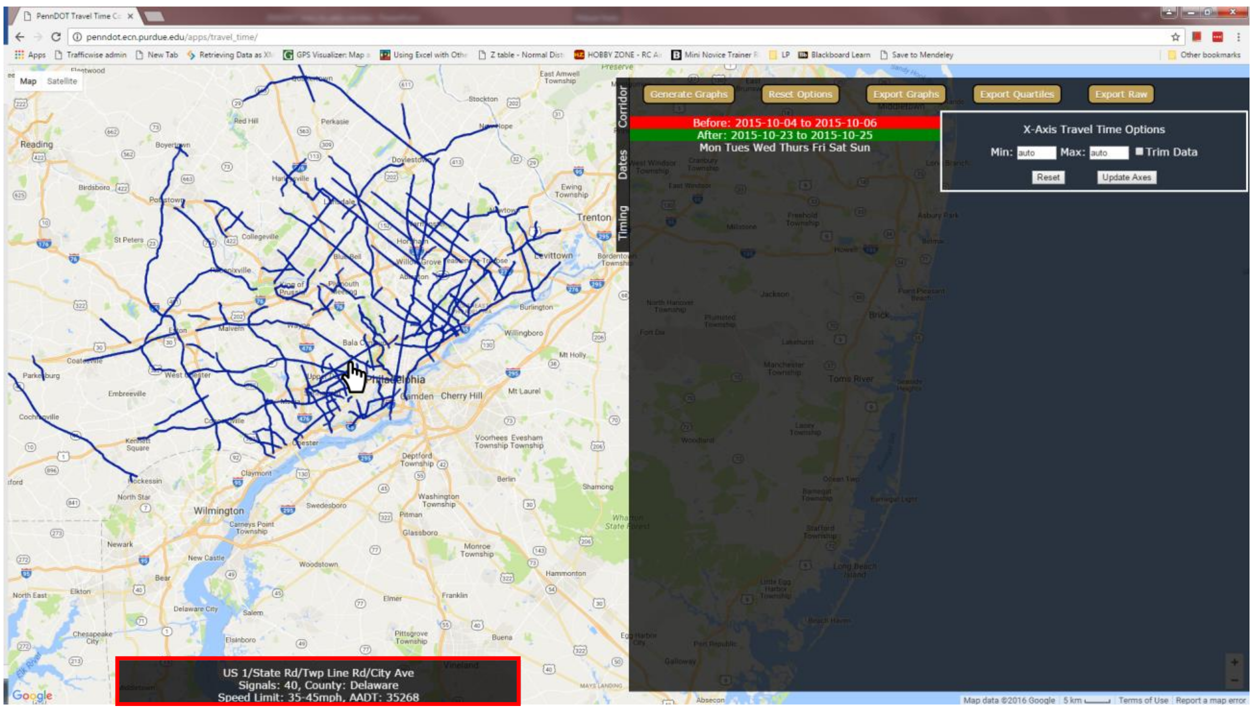
   ➢ Go to http://pdprvpmapp01.penndot.lcl/Apps/travel_time/

   ➢ Supported browsers
   - Google Chrome (Version 54.0.2840.71 m)
   - Mozilla Firefox (Version 49.0.2)
   - Internet Explorer (Version 11.0.9600.18499)
   - Microsoft Edge (Version 38.14393.0.0)

2. Selecting Corridors, Date Ranges and Timing

2.1. Corridor Summary

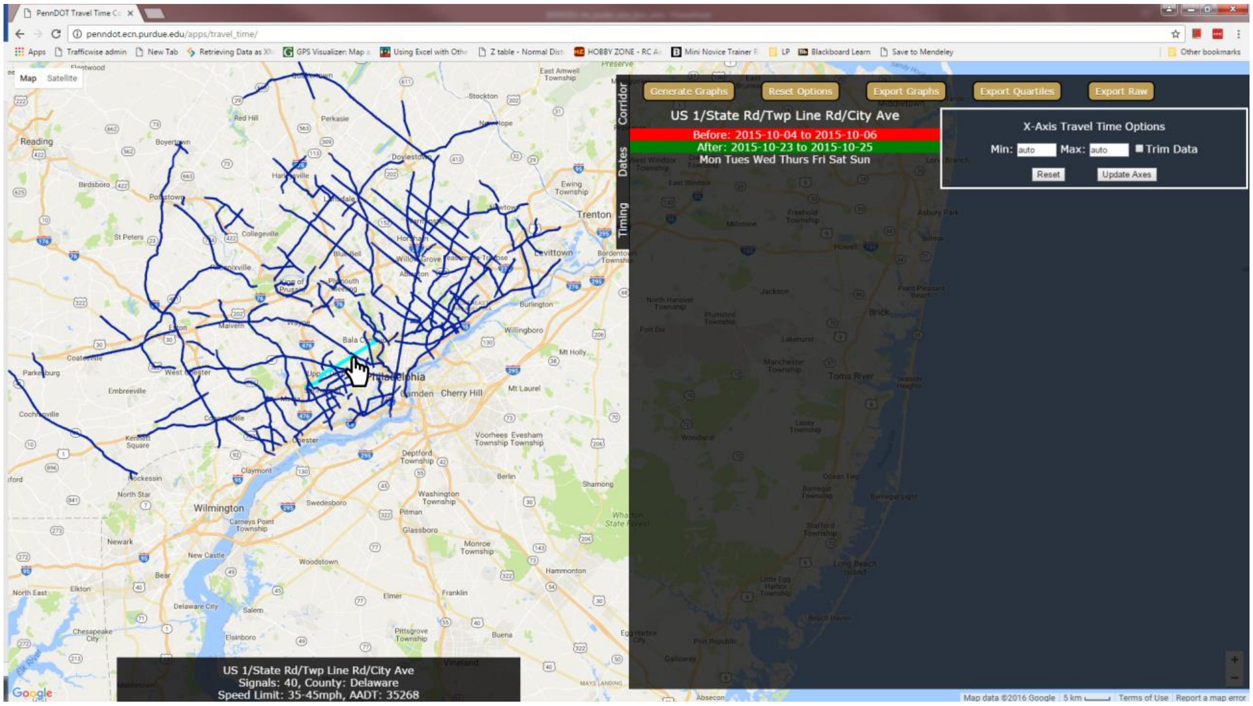
i. Mouse hover any of the corridors to view the corridor details



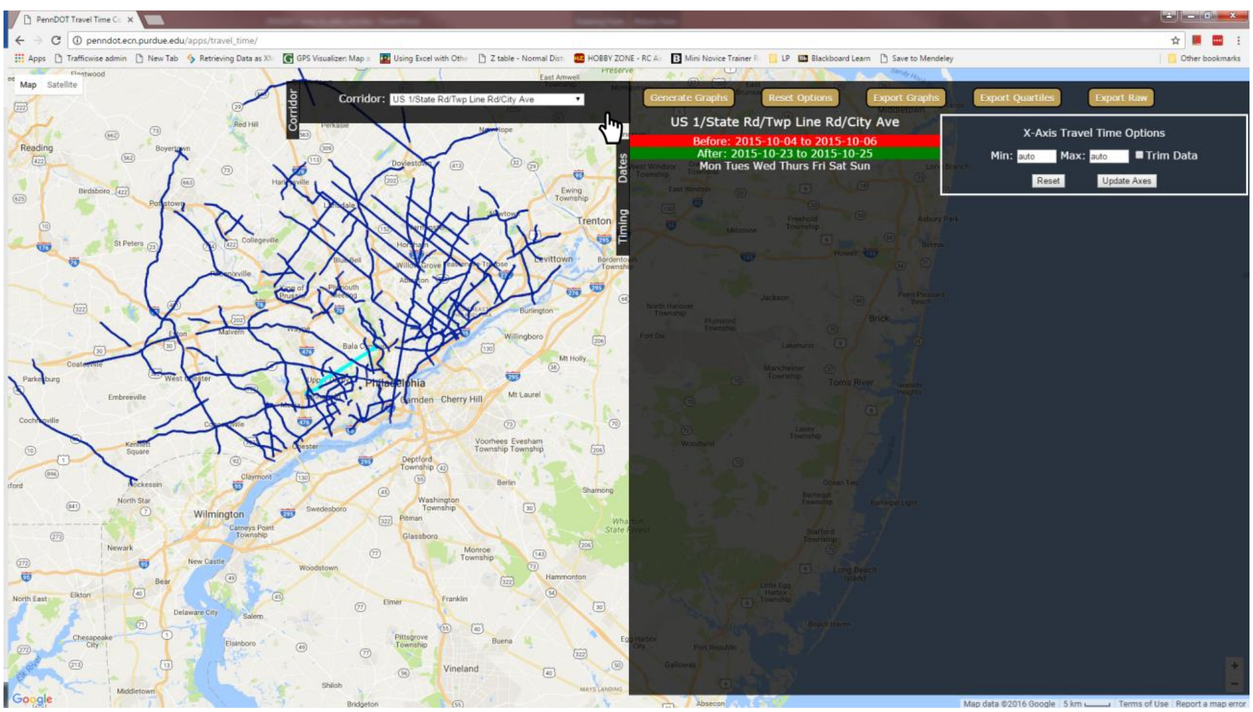
2.2. Corridor Selection

2.2.1. <u>Using Mouse</u>

i. Left click on any of the corridors to select it

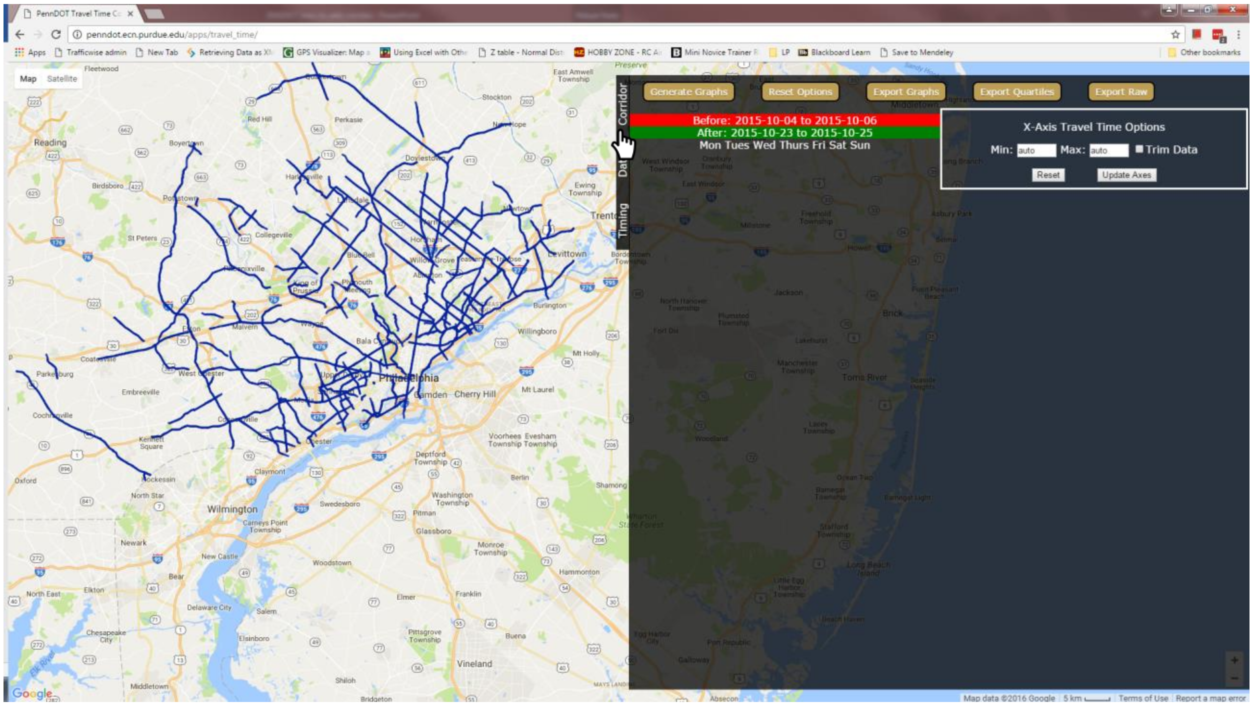


ii. Left click on the "Corridor" tab to view the selected corridor

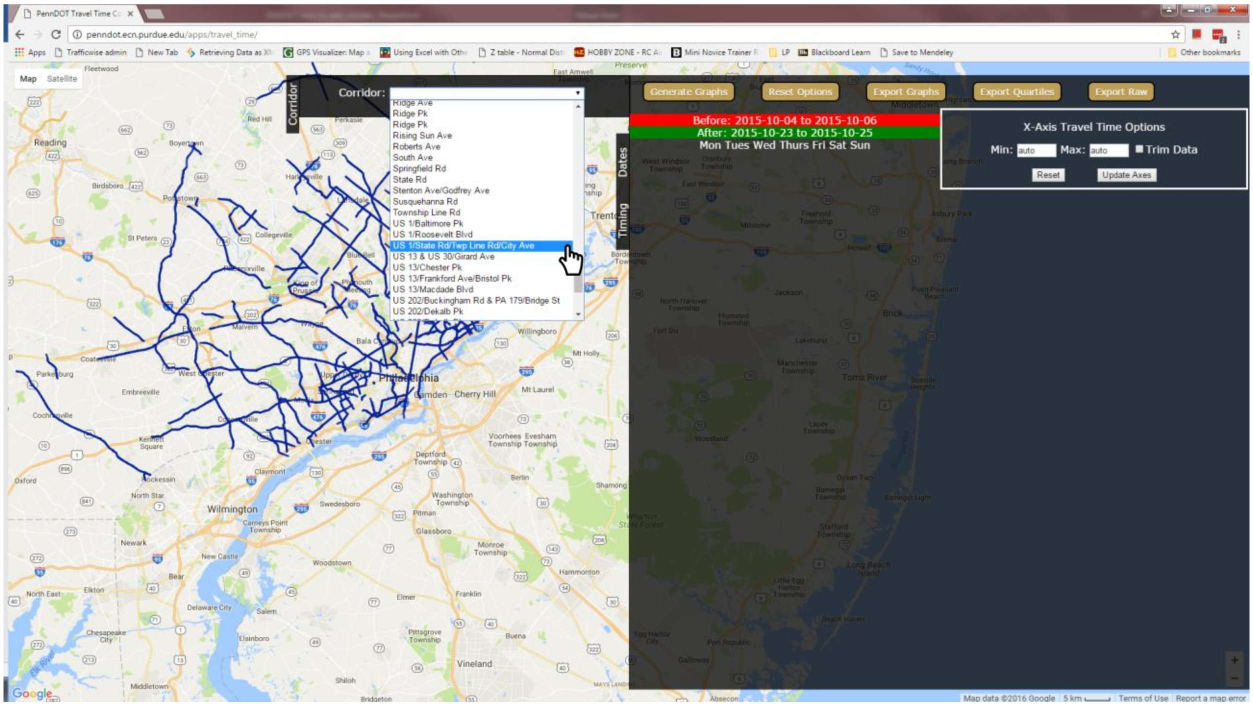


2.2.2. *Using the "Corridor" Tab*

i. Left click on the "Corridor" tab

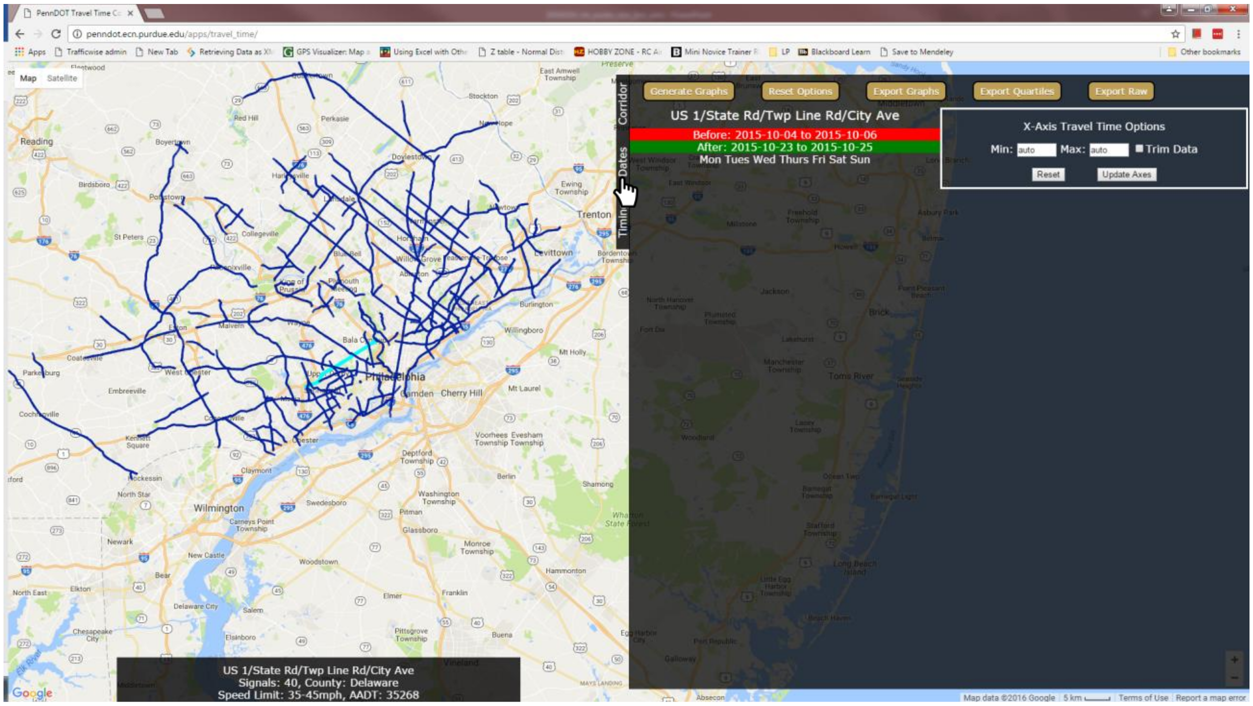


ii. Select the corridor from the drop-down menu

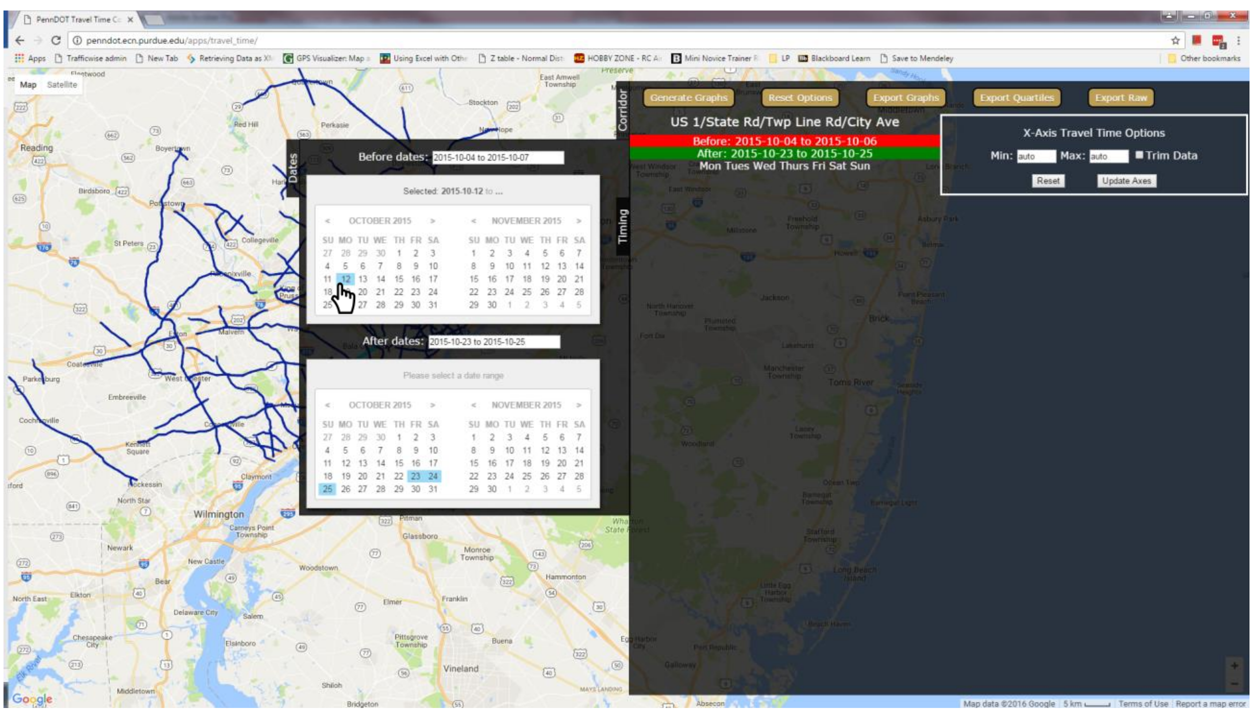


2.3. Date Range

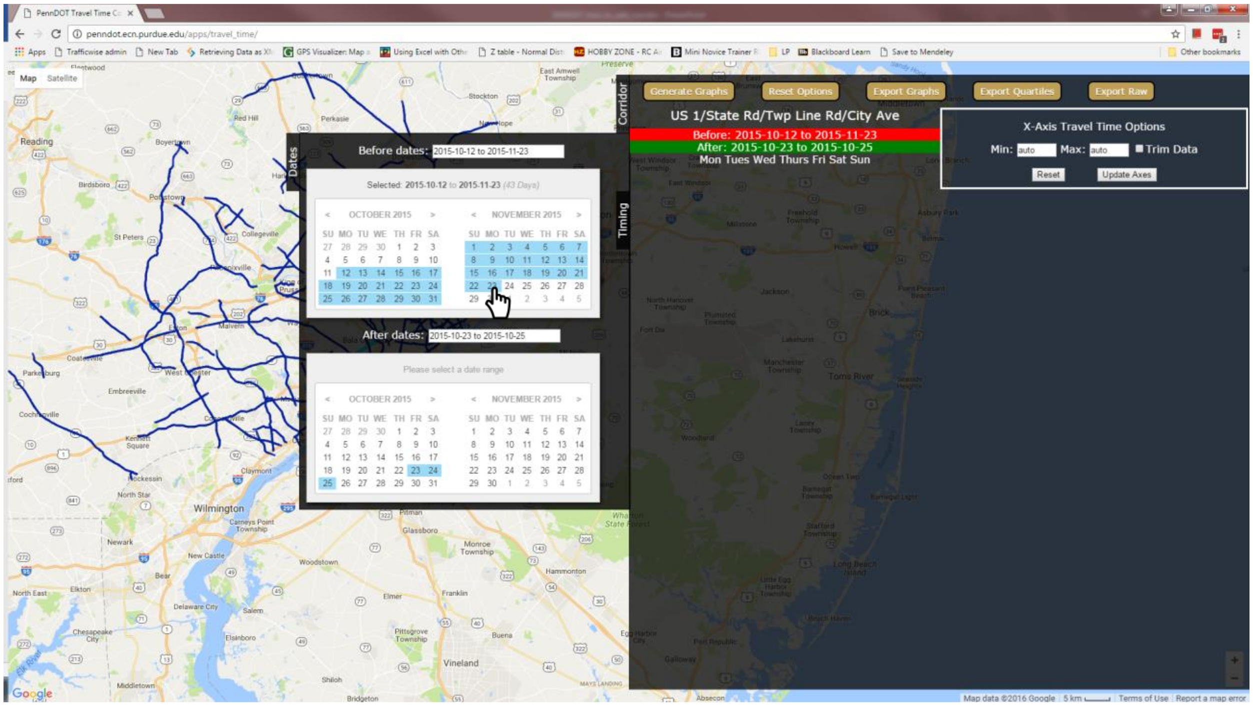
i. Left click on the "Dates" tab. For this example, let us select the date range from the TRB paper (Before: 10/12/2015 to 11/23/2015 and After: 3/7/2016 to 4/18/2016)



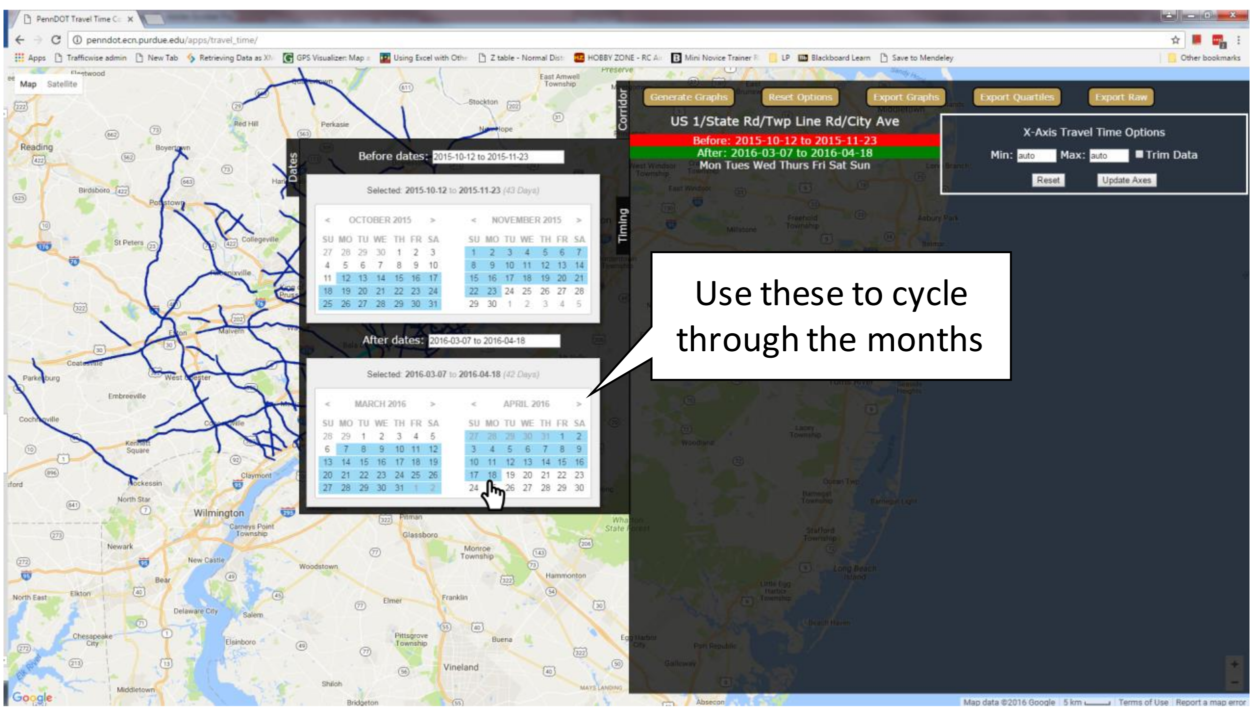
ii. To select the before date range, go to the month of October and click on 10/12/2015.



iii. Now, click on 11/23/2015 which highlights the before range

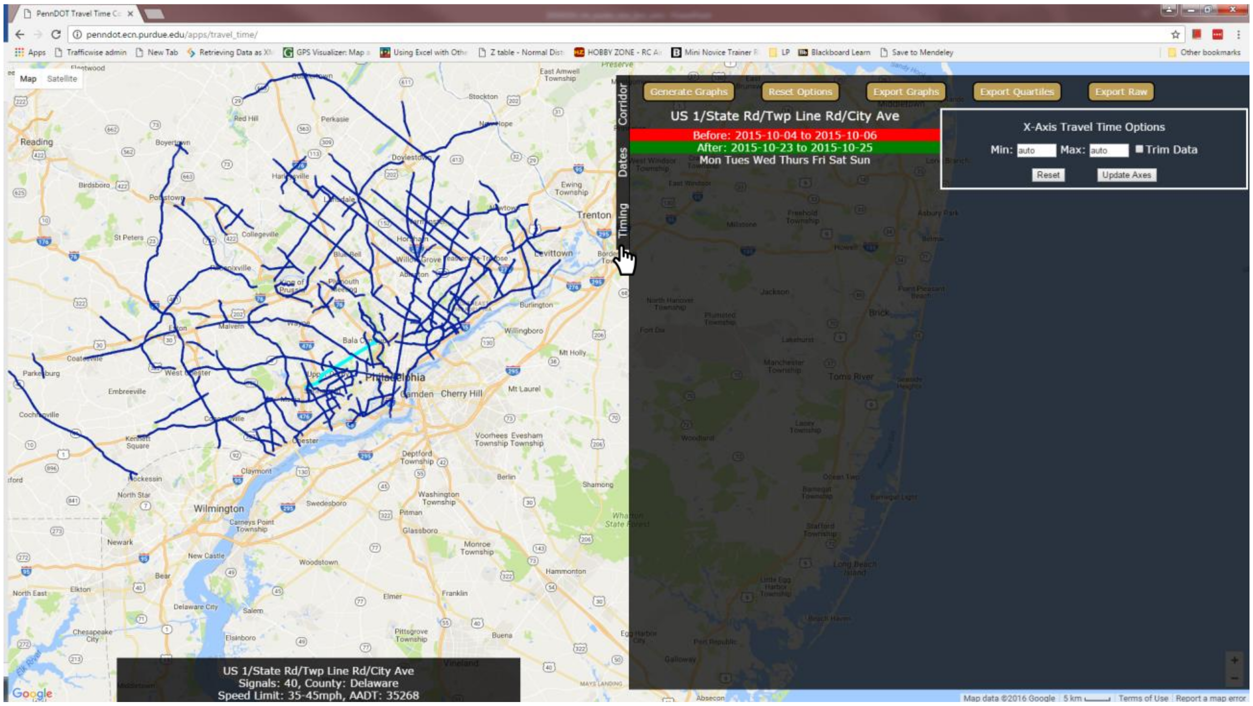


iv. Similarly select the after date range from 3/7/2016 to 4/18/2016. Use the forward and backward arrows to cycle through the months.



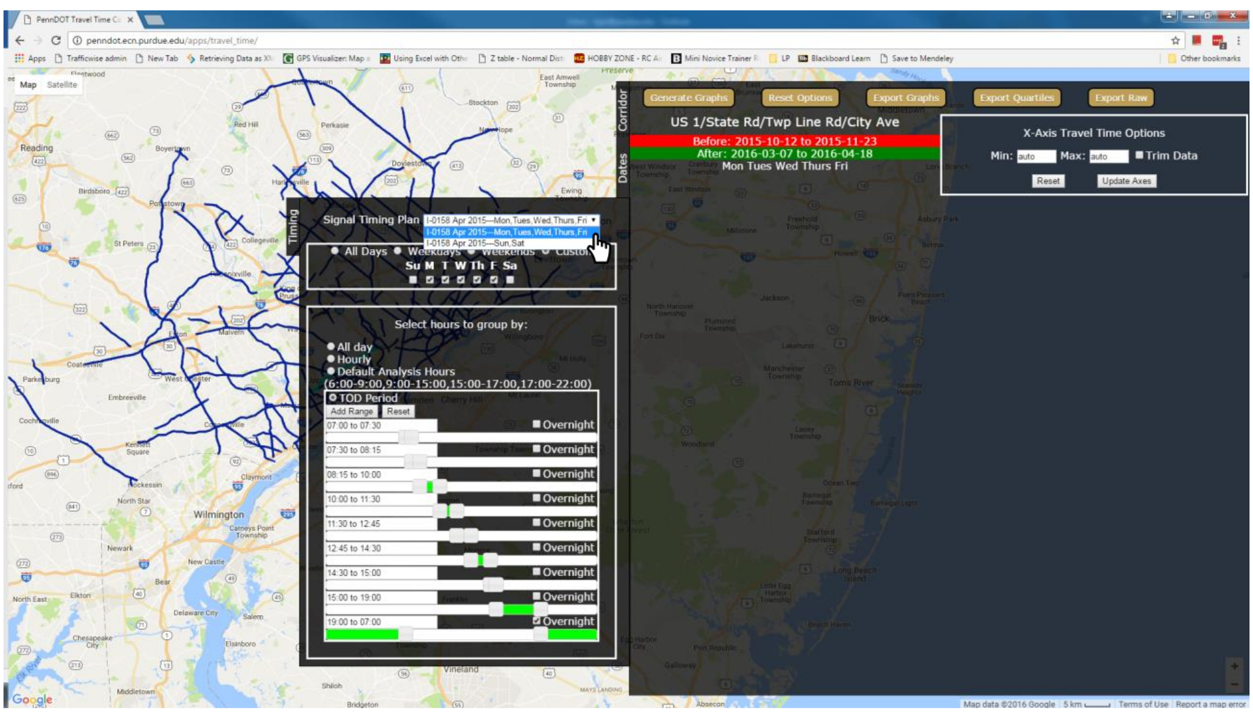
2.4. *Timing*

i. Click on the “Timing” tab

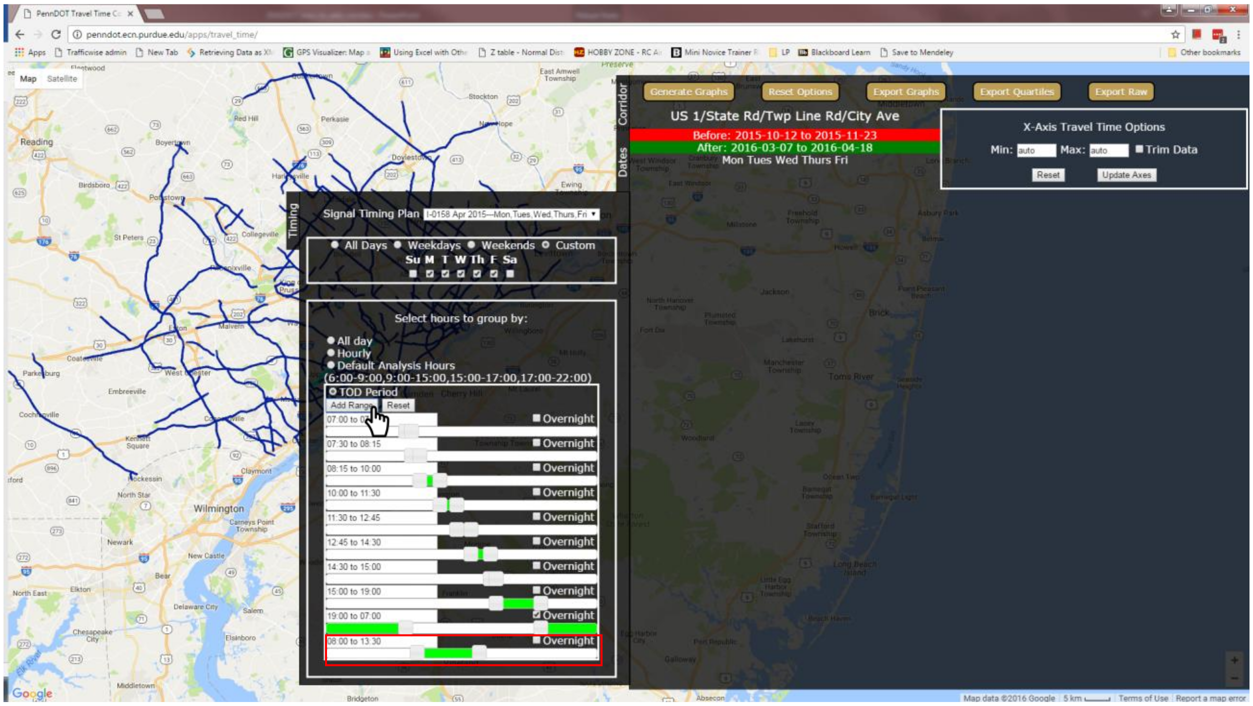


2.4.1. *Signal Timing Plan Available*

ii. Choose the required timing plan from the dropdown menu. A preloaded timing plan is then loaded from the Signal Timing Plan dropdown, which populates a set of *TOD* Period ranges.

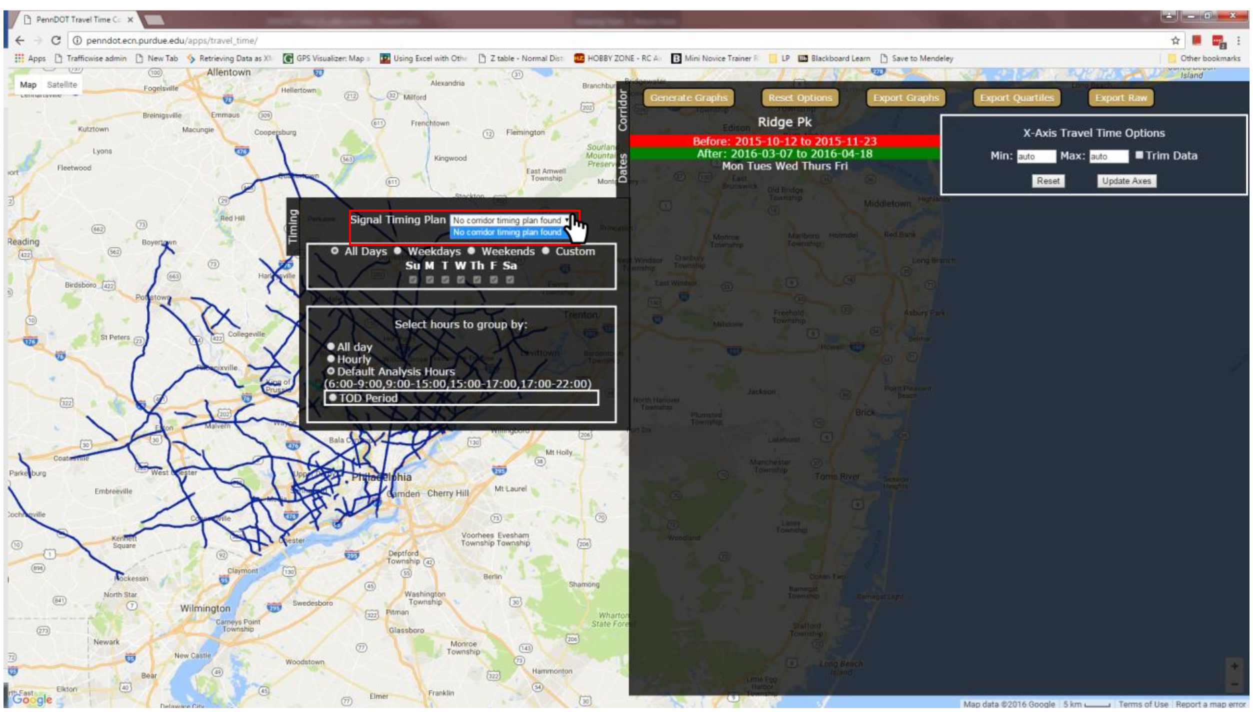


iii. Click on the “Add Range” button to add a custom range. Use the sliders to set the time of the day range.



2.4.2. Signal Timing Plan Not Available

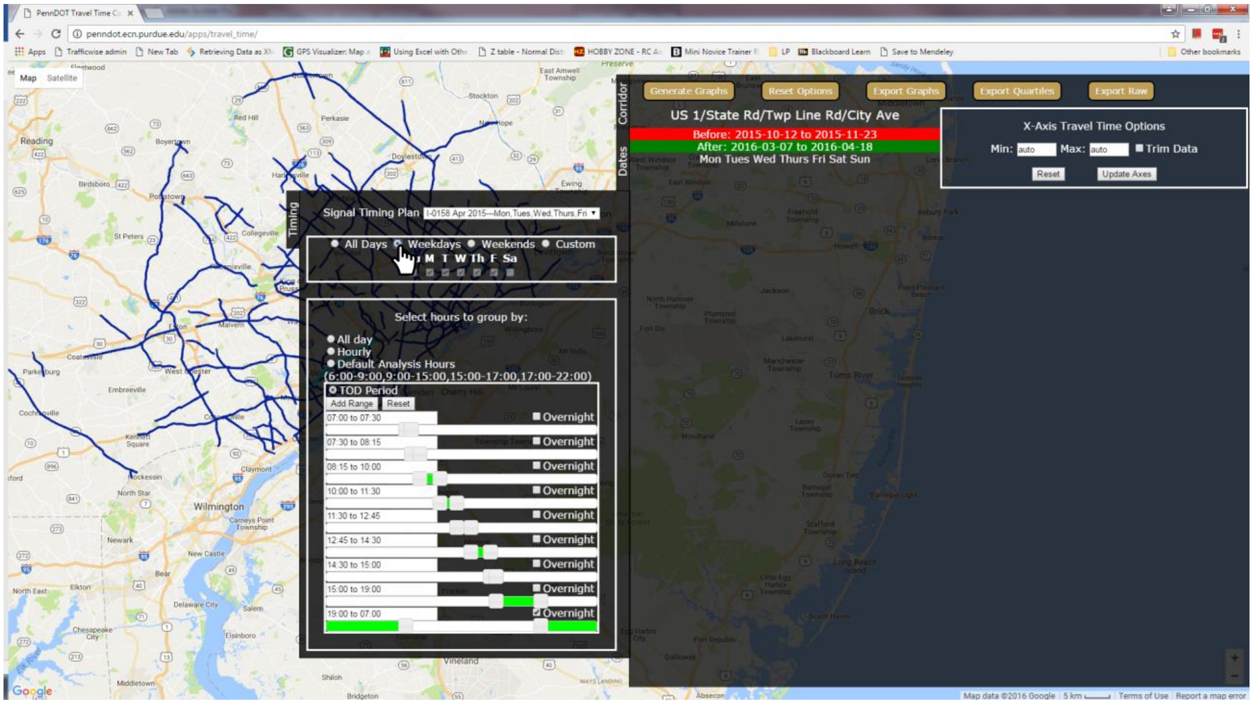
ii. if the signal timing plan is not available for a particular corridor, the dropdown will show “*No corridor timing plan found*”



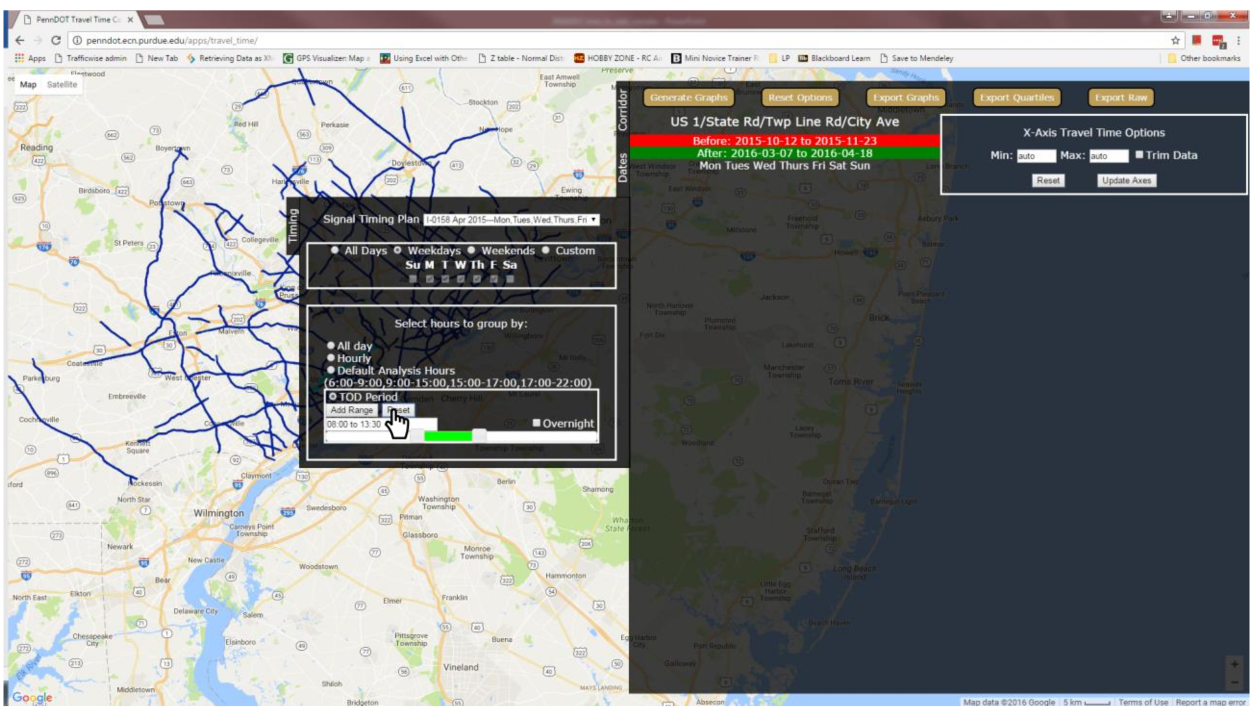
2.4.3. *Setting the Timing to a Custom Range*

Click on the "*Custom*" button, then the "*Reset*" button under "*TOD Period"* and use the sliders to set the required range. For this example, set the timing range to 17:00 – 18:00 on all weekdays.

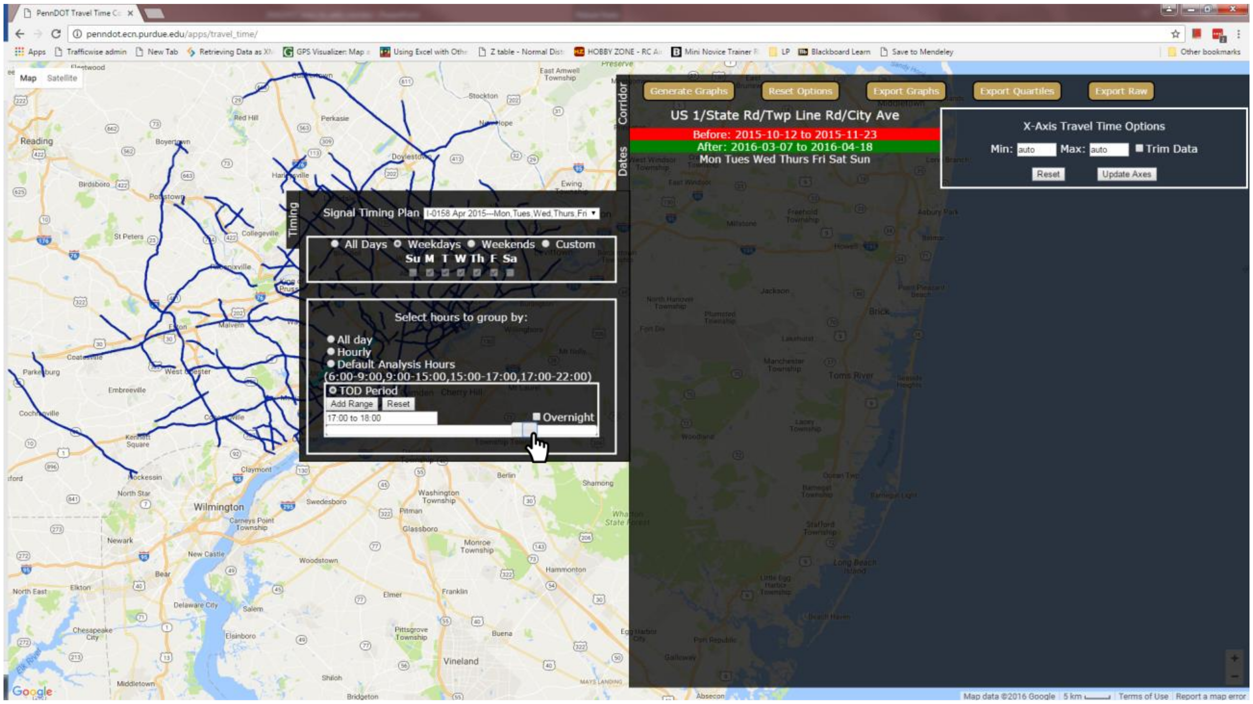
i. Click on "*Weekdays*"



ii. Click on "*Reset"* under the "*TOD Period*" to reset the timing plan

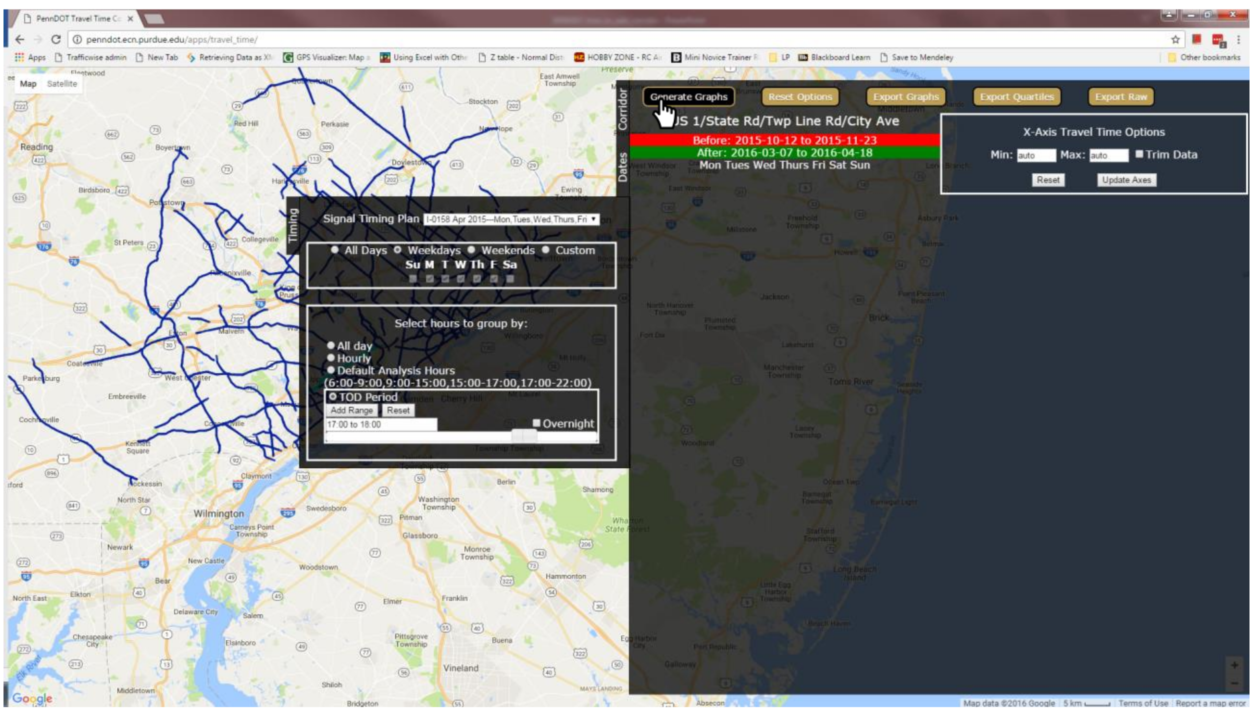


iii. Use the sliders to adjust the time from 17:00 – 18:00

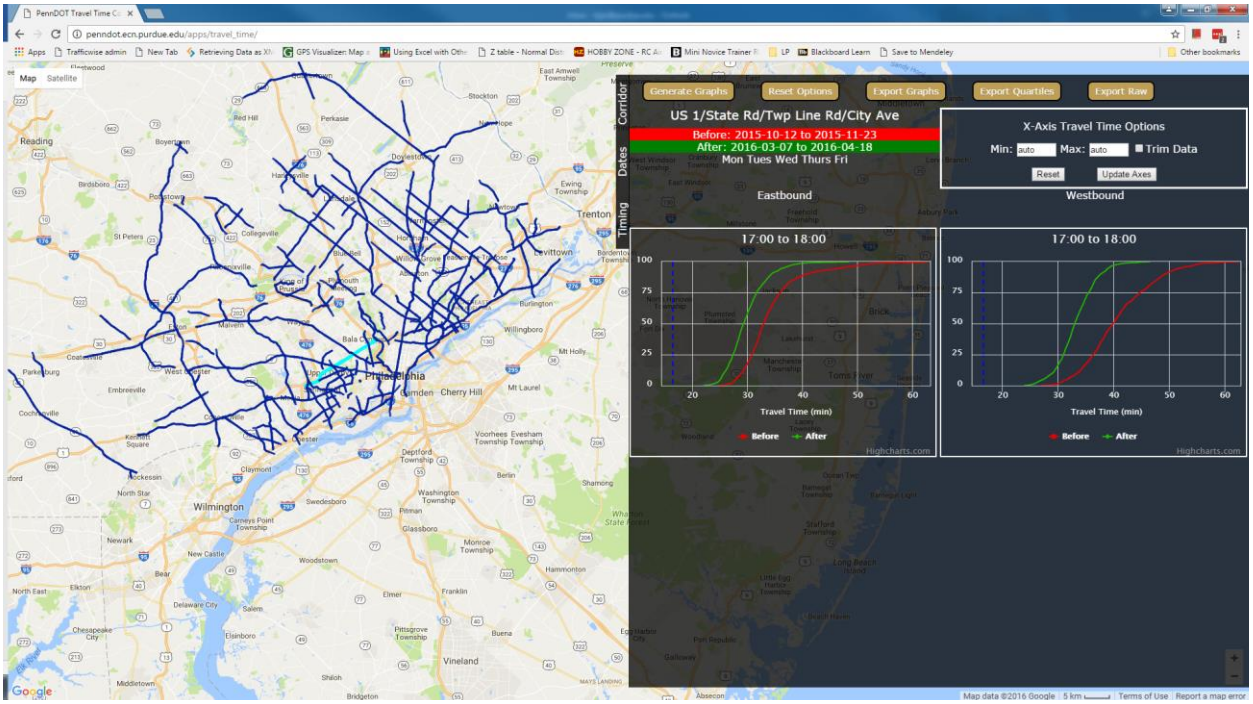


2.5. *Generating Graphs and Adjusting Axes*

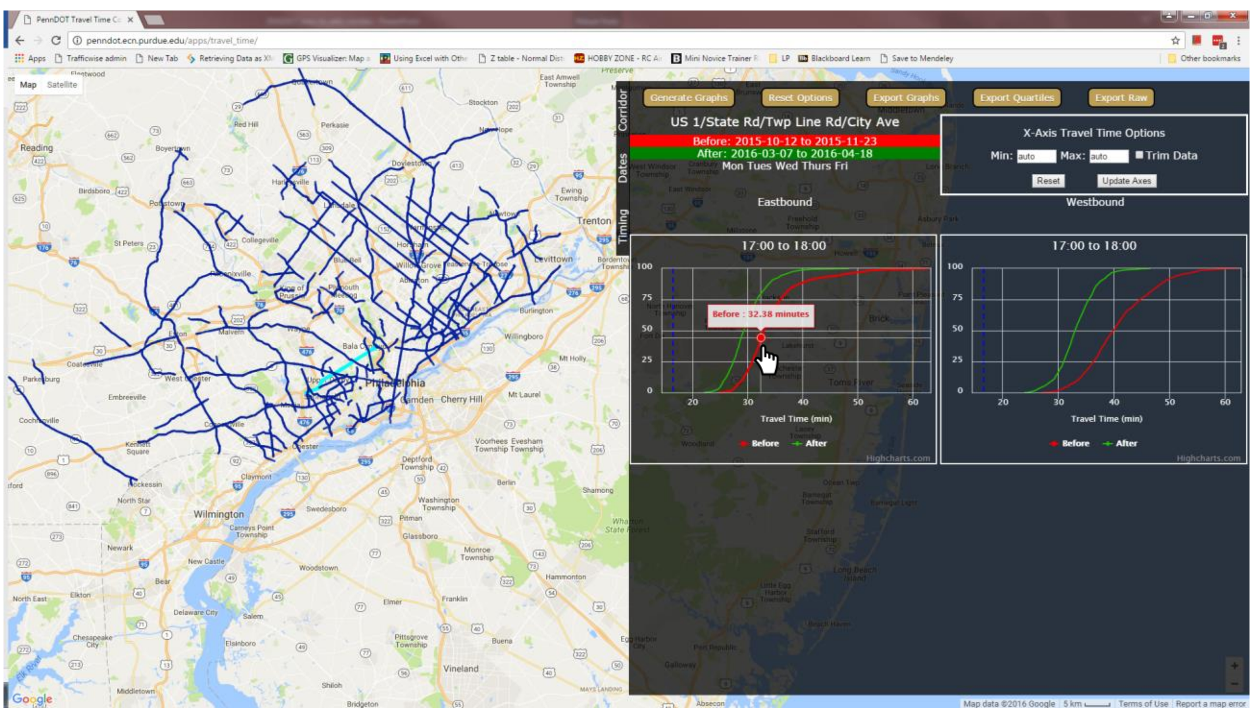
i. To generate the graphs, click on "*Generate Graphs"*.



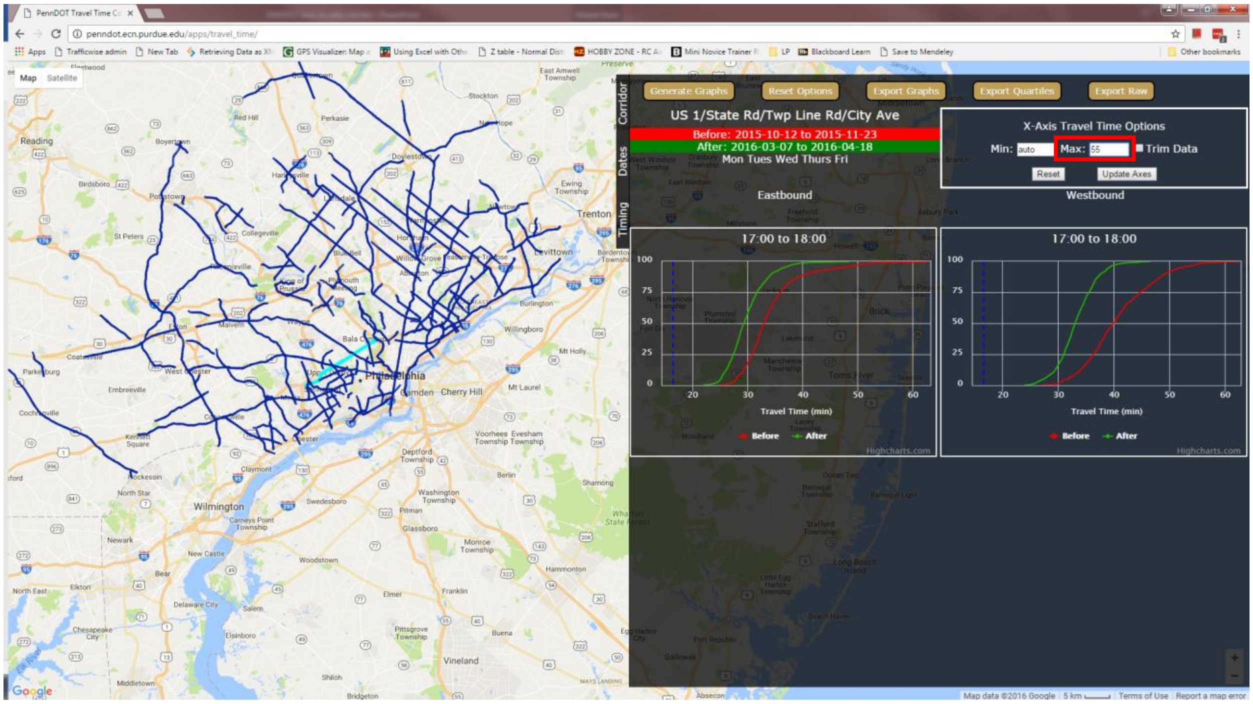
ii. This will generate the graphs as shown below. The red line shows the CFD's for the before period whereas the green one shows the CFD's for the after period. The travel time at speed limit is depicted by the dotted blue line.



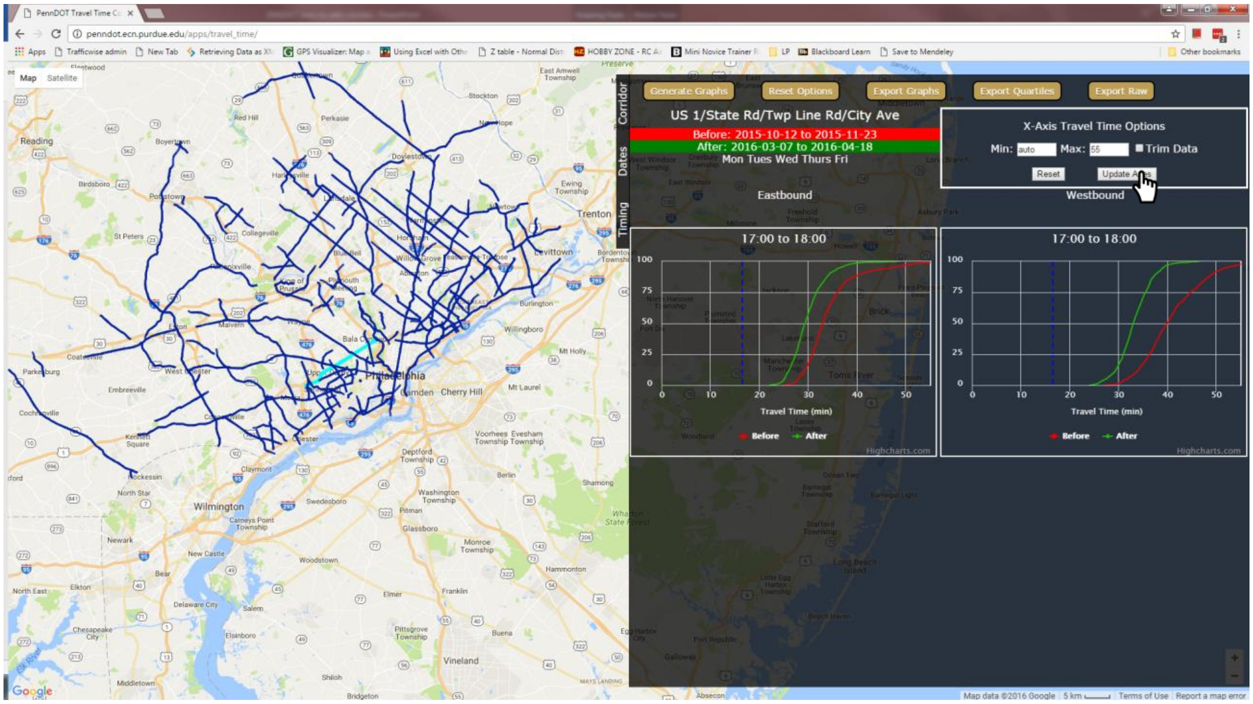
iii. Move the cursor over the CFD's to view the values at a particular percentile



iv. To adjust the travel time axis limits, use the "*X-Axis Travel Time Options*" tab to set the minimum and maximum limits. For this example, in order to set the maximum time limit on x-axis to 55 minutes, type in 55 in the "*Max*" section.



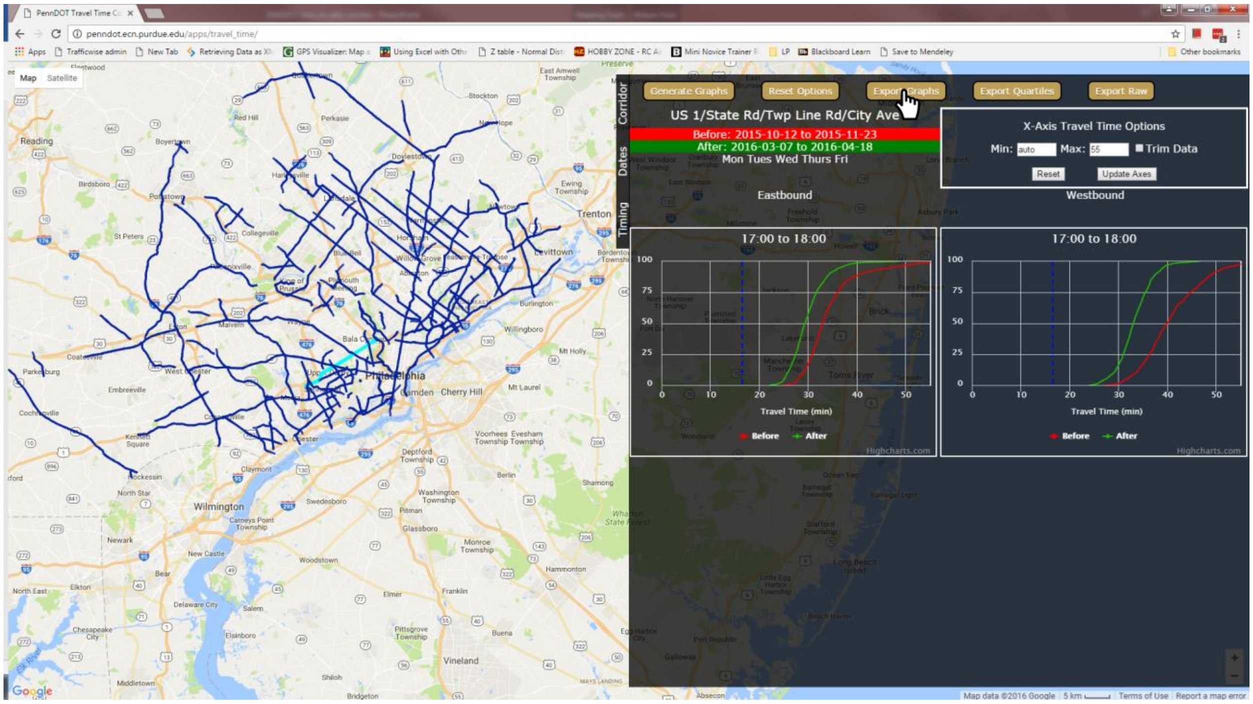
v. Click on the "*Update Axes"* to view the updated charts.



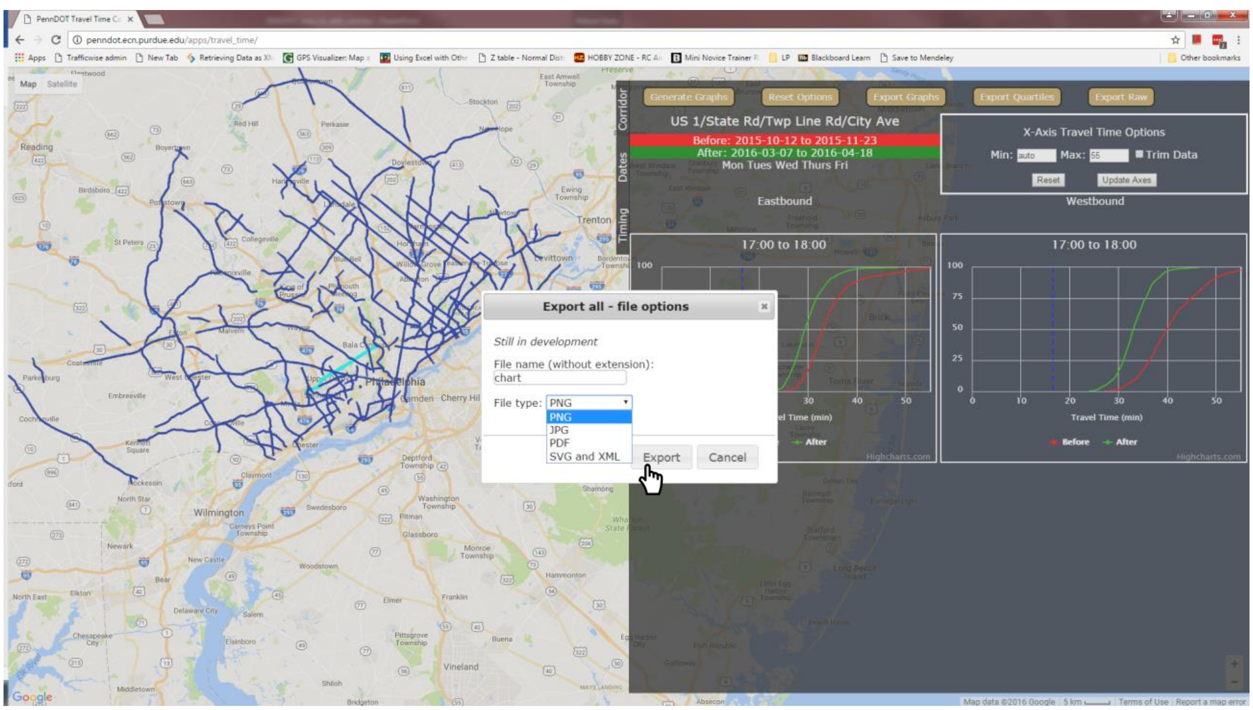
3. Export Options

3.1. Graphs

i. Click on the "*Export Graphs*" button to export the graphs

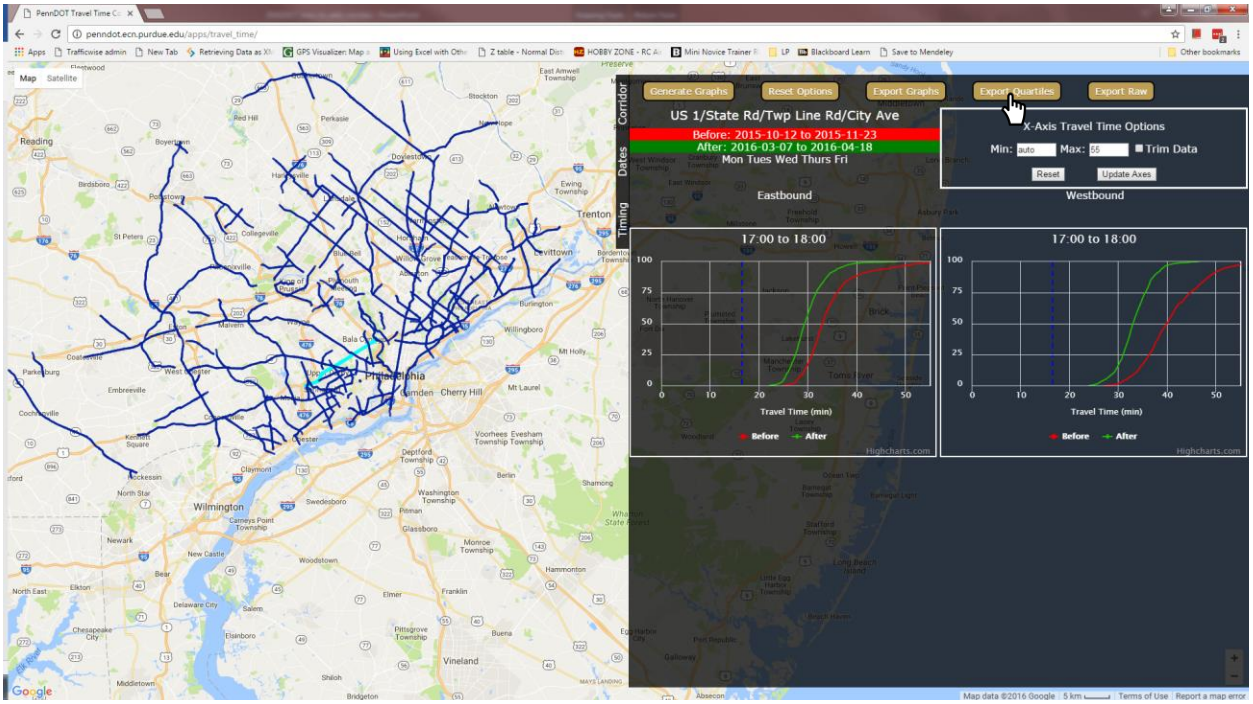


ii. Enter the filename, select the desired file type and click on "*Export*"

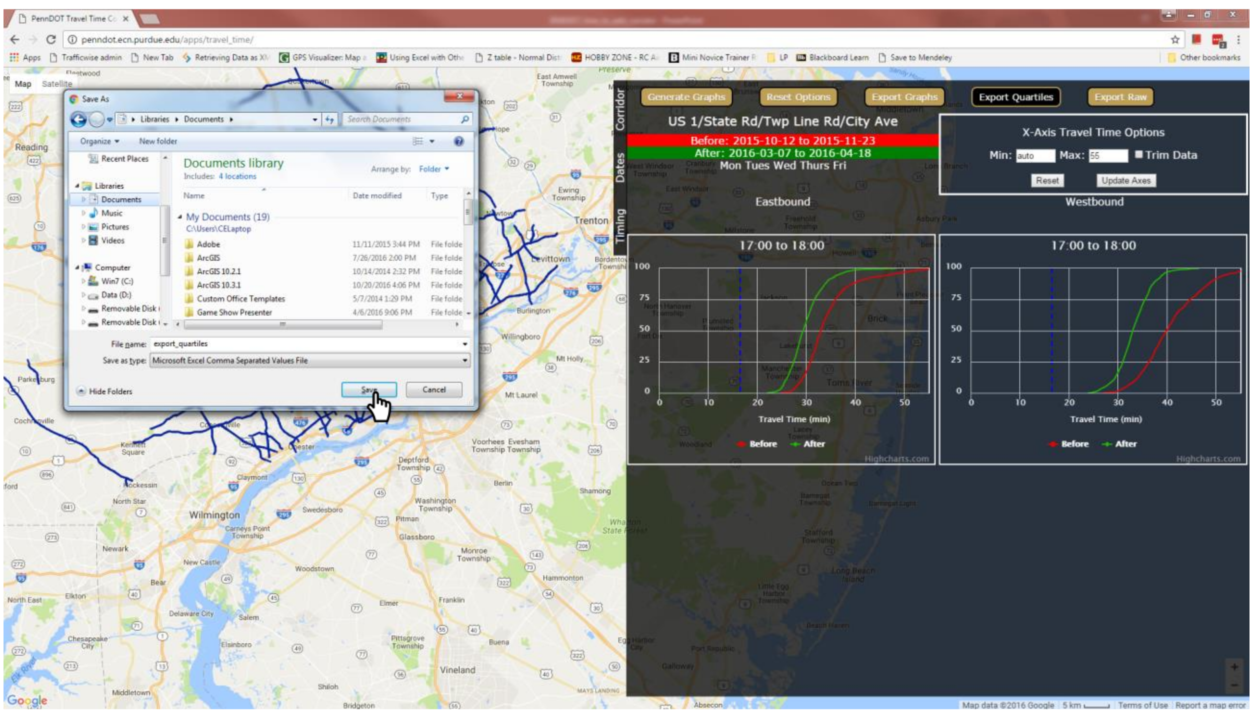


3.2. Quartiles

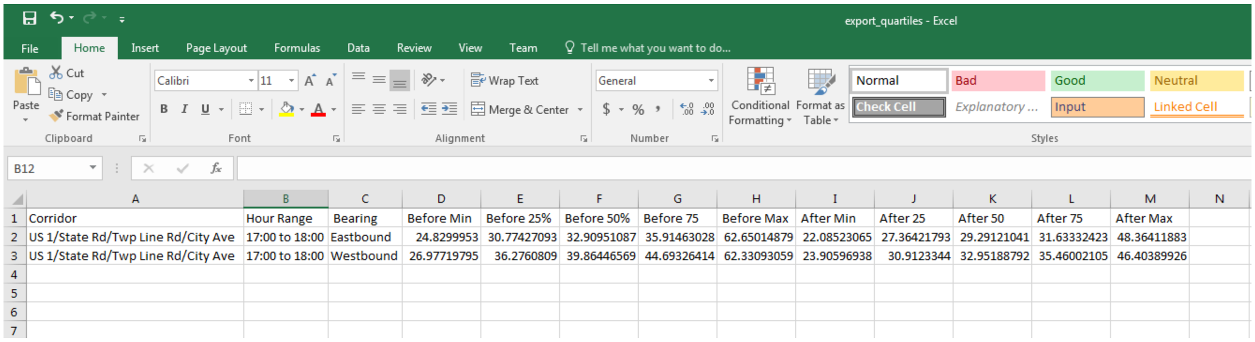
i. Click on the “*Export Quartiles”* button to export the quartile values



ii. Provide a filename and save it in the desired location



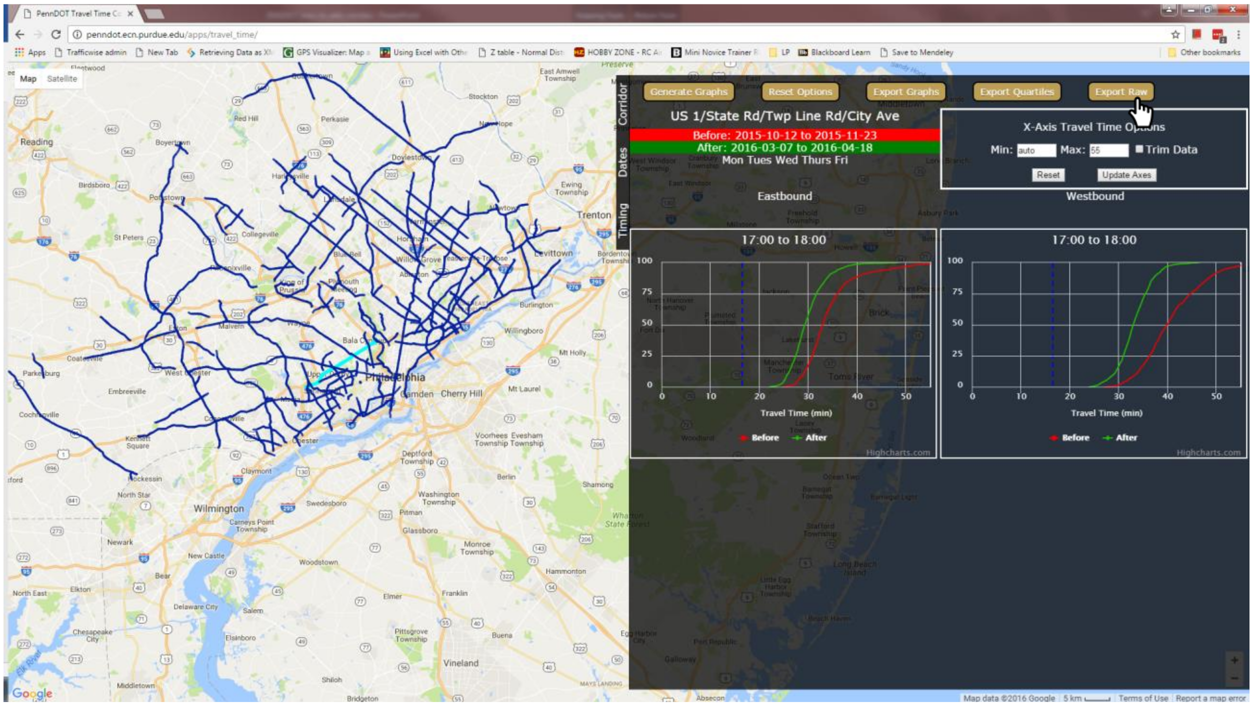
iii. Open the csv file to view the quartiles and min/max values



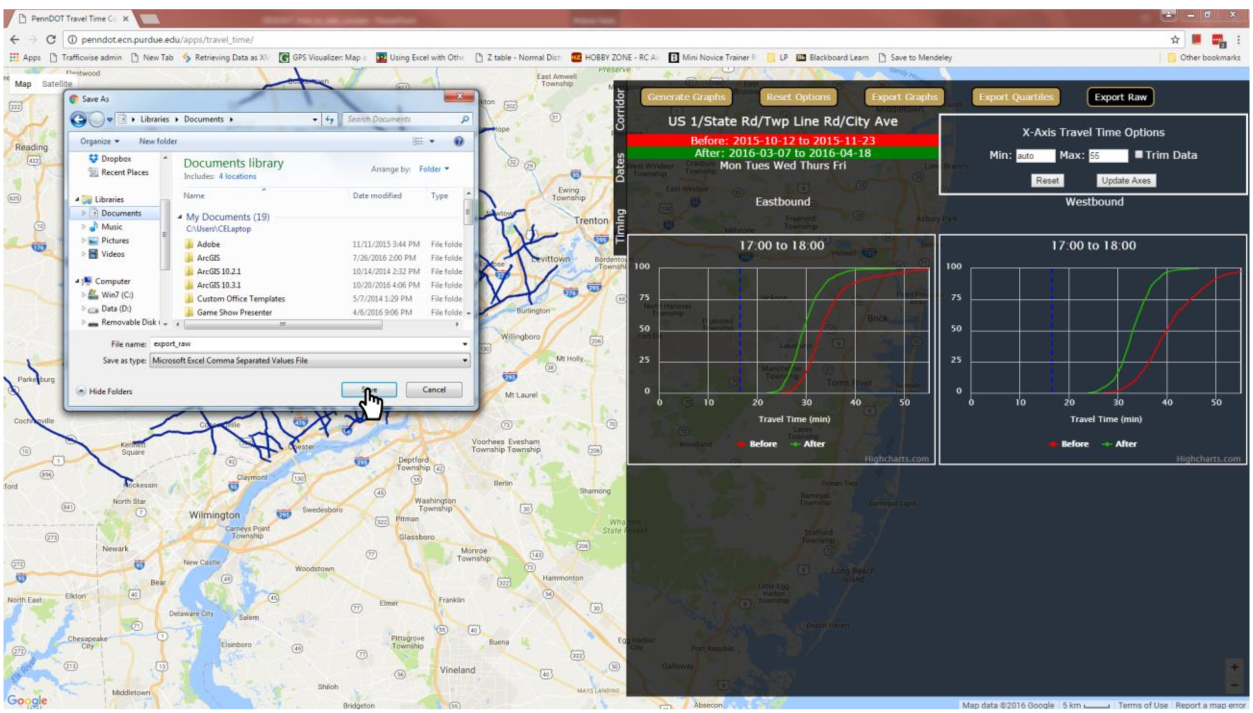
Corridor	Hour Range	Bearing	Before Min	Before 25%	Before 50%	Before 75	Before Max	After Min	After 25	After 50	After 75	After Max
US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	24.8299953	30.77427093	32.90951087	35.91463028	62.65014879	22.08523065	27.36421793	29.29121041	31.63332423	48.36411883
US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Westbound	26.97719795	36.2760809	39.86446569	44.69326414	62.33093059	23.90596938	30.9123344	32.95188792	35.46002105	46.40389926

3.3. *Raw*

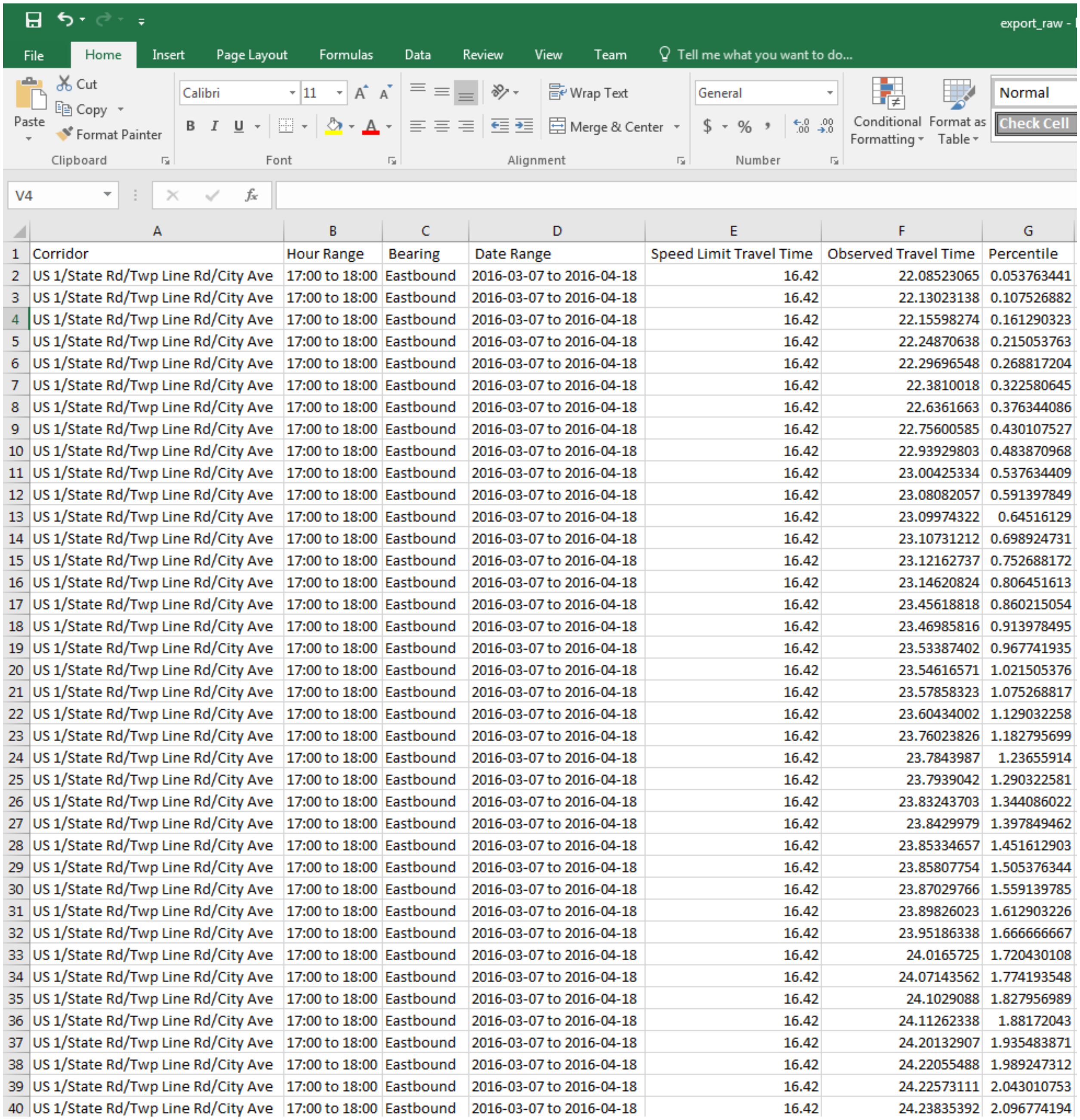
i. Click on the “*Export Raw”* button to export all the raw values



ii. Provide a filename and save it in the desired location



iii. Open the csv file



	A	B	C	D	E	F	G
1	Corridor	Hour Range	Bearing	Date Range	Speed Limit Travel Time	Observed Travel Time	Percentile
2	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	22.08523065	0.053763441
3	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	22.13023138	0.107526882
4	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	22.15598274	0.161290323
5	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	22.24870638	0.215053763
6	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	22.29696548	0.268817204
7	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	22.3810018	0.322580645
8	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	22.6361663	0.376344086
9	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	22.75600585	0.430107527
10	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	22.93929803	0.483870968
11	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.00425334	0.537634409
12	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.08082057	0.591397849
13	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.09974322	0.64516129
14	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.10731212	0.698924731
15	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.12162737	0.752688172
16	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.14620824	0.806451613
17	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.45618818	0.860215054
18	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.46985816	0.913978495
19	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.53387402	0.967741935
20	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.54616571	1.021505376
21	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.57858323	1.075268817
22	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.60434002	1.129032258
23	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.76023826	1.182795699
24	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.7843987	1.23655914
25	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.7939042	1.290322581
26	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.83243703	1.344086022
27	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.8429979	1.397849462
28	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.85334657	1.451612903
29	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.85807754	1.505376344
30	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.87029766	1.559139785
31	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.89826023	1.612903226
32	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	23.95186338	1.666666667
33	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	24.0165725	1.720430108
34	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	24.07143562	1.774193548
35	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	24.1029088	1.827956989
36	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	24.11262338	1.88172043
37	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	24.20132907	1.935483871
38	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	24.22055488	1.989247312
39	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	24.22573111	2.043010753
40	US 1/State Rd/Twp Line Rd/City Ave	17:00 to 18:00	Eastbound	2016-03-07 to 2016-04-18	16.42	24.23835392	2.096774194

MULTI-CRITERIA ARTERIAL RANKING TOOL

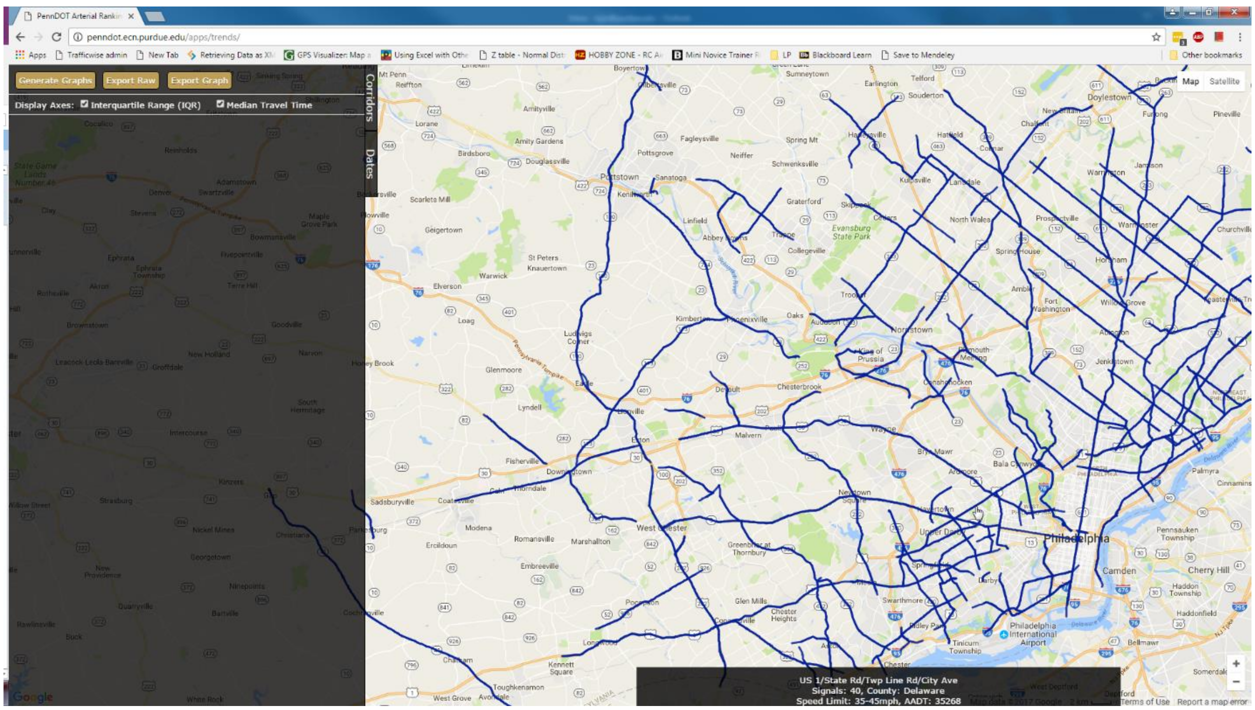
1. Link

- ➢ Go to http://pdprvpmapp01.penndot.lcl/Apps/trends
- ➢ Supported browsers (Optimized for Google Chrome)
    - Google Chrome (Version 54.0.2840.71 m)
    - Mozilla Firefox (Version 49.0.2)
    - Internet Explorer (Version 11.0.9600.18499)
    - Microsoft Edge (Version 38.14393.0.0)

2. Selecting Corridors, Date Ranges and Timing

2.1. Corridor Summary

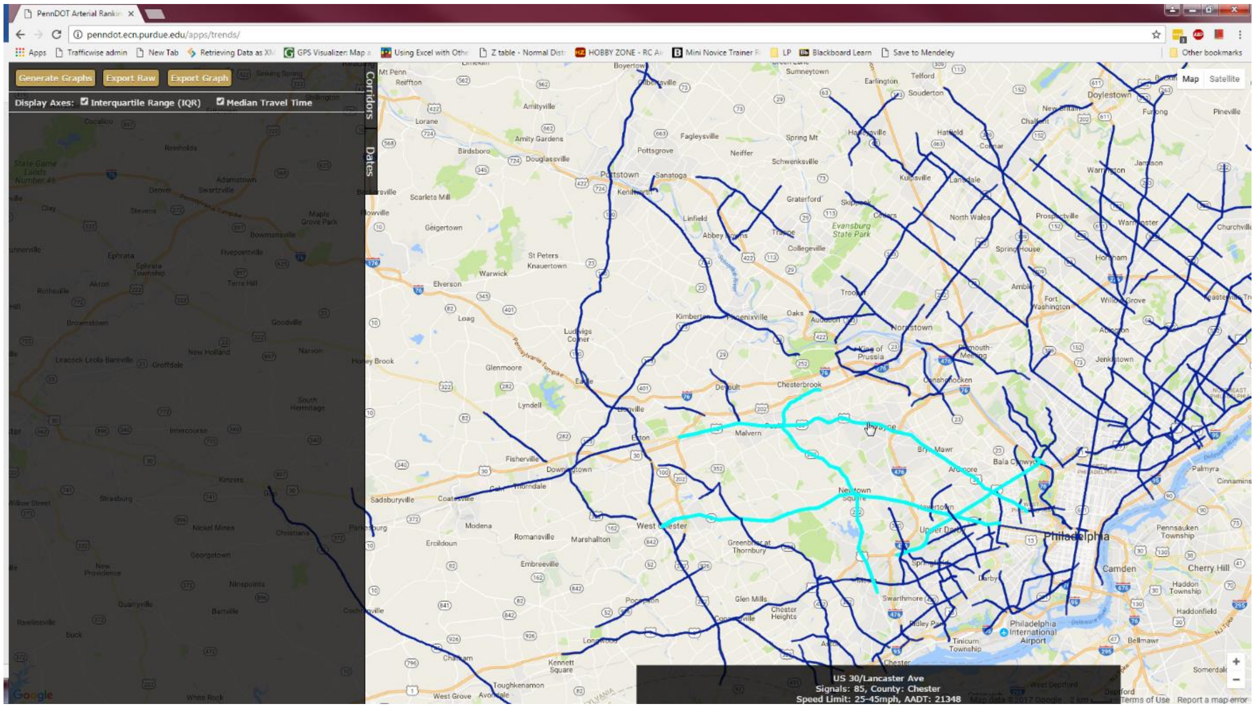
i. Move the cursor over any of the corridors to view the corridor details



2.2. *Corridor Selection*

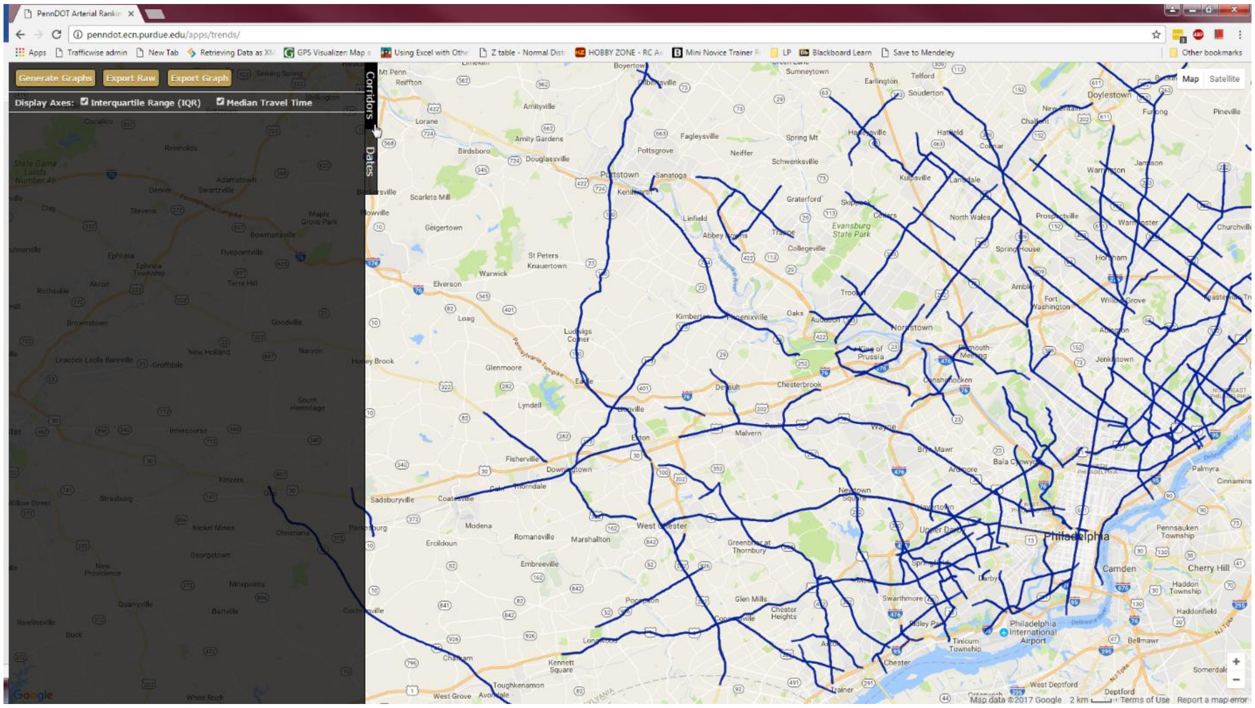
2.2.1. *Using Mouse*

i. Left click on the corridors to select/deselect it. A maximum of 50 corridors can be selected at once.

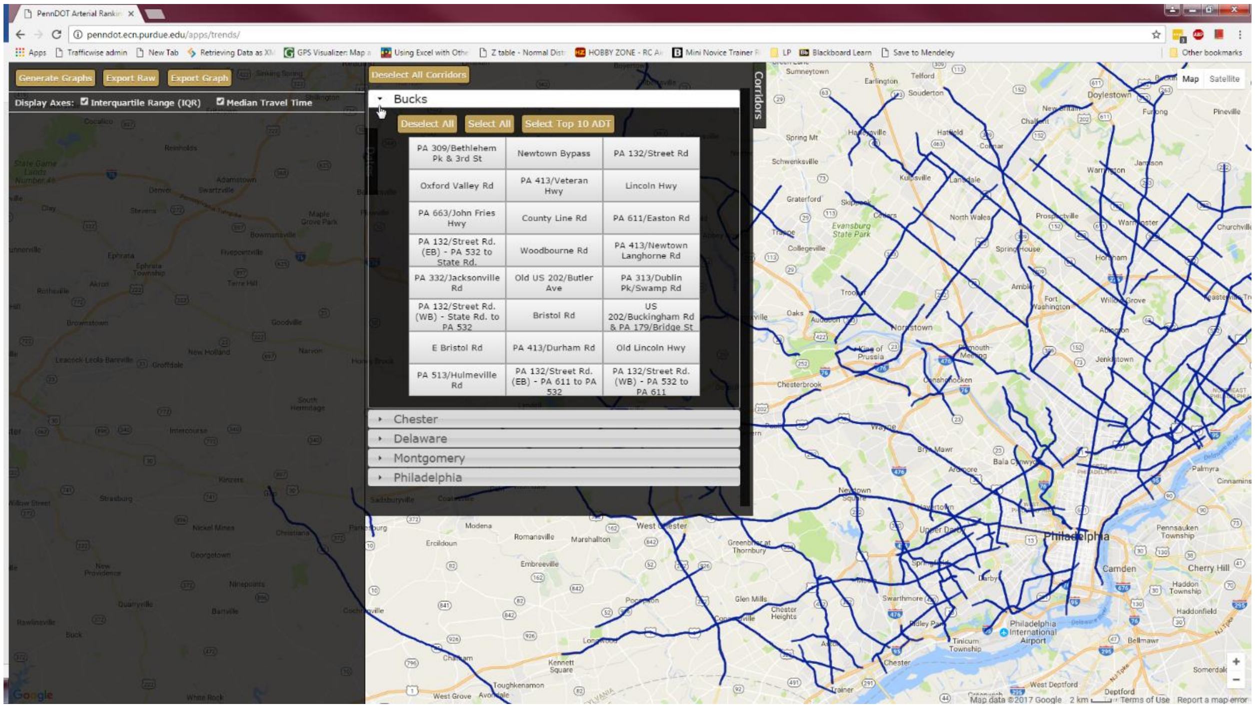


2.2.2. *Using the "Corridor" Tab*

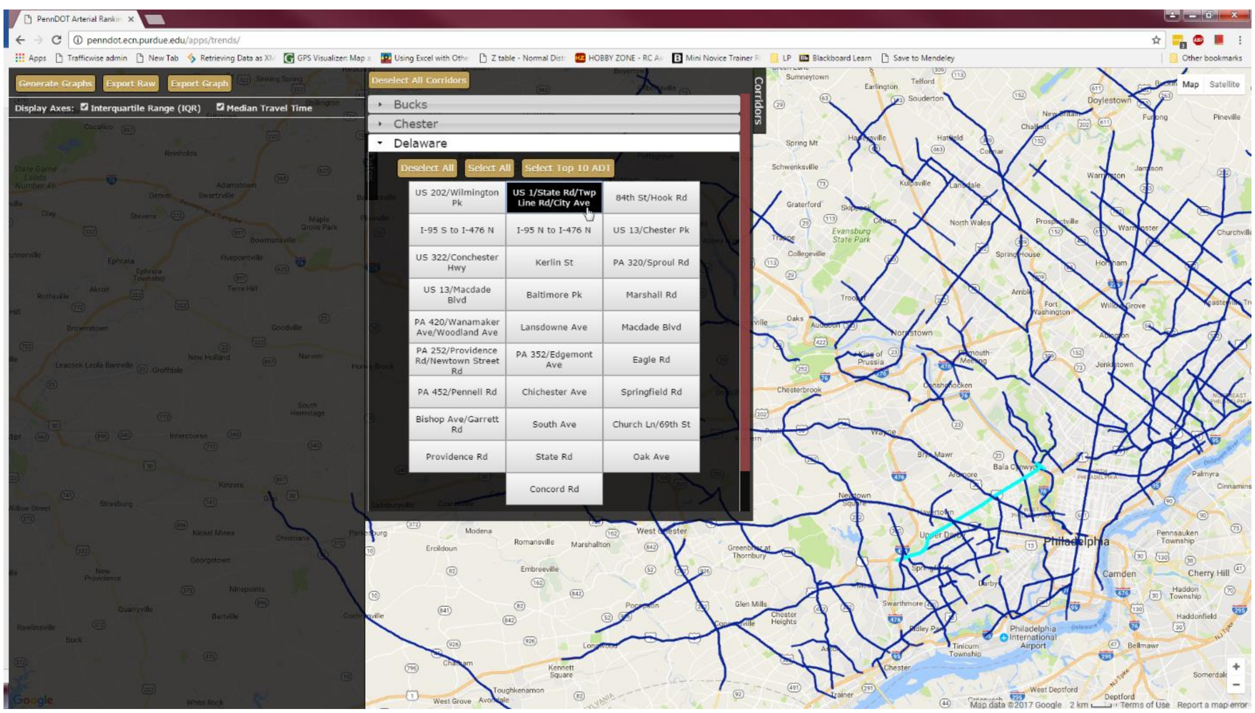
i. Left click on the "Corridor" tab



ii. Click on the *County* to view corridors within the county

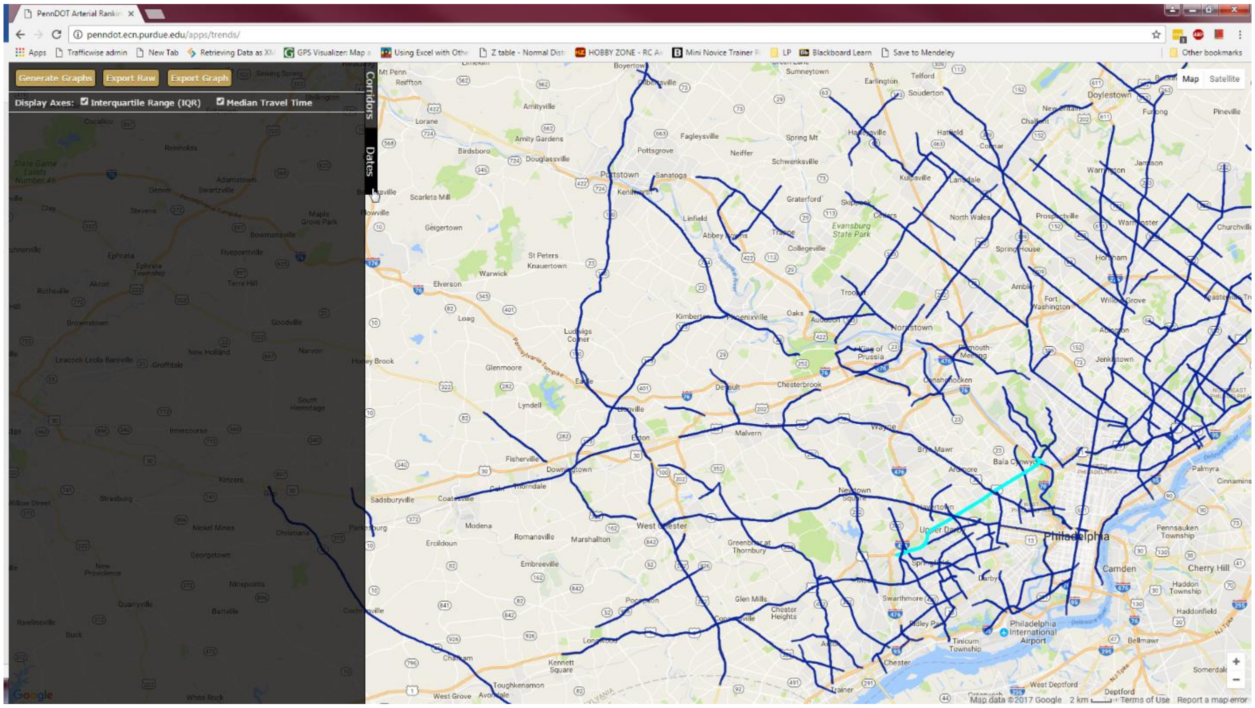


iii. To select a corridor, click on it. For this example, first click on "*Delaware*" county and then click on "*US 1/State Rd/Twp Line Rd/City Ave*"

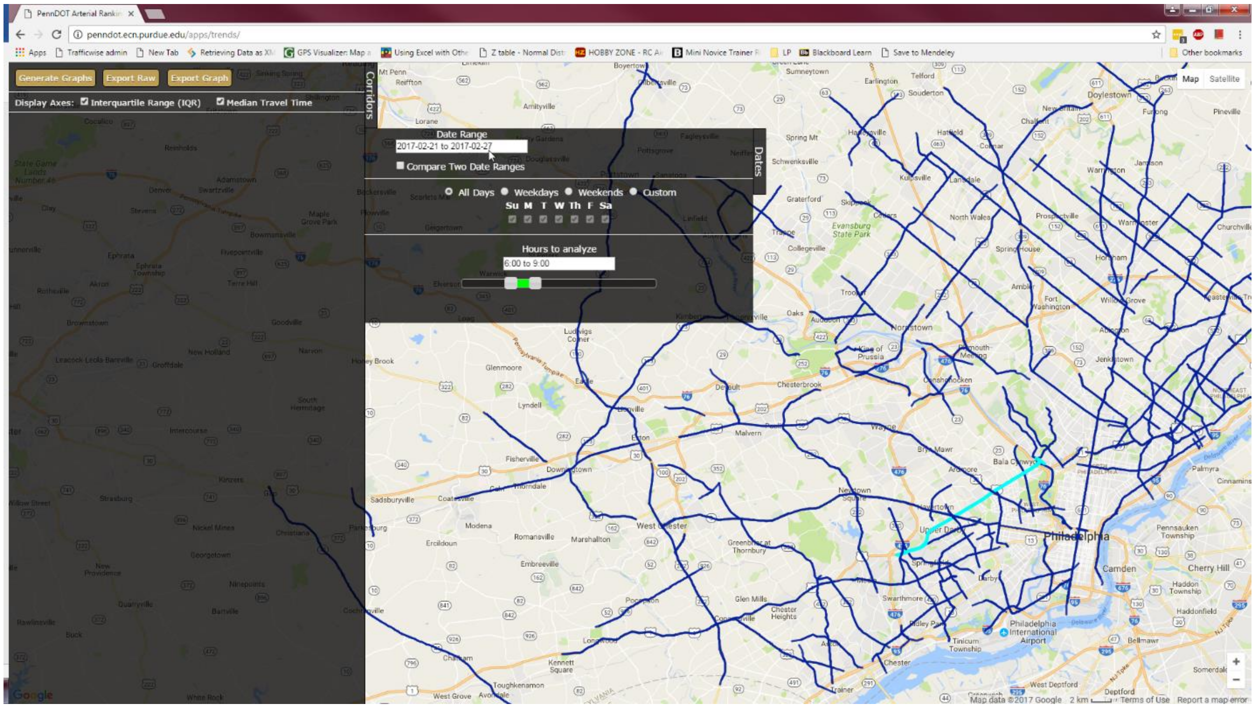


2.3. *Date Range*

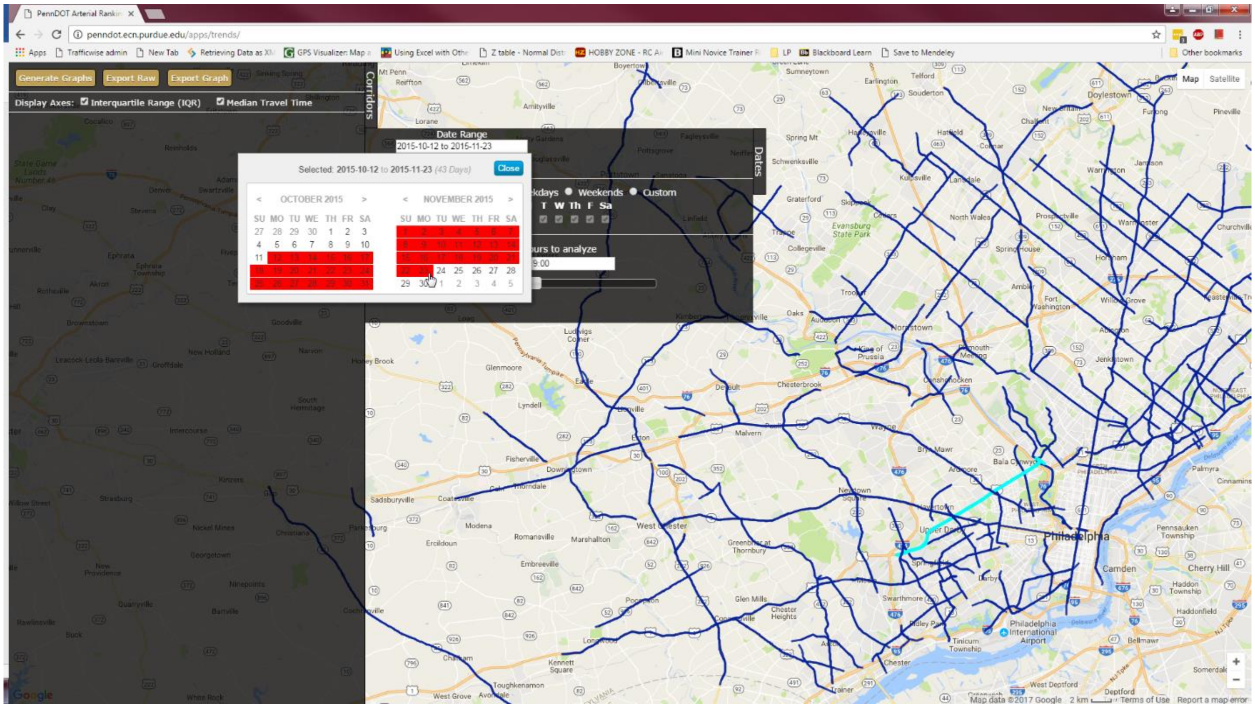
i. Click on the "*Dates"* tab



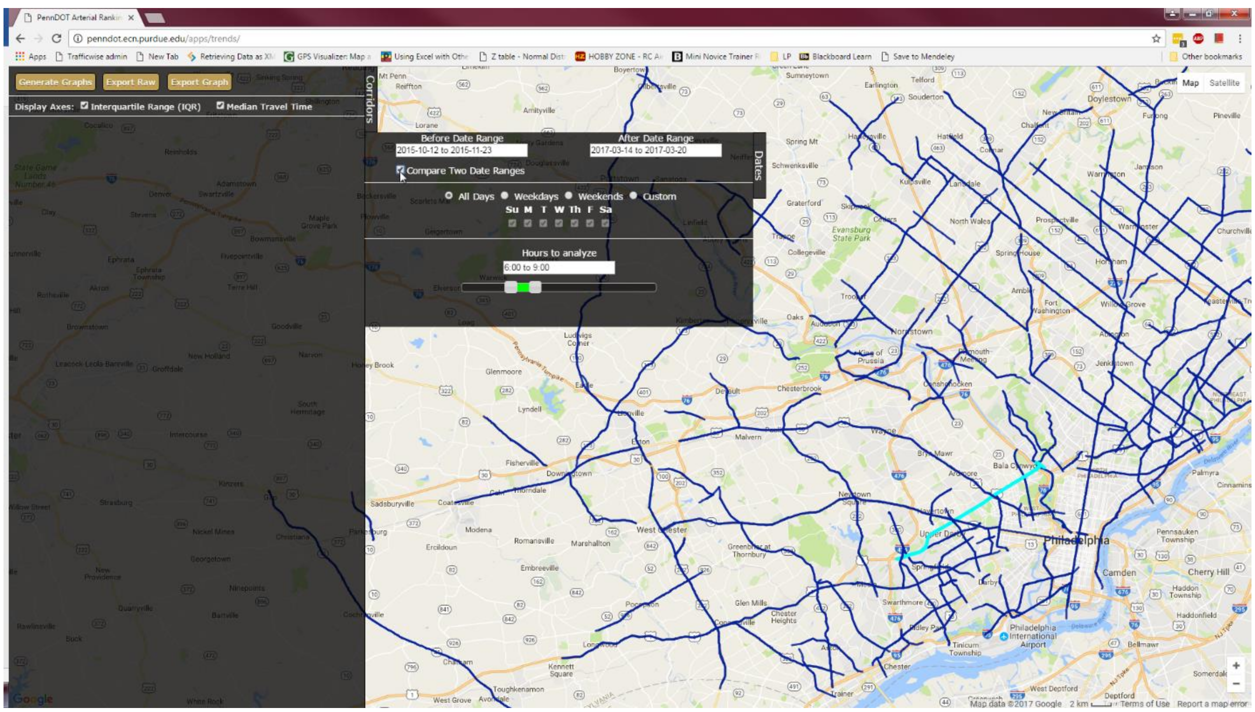
ii. Click on the dates below the "*Date range*"



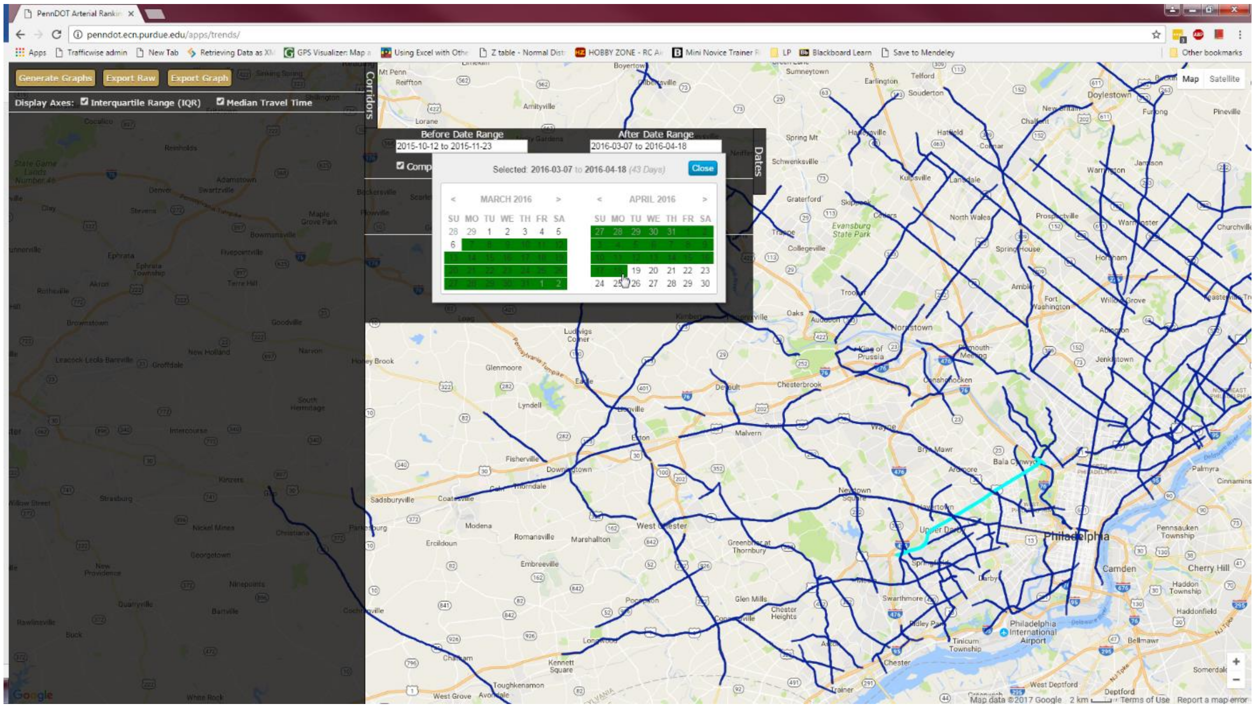
iii. Select the date range (for example from 10/12/2015 to 11/23/2015)



iv. To compare over 2 date ranges, check the "*Compare Two Date Ranges"* option which pops up the before and after date ranges



v. Select the before and after date ranges (Before: 10/12/2015 to 11/23/2015 and After: 3/7/2016–4/18/2016)



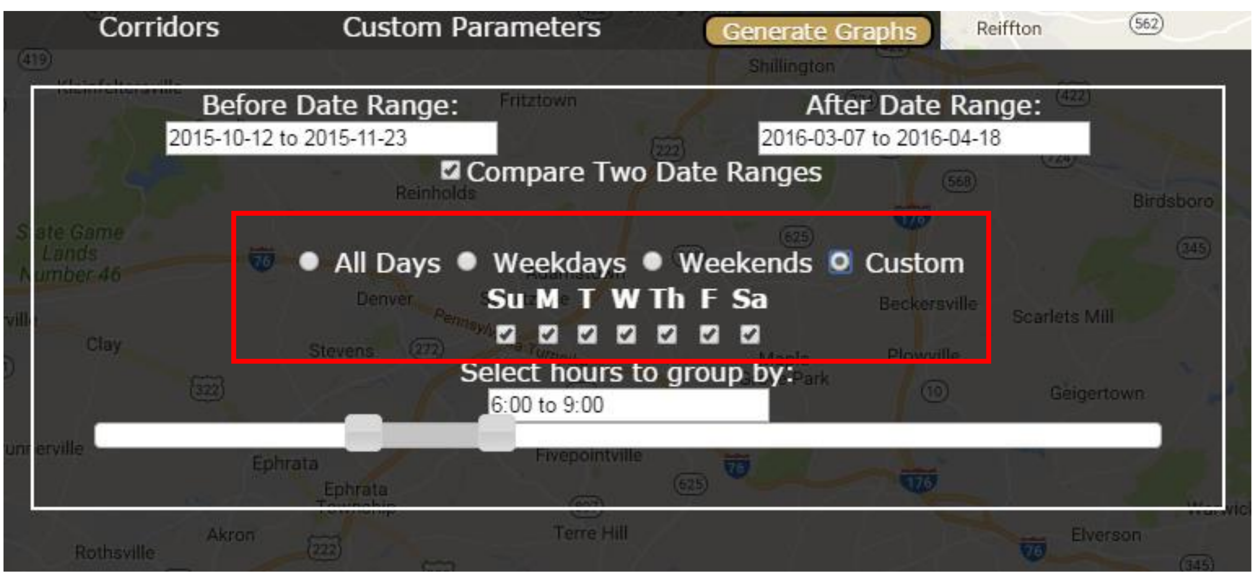
vi. Other options include:

a. All days: Includes all days in the date range

b. Weekdays: Selects only the weekdays in the date range

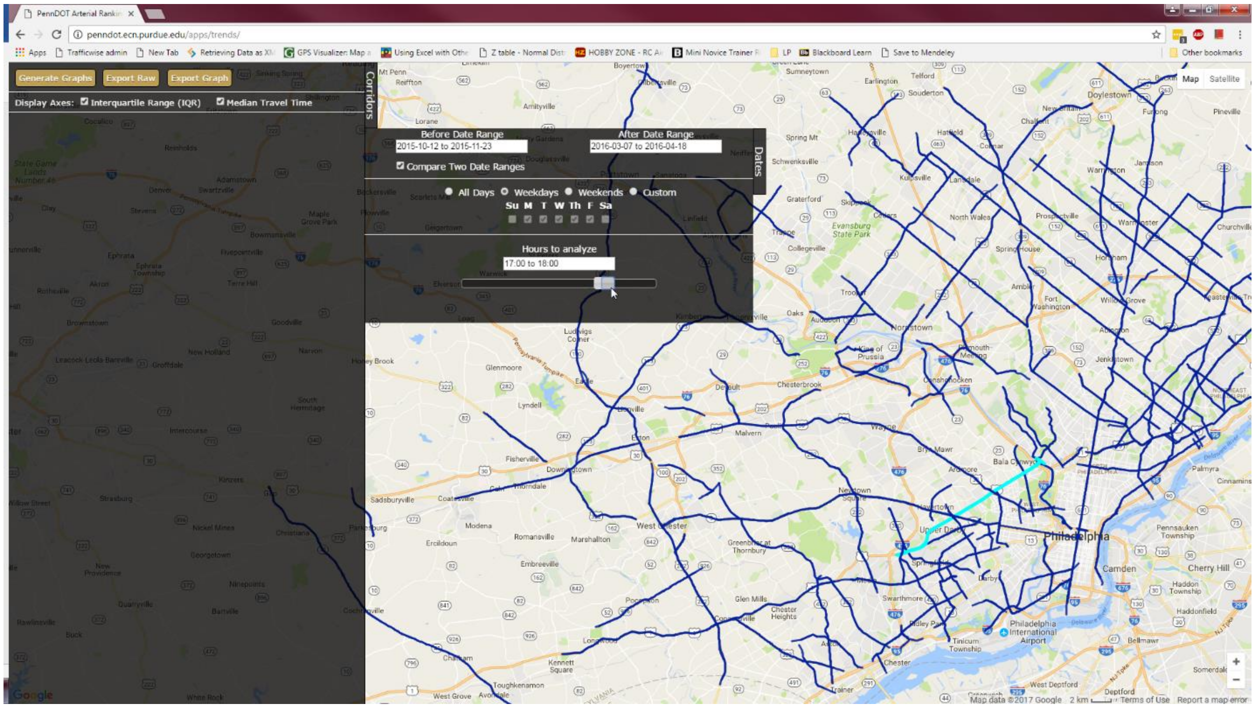
c. Weekends: Only selects the weekends

d. Custom: Select custom days for analysis. Use the checkbox to select the desired days.



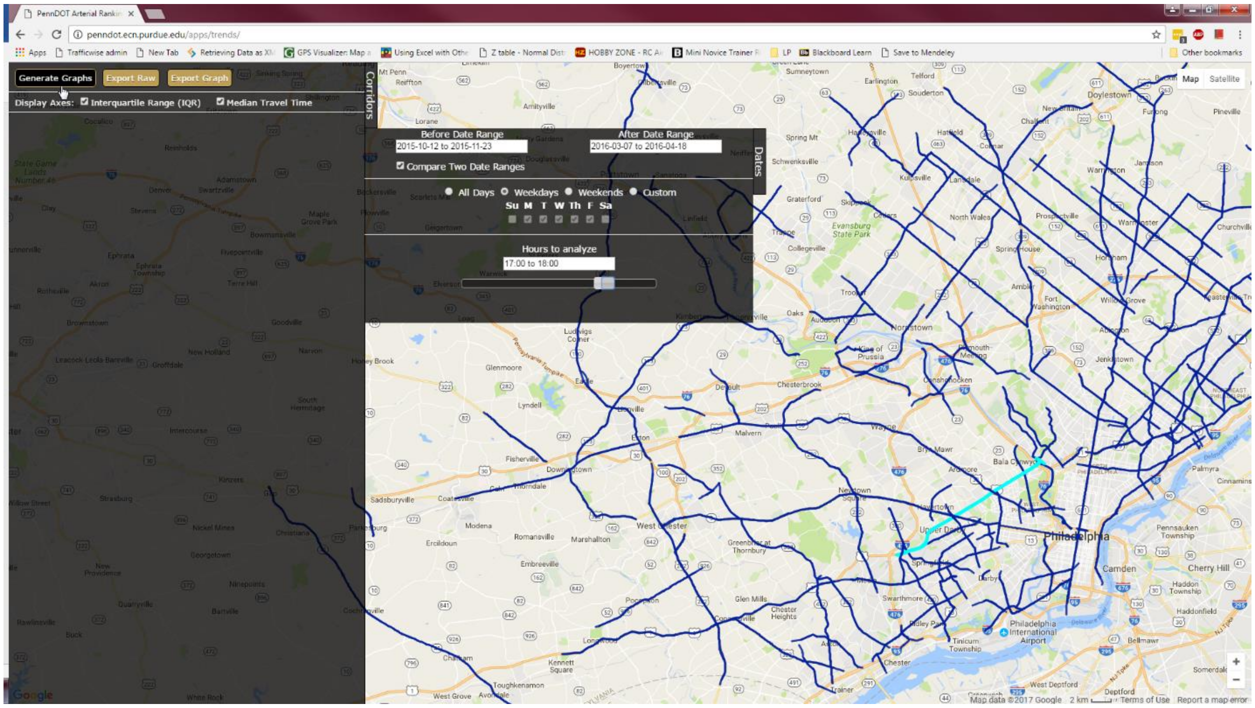
2.4. Timing

i. Use the slider to set the time of the day. The below screen scrape shows the time of the day set to 17:00 – 18:00 hours

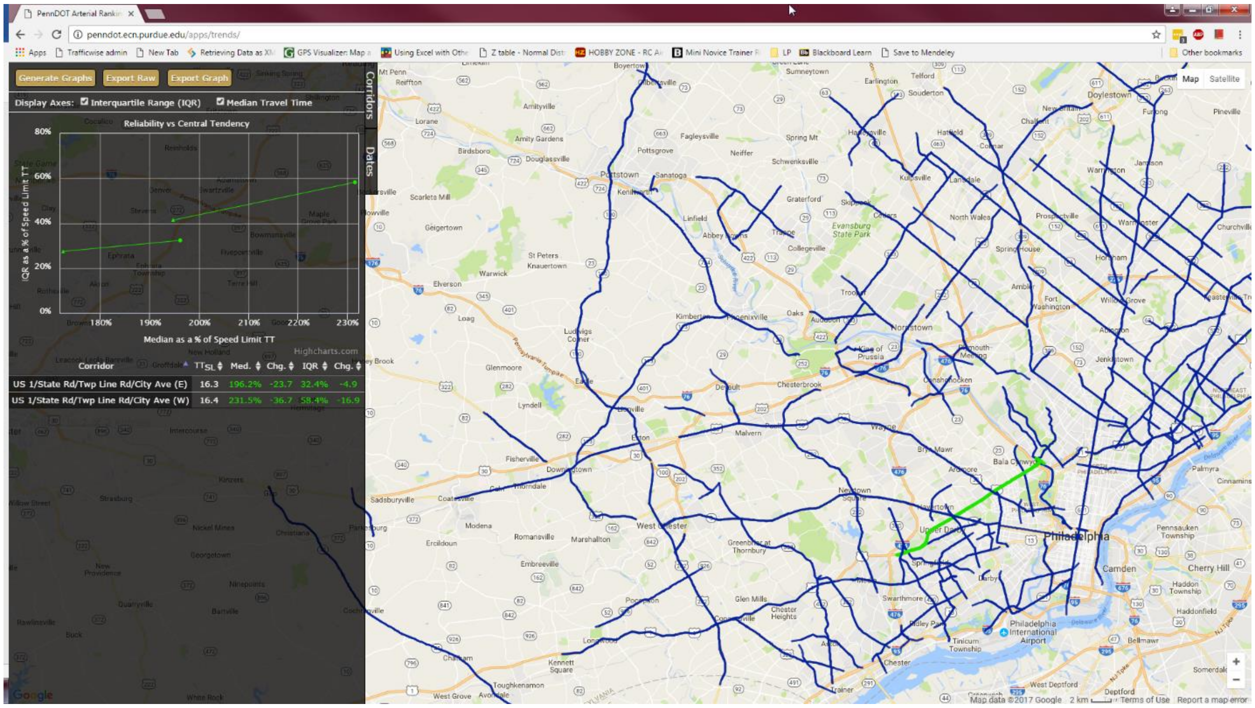


3. Graphs

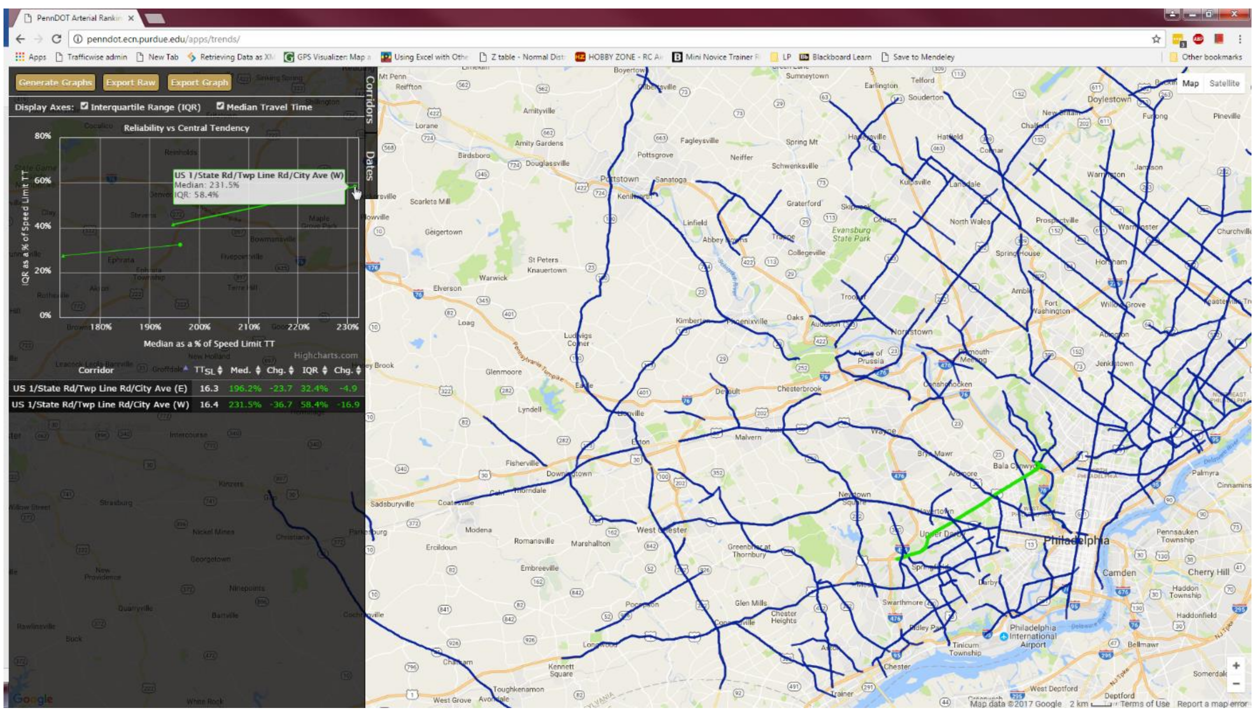
i. Click on "*Generate Graphs*"



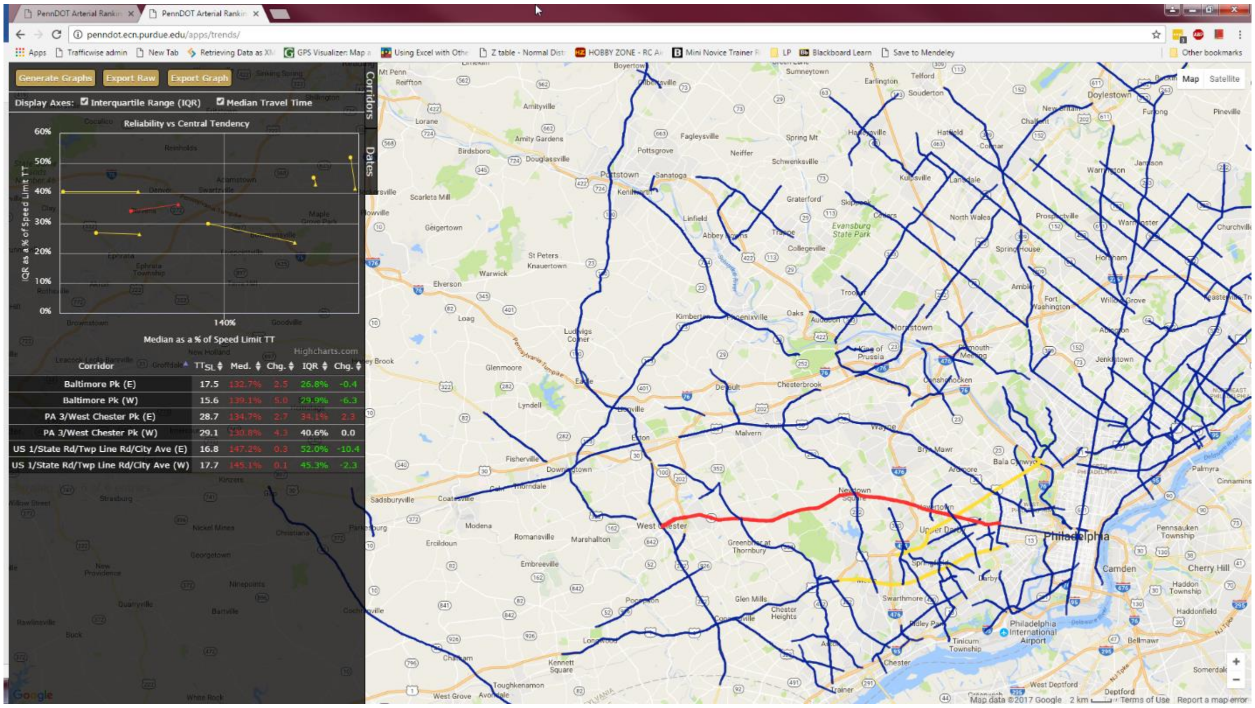
ii. This pops up the trends graph as well as the ranking table based on the median and IQR normalization. The below plot is for the date range (Before: 10/12/2015 to 11/23/2015 and After: 3/7/2016–4/18/2016), all weekdays and time range 17:00-18:00.



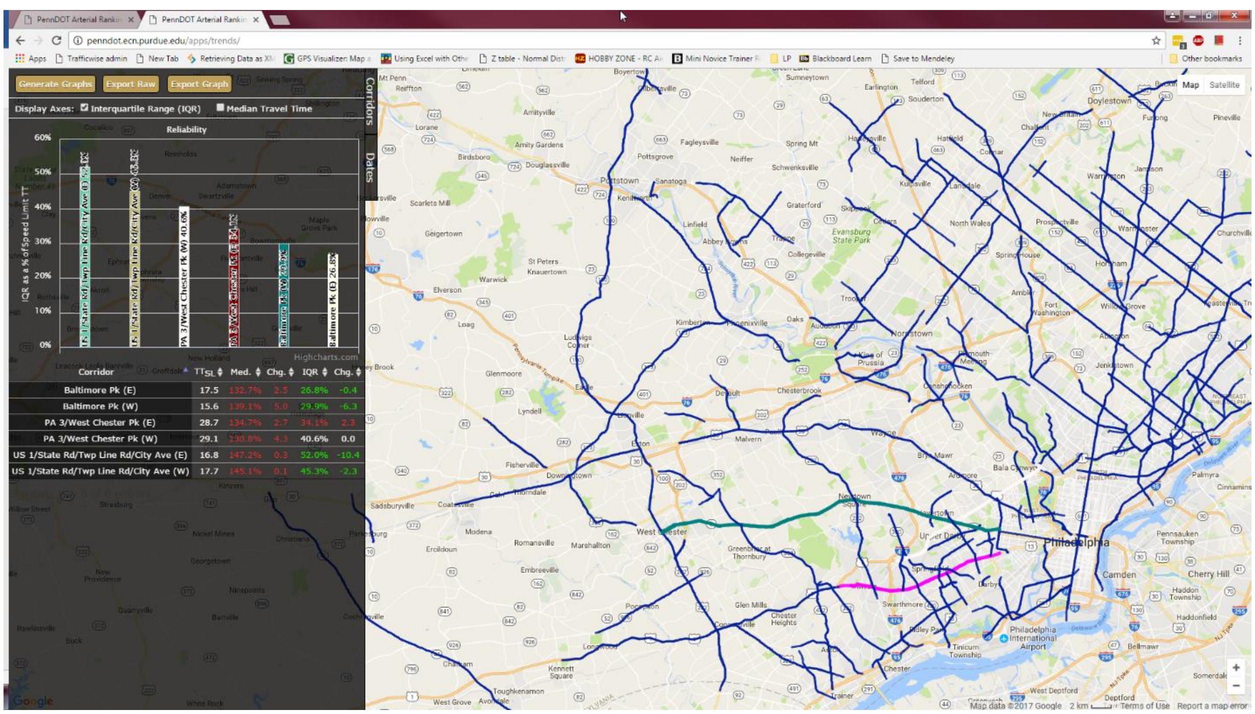
iii. Move the cursor over the plot to view the median and IQR values



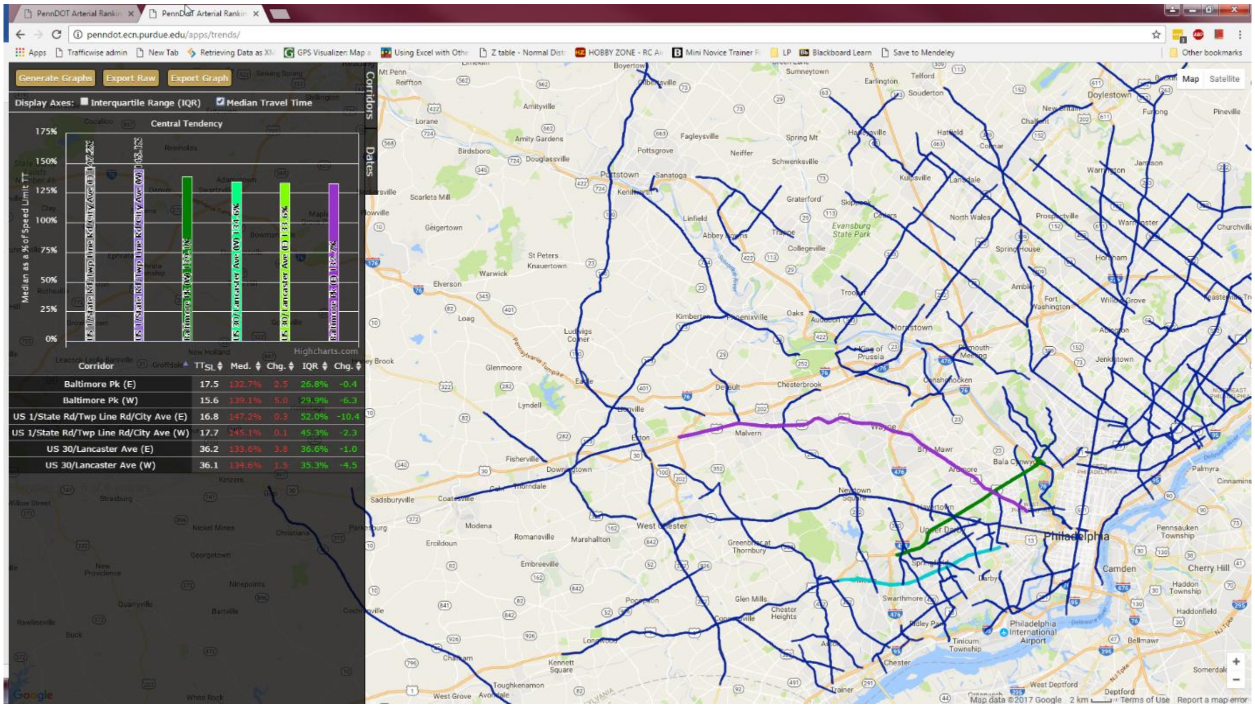
iv. Selecting more than 1 corridor, generates the graphs and tables color coded by the median and IQR values (*Routes that had decreases in both the median and IQR are colored green, while routes that had increases in both median and IQR degradation are colored red. Corridors with mixed results are colored orange*)



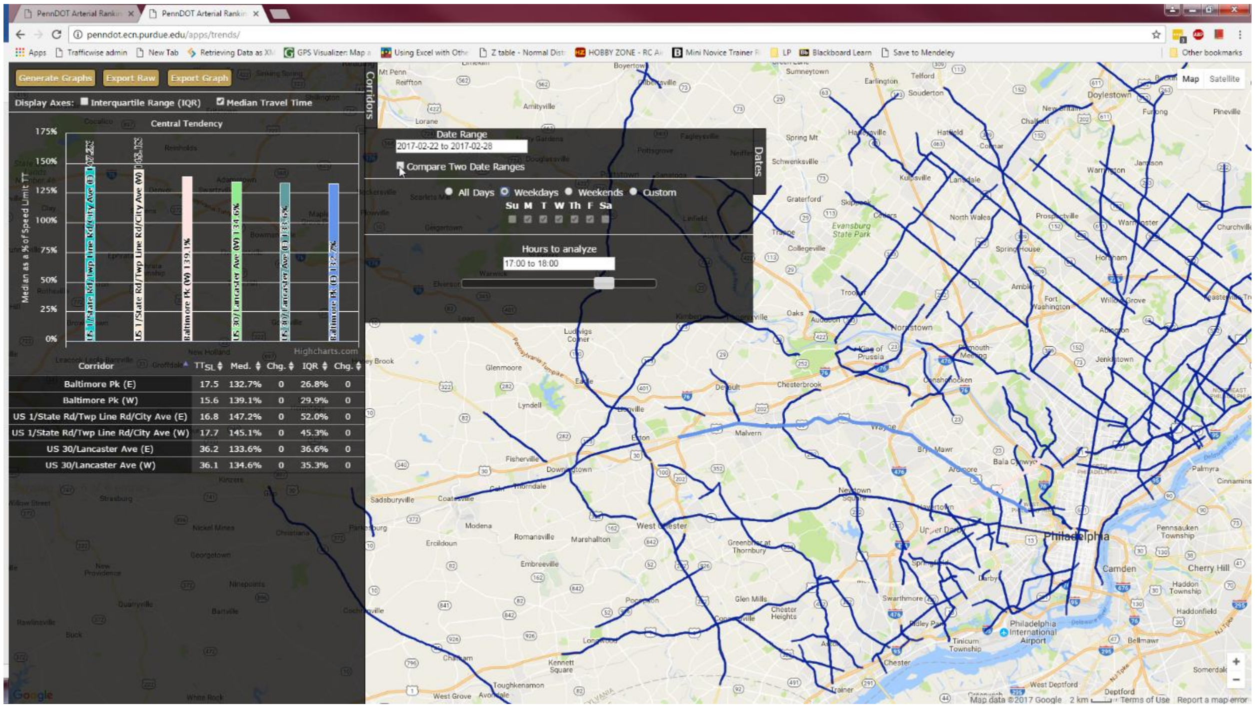
v. To view the arterial ranking based on IQR range, check the "*IQR* Range" and uncheck the "*Speed Limit TT*". Generating the graphs again will show the IQR for the corridors (color-coded by corridor) during the particular date ranges.



vi. Similarly, to view the ranking based on the speed limit travel time, check the *"Speed Limit TT"* and uncheck the "*IQR* Range".

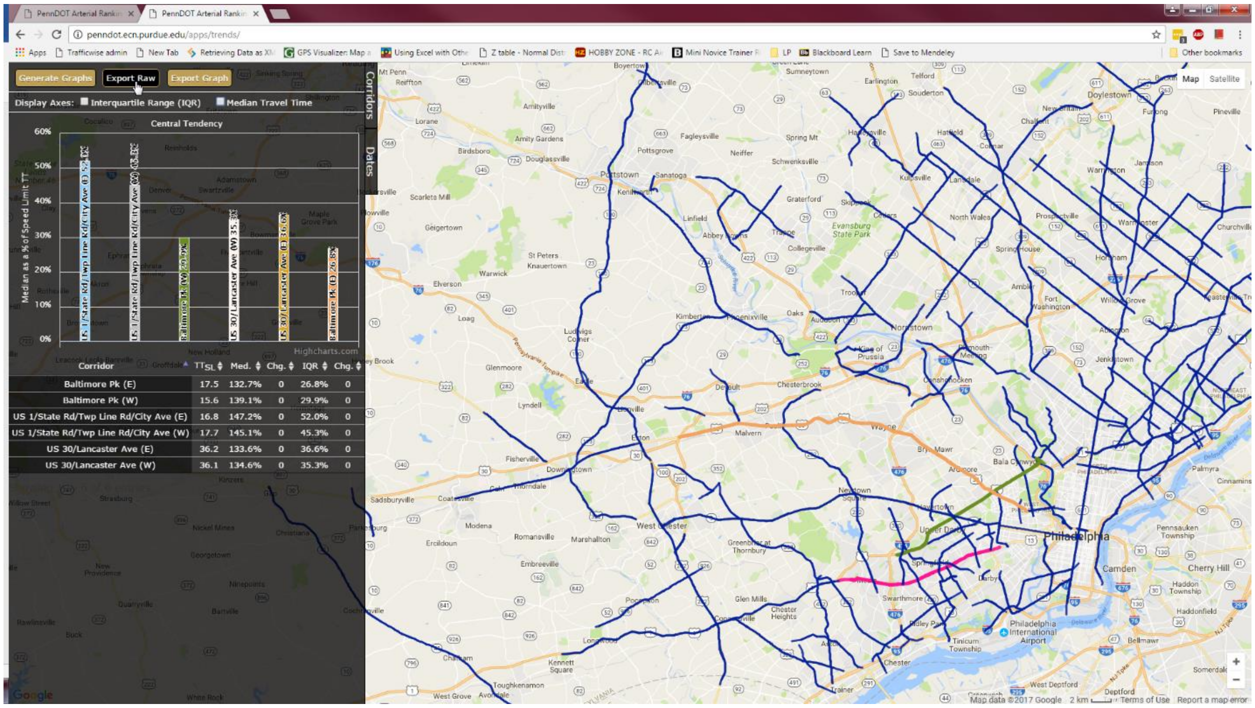


vii. To view all the above graphs for only the before date range, uncheck the "*Compare Two Date Ranges*" in the Dates tab. Notice that the change (Chg.) column in the table resets to zero.

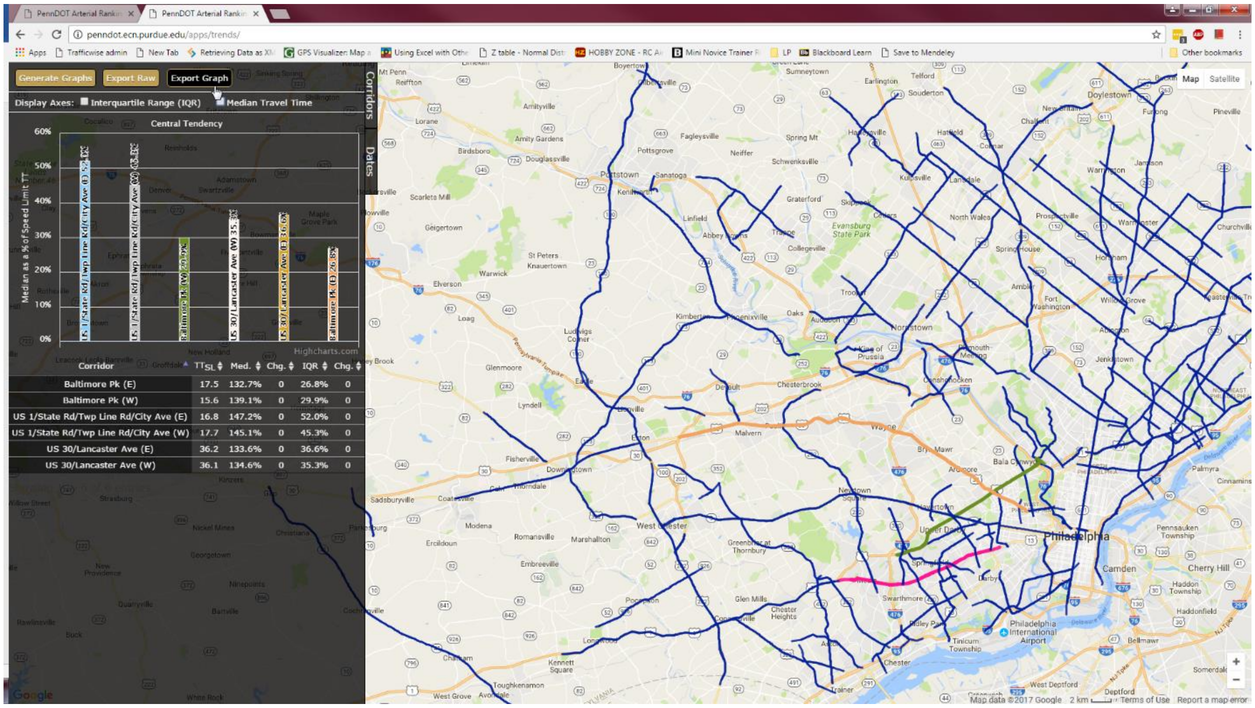


4. Export Options

i. Click on "*Export Raw*" to export the raw data



ii. Similarly, to export the graphs, click on "*Export Graphs*"



TRAVEL DELAY MONITOR

1. Link

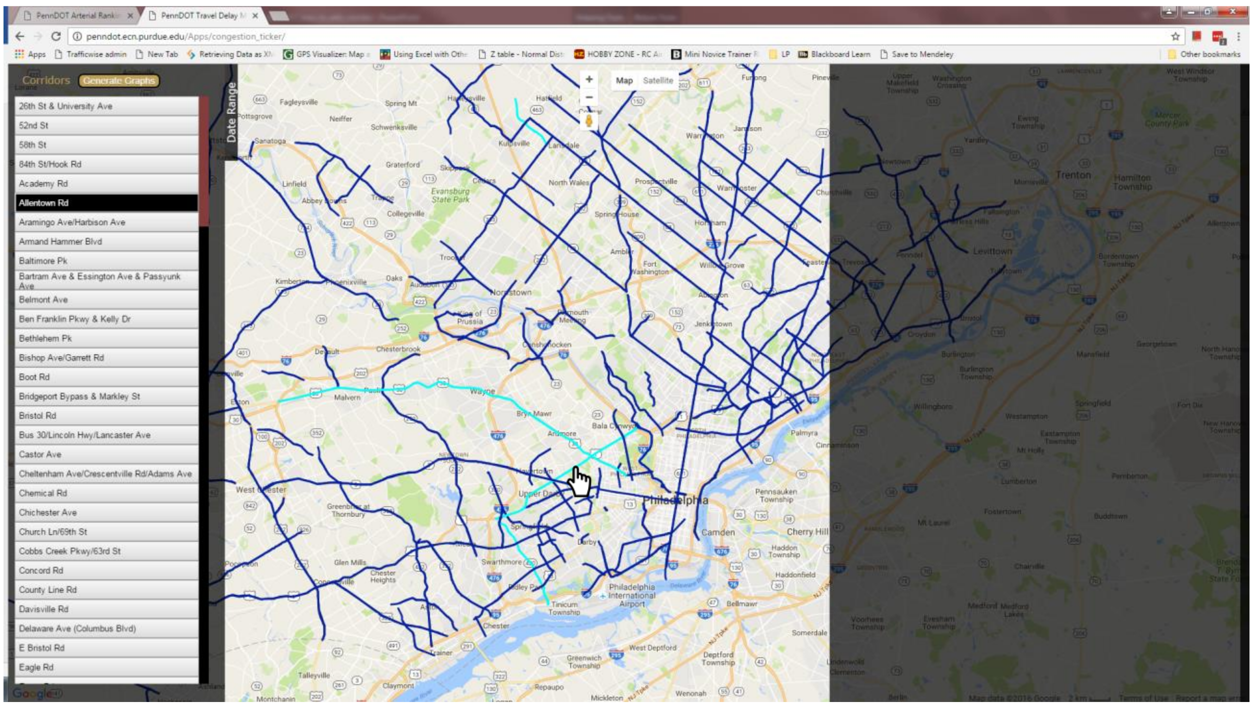
- Go to http://pdprvpmapp01.penndot.lcl/Apps/congestion_ticker
- Supported browsers (Optimized for Google Chrome)
  - Google Chrome (Version 54.0.2840.71 m)
  - Mozilla Firefox (Version 49.0.2)
  - Internet Explorer (Version 11.0.9600.18499)
  - Microsoft Edge (Version 38.14393.0.0)

2. Selecting Corridors and Date Ranges

2.1. Corridor Selection

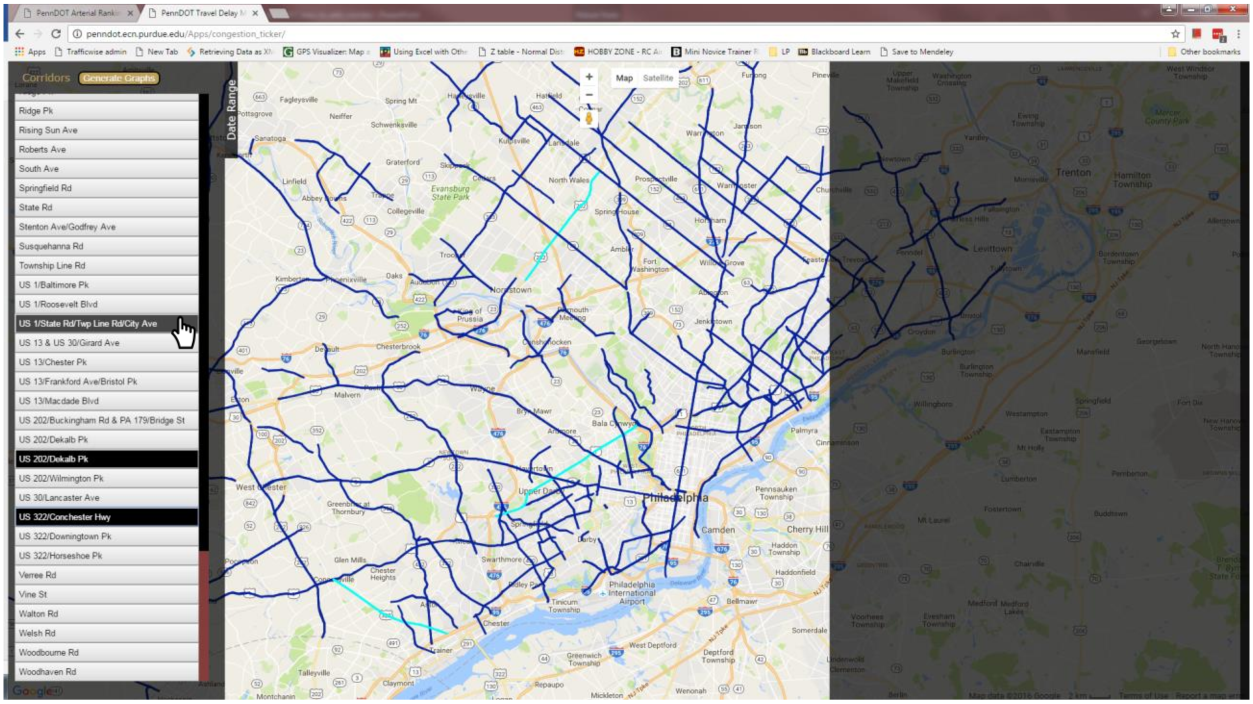
2.1.1. <u>Using Mouse</u>

i. Left click on the corridors to select/deselect it. A maximum of 5 corridors can be selected at once.



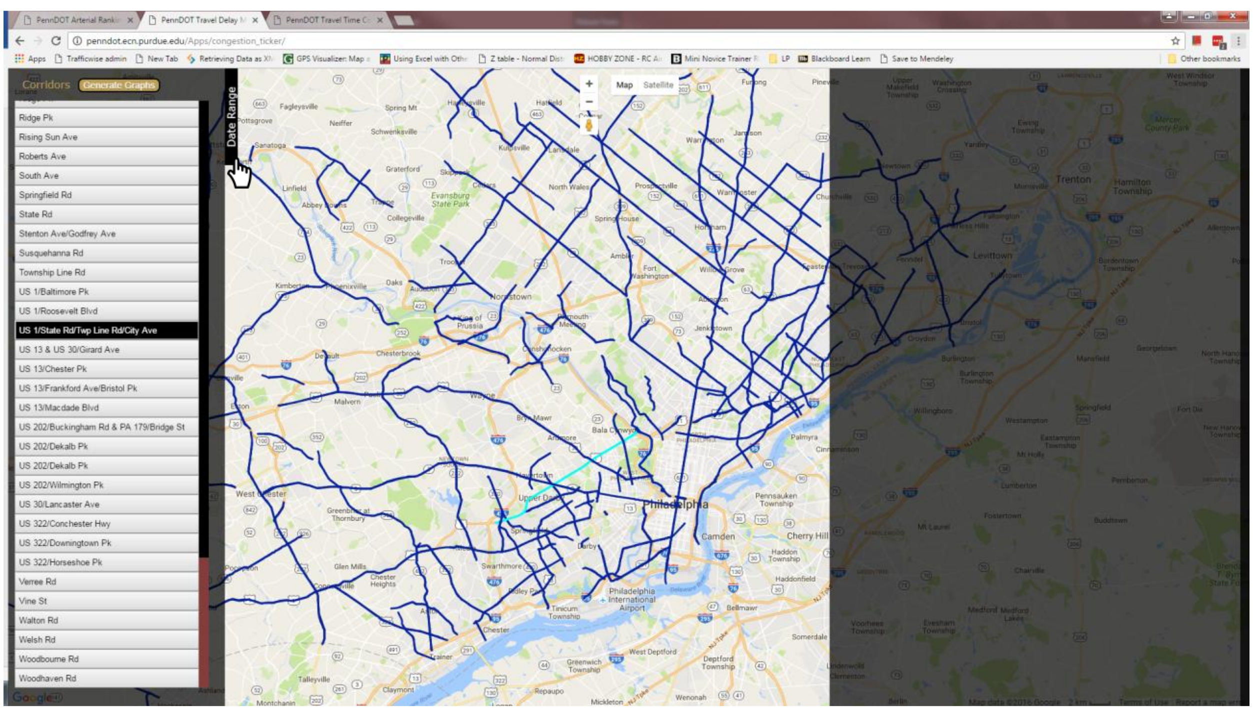
2.1.2. <u>Using GUI</u>

i. Click on the corridor name to select/deselect it. You can select up to a maximum of 5 corridors at a time

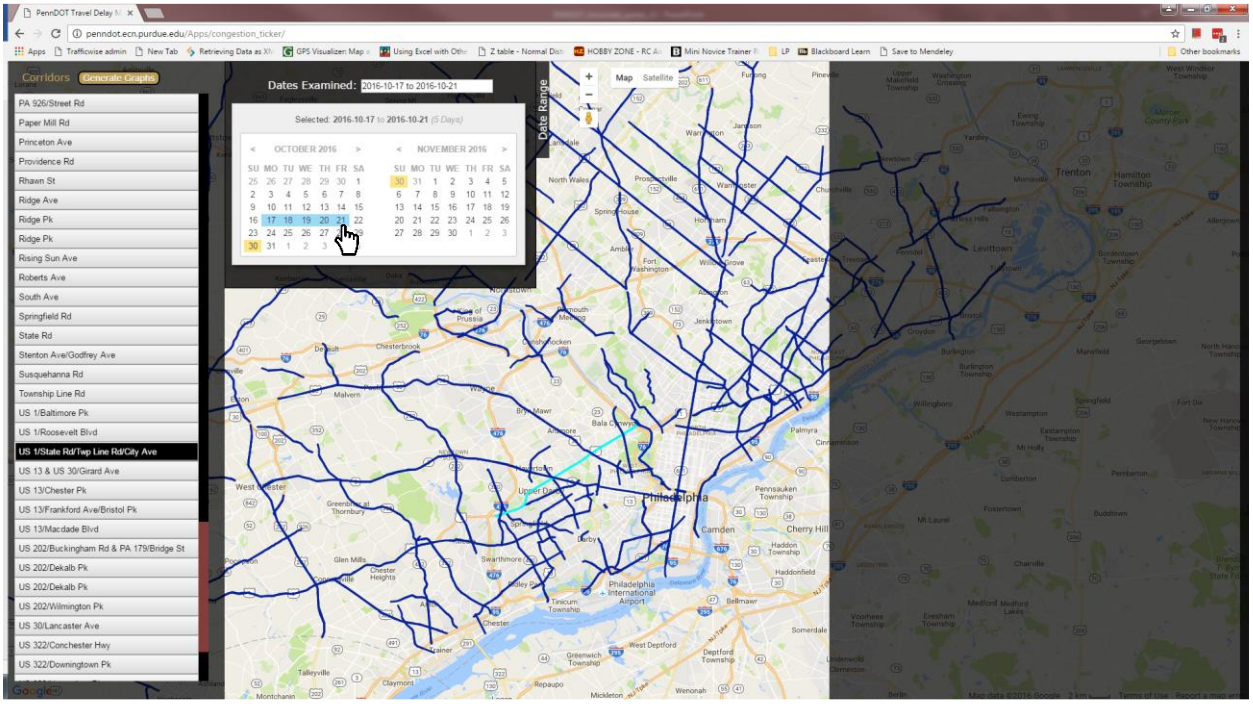


2.2. Date Range

i. Click on the "*Date Range*" tab

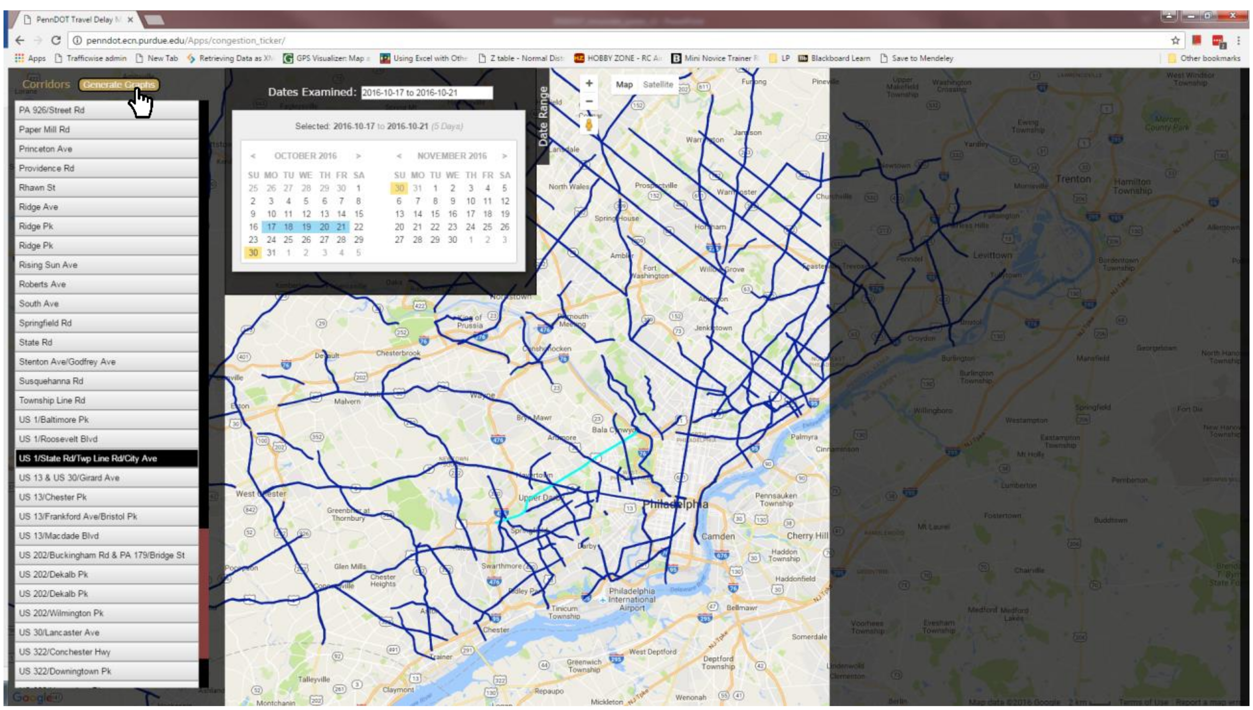


ii. Select the date range

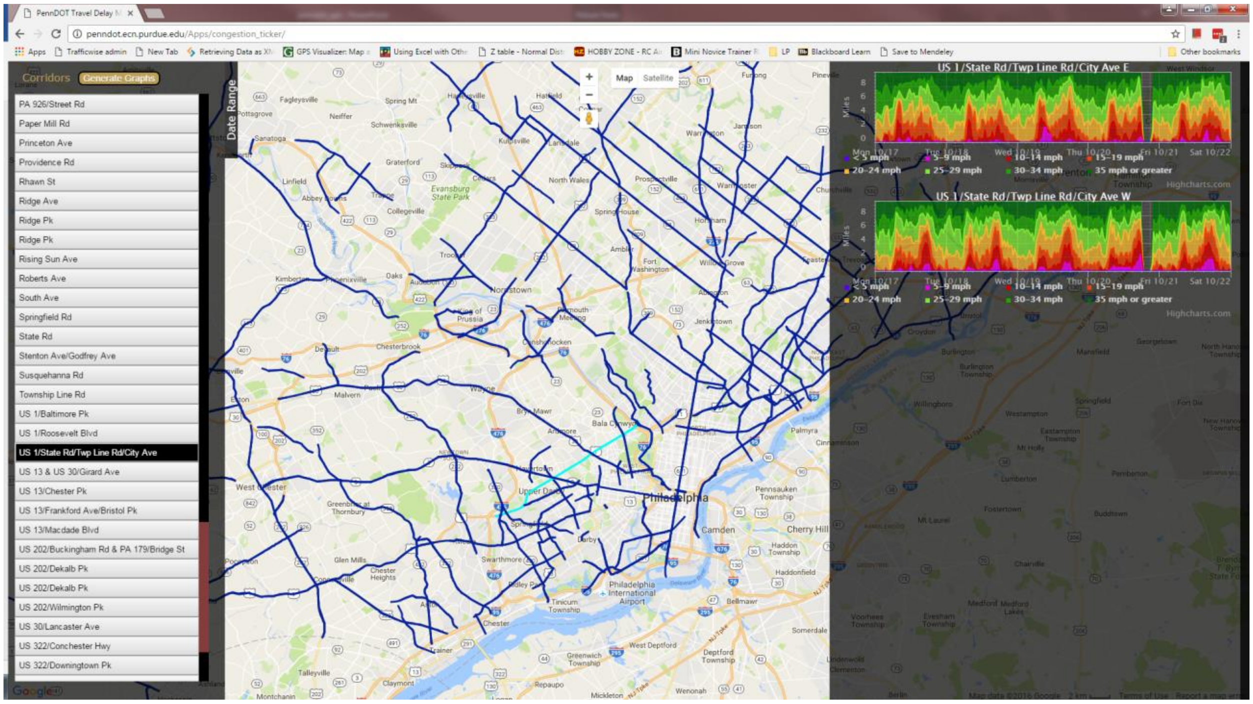


3. Generating Graphs

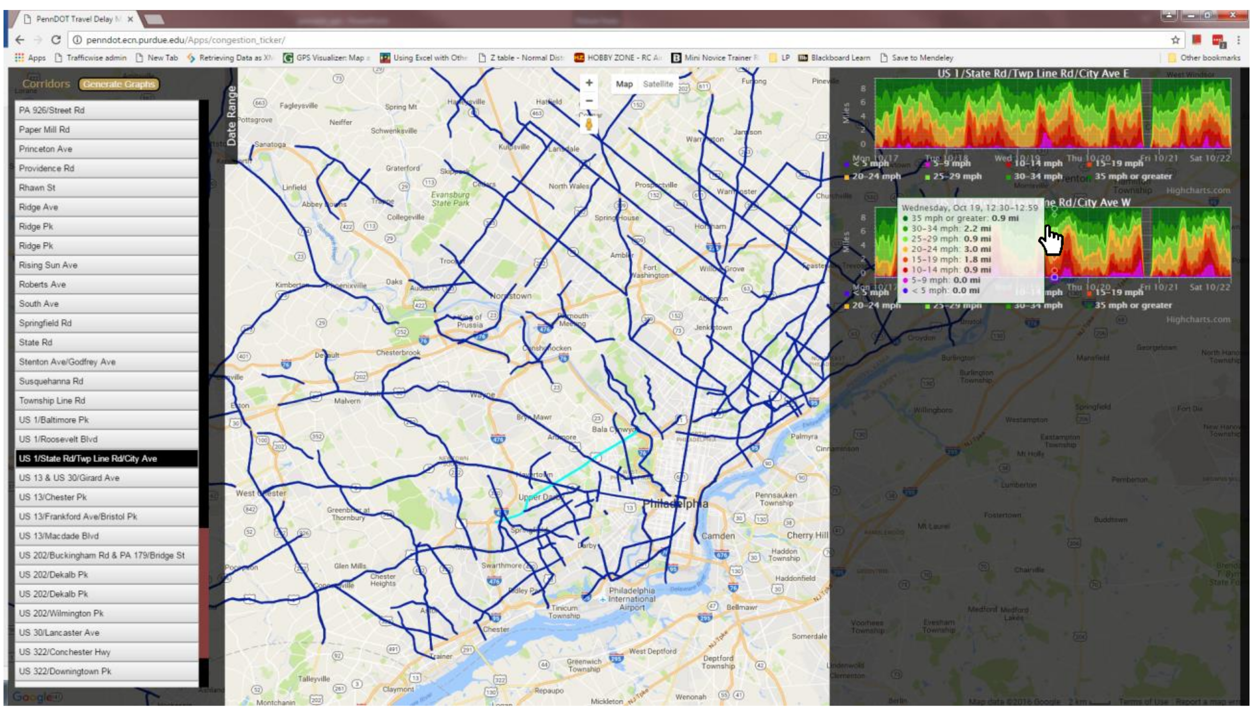
i. Click on "*Generate Graphs*"



ii. This generates the travel delay monitor for both the directions on the corridor.

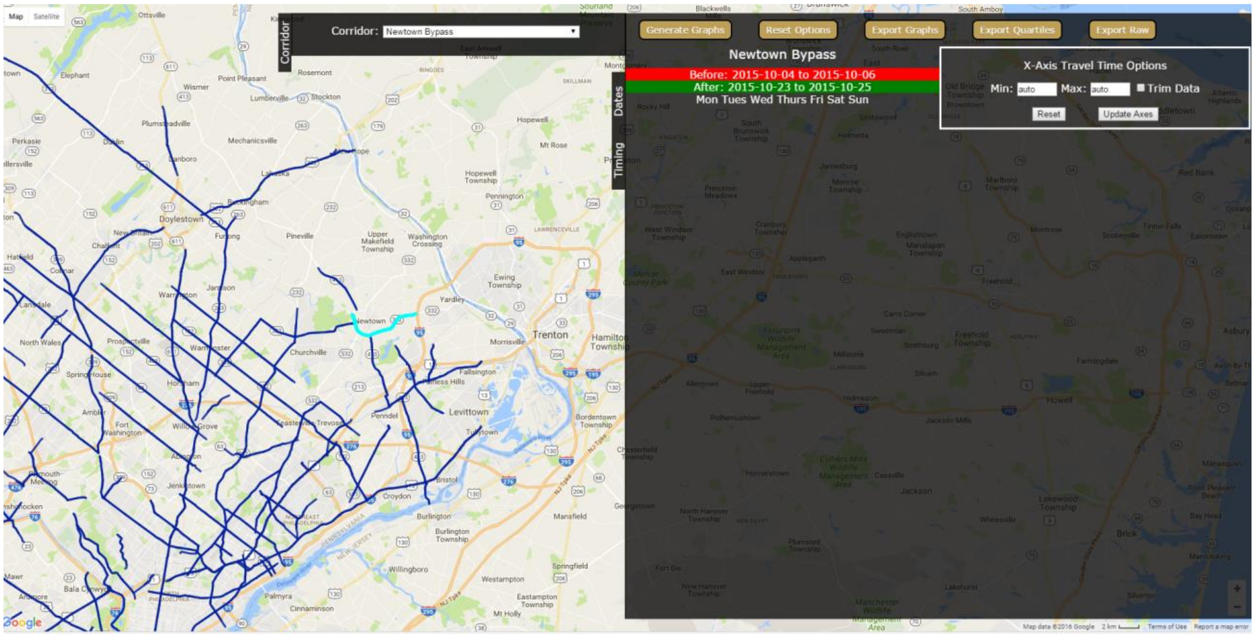


iii. Move the mouse over the graphs to view more details

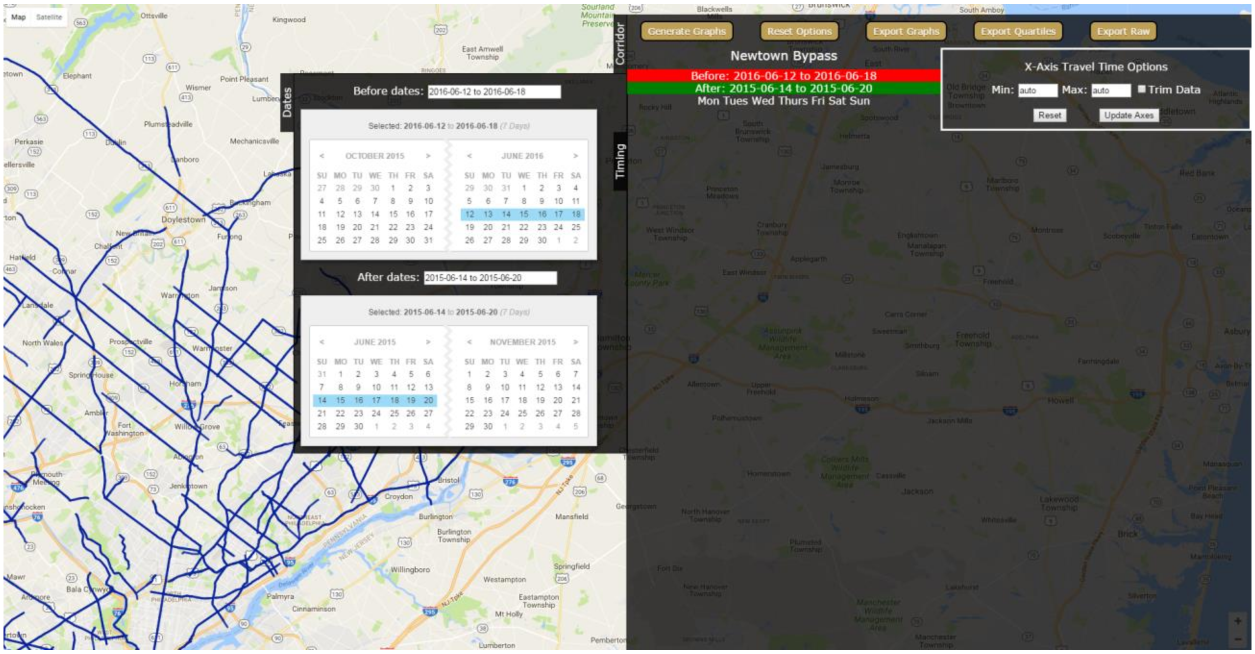


USER COST/BENEFIT CALCULATION

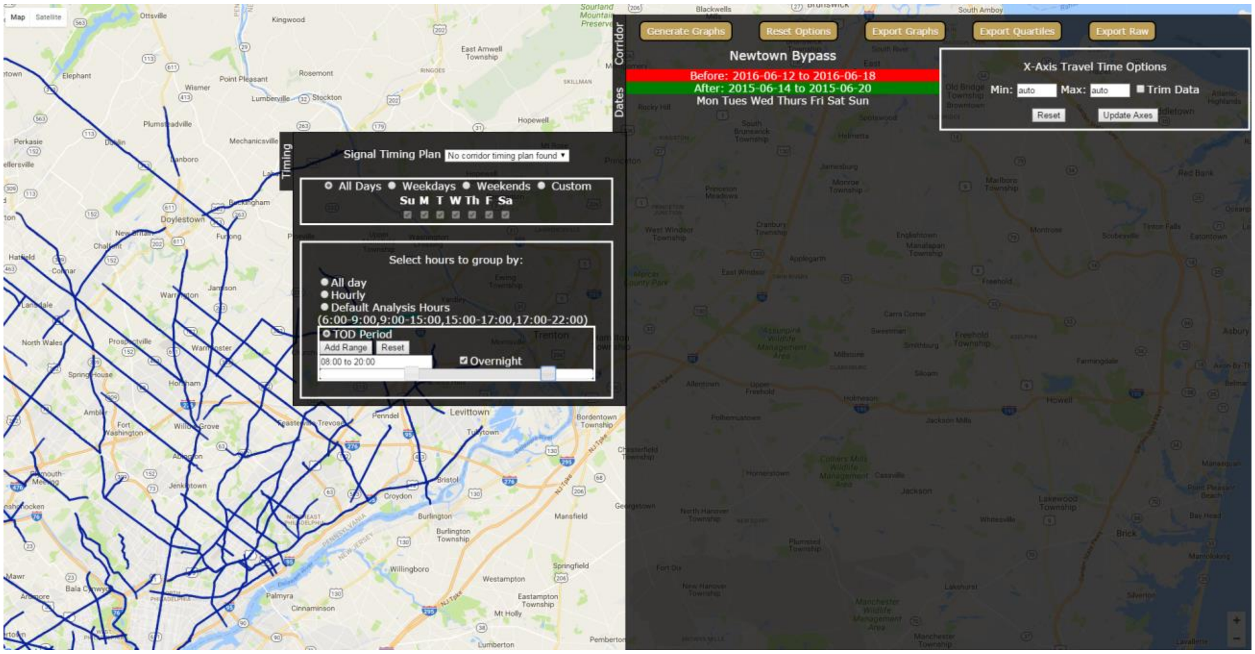
i. From the *Travel Time Comparison Tool*, select a corridor (**Newtown Bypass** shown)



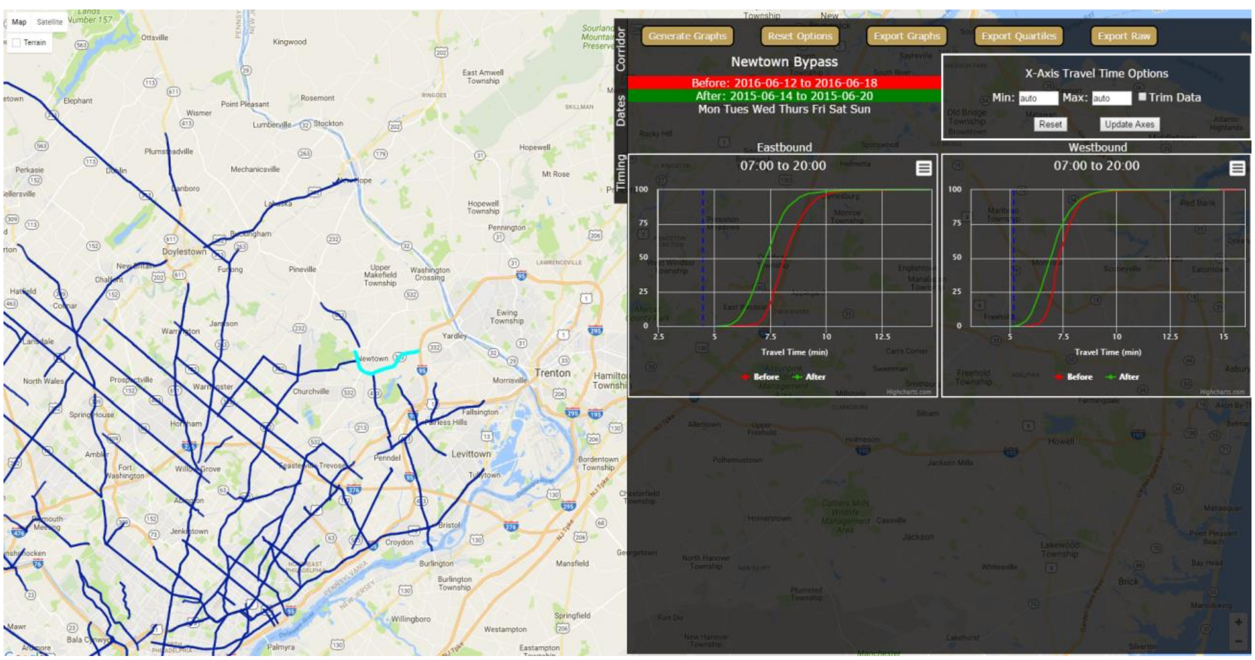
ii. Select a before and after date (June dates shown)



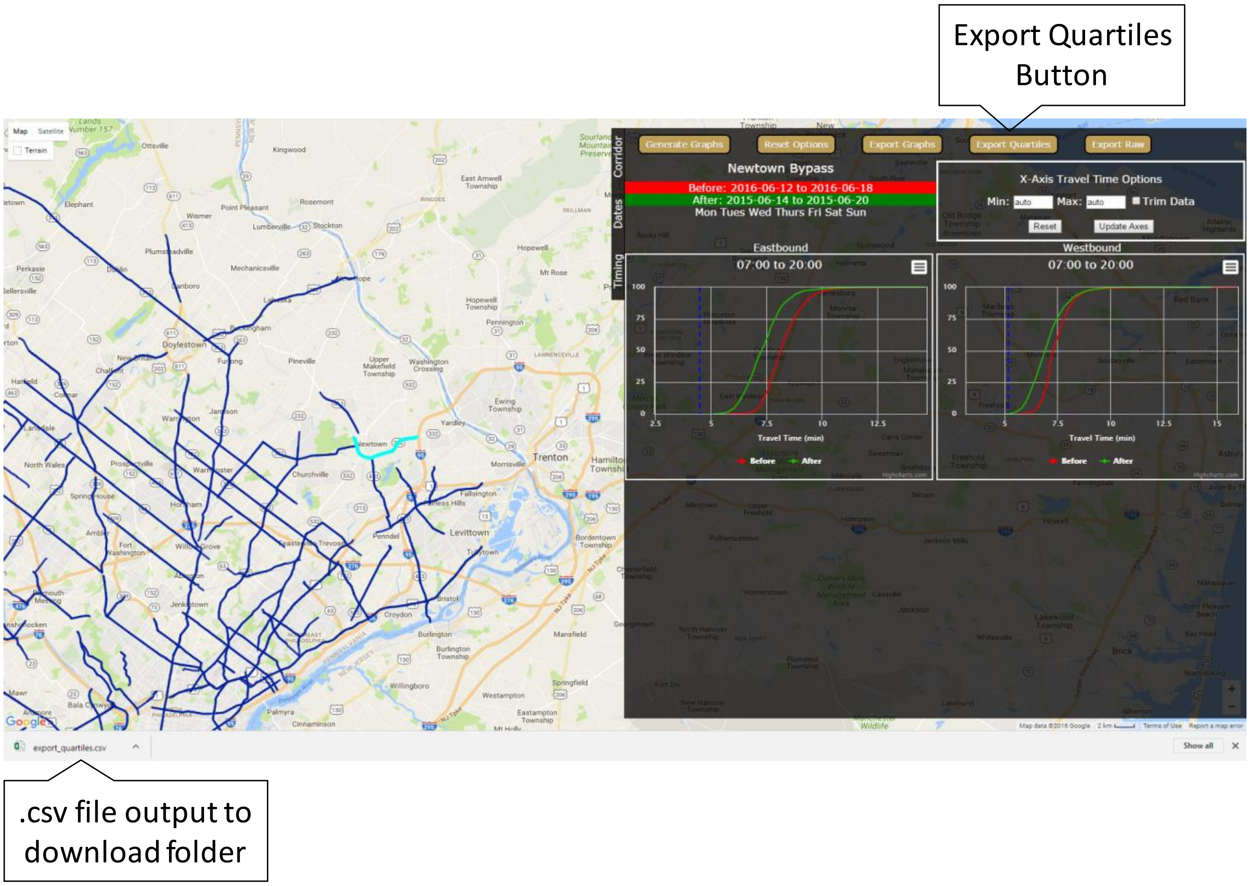
iii. Select time interval (8 AM – 8 PM shown)



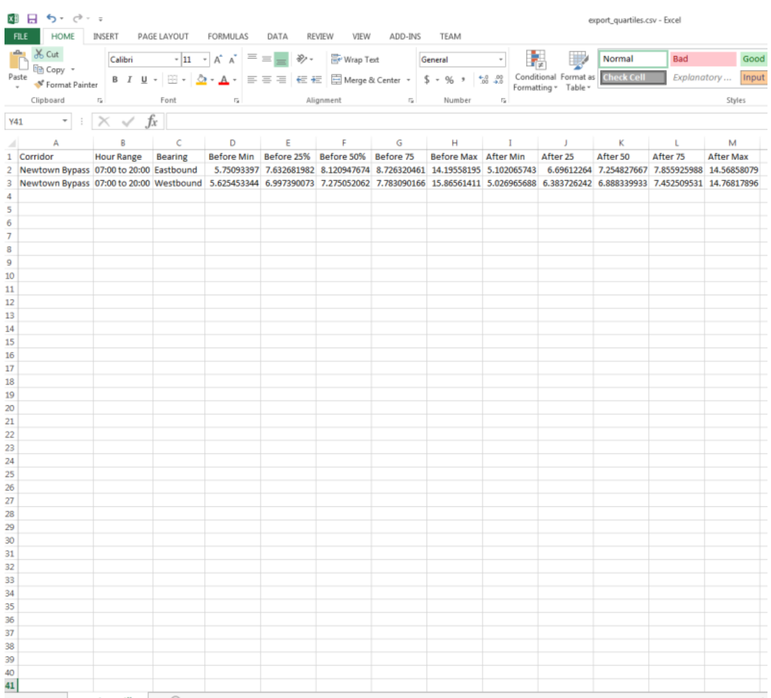
iv. Generate Graphs



v. Export Quartiles

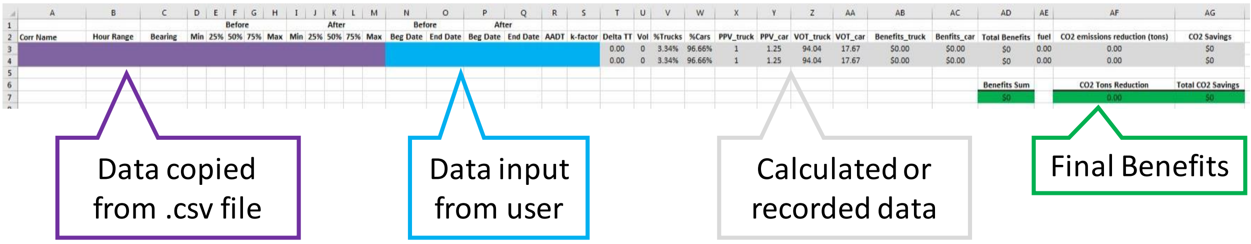


vi. Open .csv file in Excel

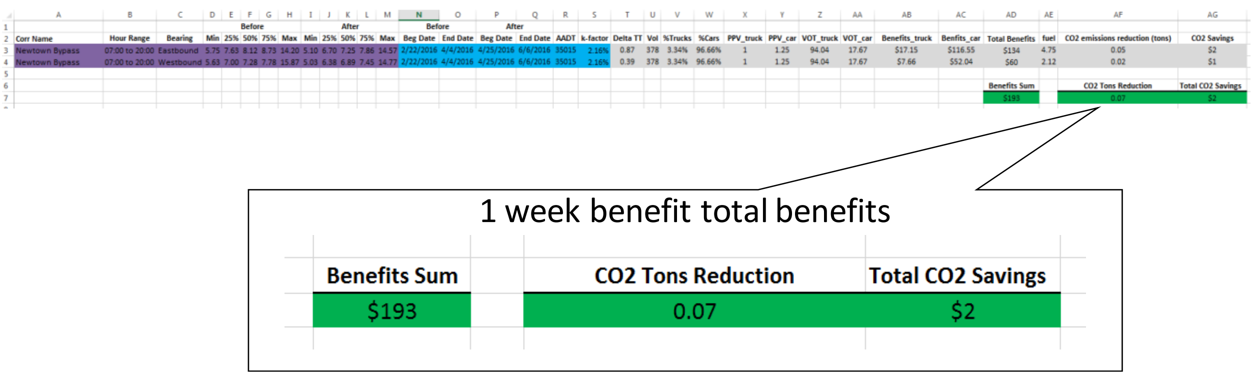


Corridor	Hour Range	Bearing	Before Min	Before 25%	Before 50%	Before 75	Before Max	After Min	After 25	After 50	After 75	After Max
Newtown Bypass	07:00 to 20:00	Eastbound	5.75093397	7.632681982	8.120947674	8.726320461	14.19558195	5.102065743	6.69612264	7.254827667	7.855925988	14.56858079
Newtown Bypass	07:00 to 20:00	Westbound	5.625453344	6.997390073	7.275052062	7.783090166	15.86561411	5.026965688	6.383726242	6.888339933	7.452509531	14.76817896

vii. Open User Cost Template in Excel



viii. Input data and get results

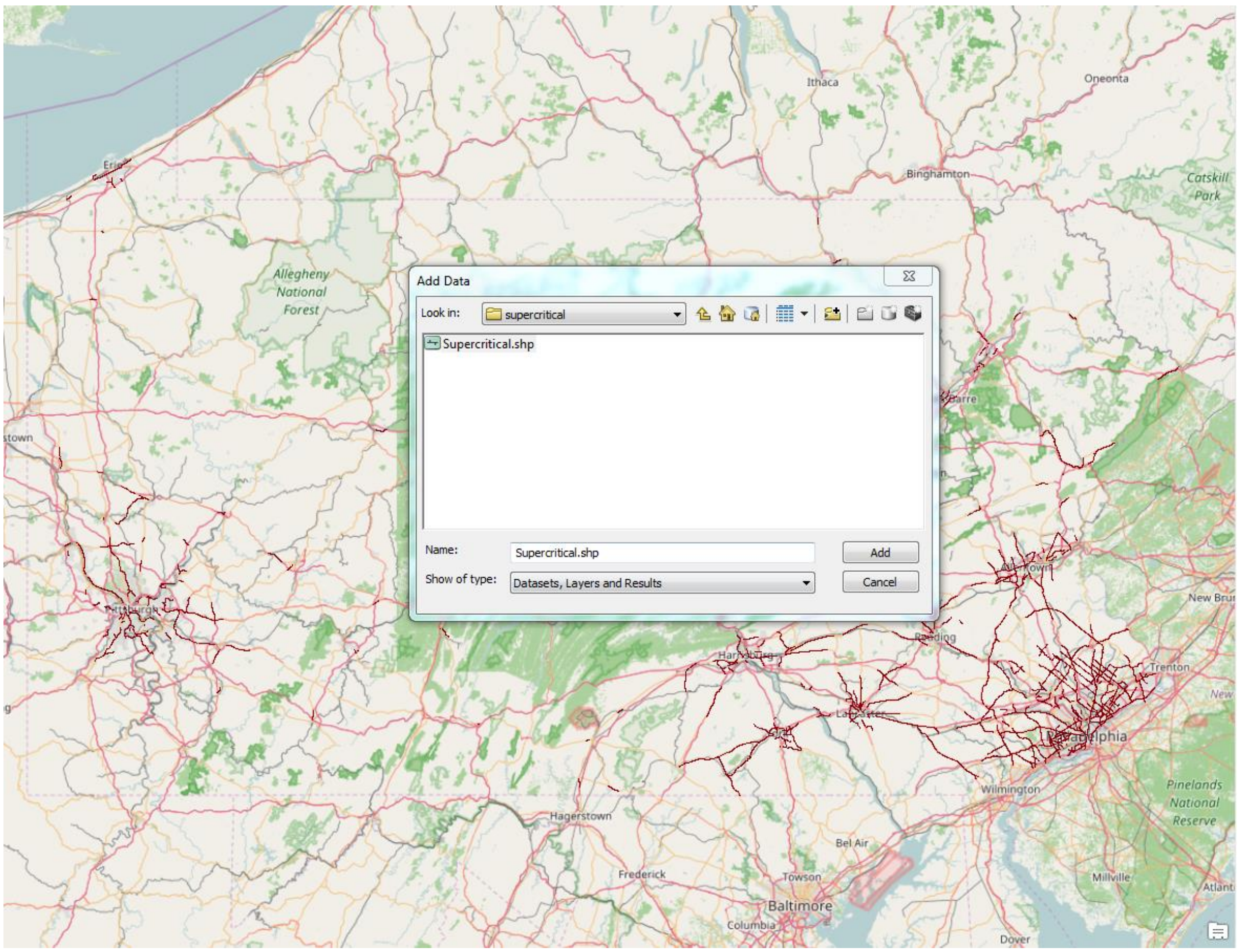


APPENDIX II – MAPPING CORRIDORS, TIMING PLANS AND DATABASE MANAGEMENT (WEBINAR TOPIC)

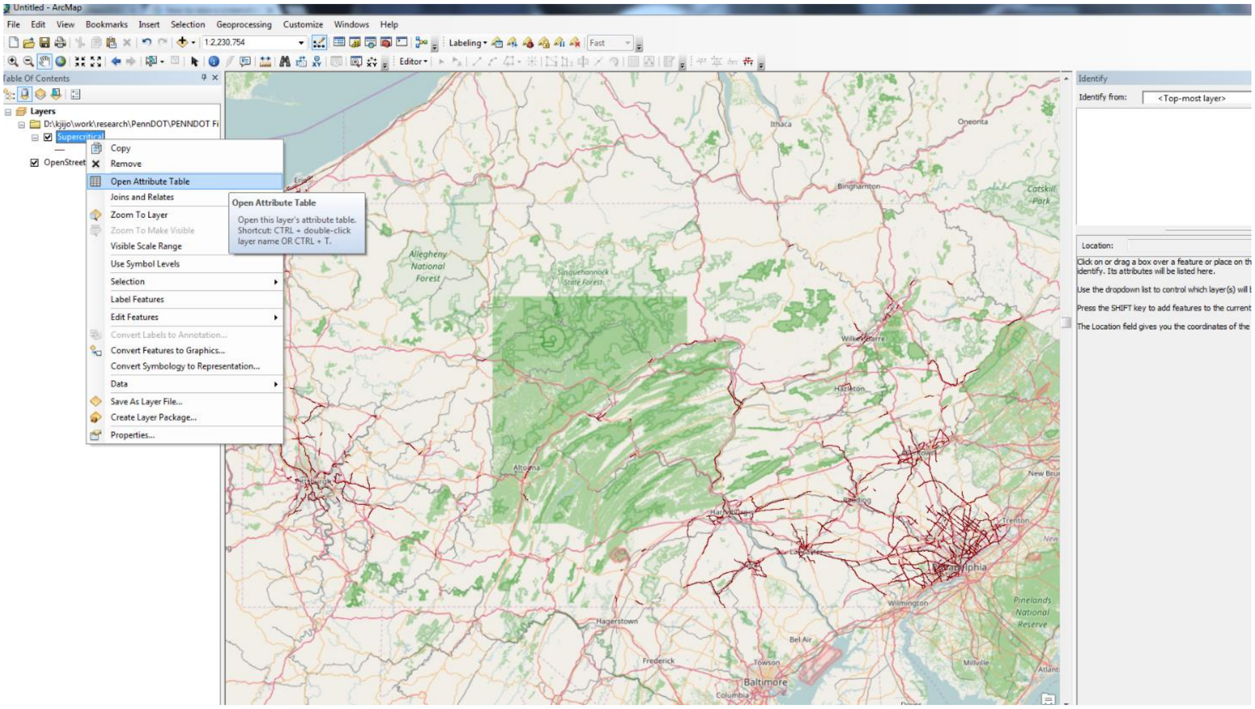
A detailed video showing the corridor mapping process using ESRI ArcMap and database management using Microsoft SQL Server can be viewed at: https://youtu.be/Vva5RpIRIYM

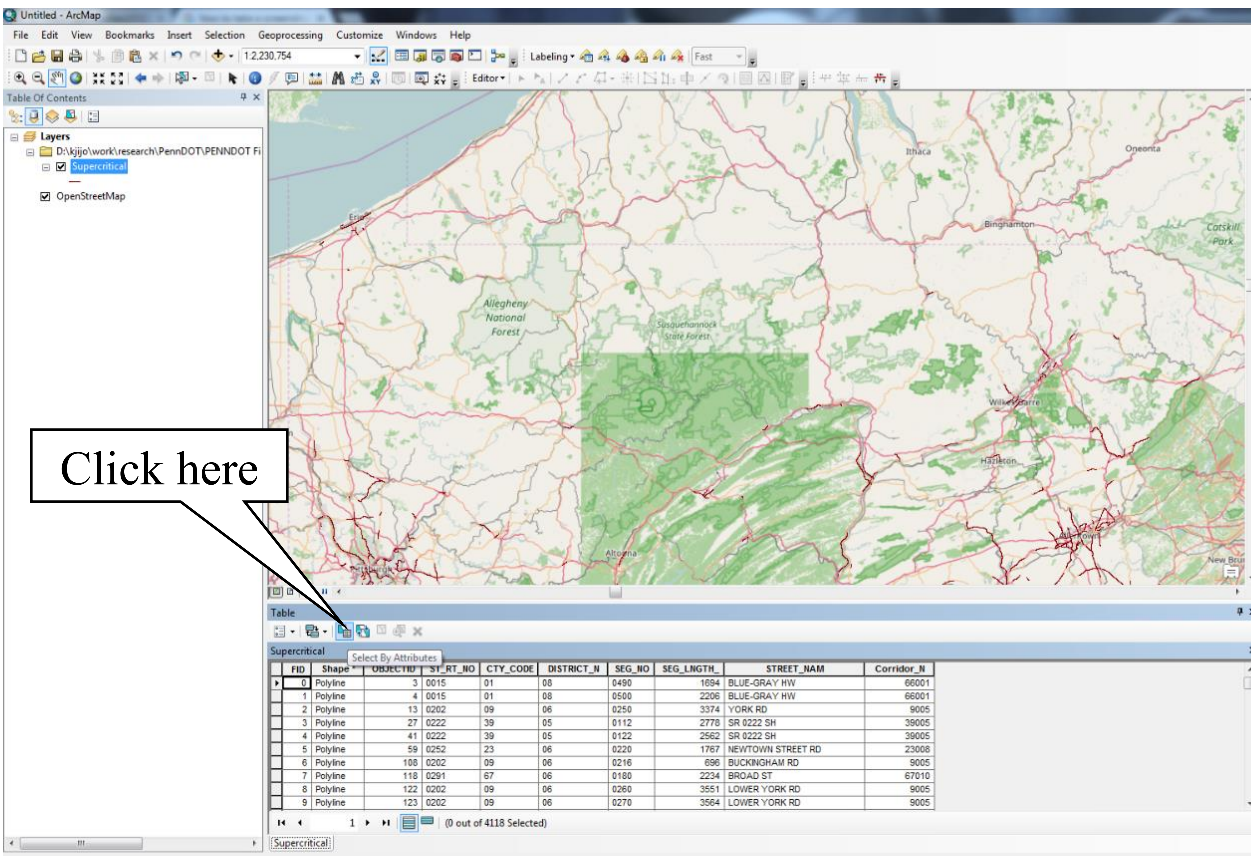
To add a corridor to the database so it can be used in the application, the *Pennsylvania Supercritical Corridors shapefile*, *AADT data file*, the *speed limit shapefile*, and the *INRIX XD Pennsylvania shapefile* are needed. Additionally, the *ArcMap* program from ArcGIS is needed to perform some of the mapping steps. *SQL Management Studio* is required to work with the database, and *Microsoft Excel* is required to format the data.

Import the supercritical corridor shapefile into ArcMap

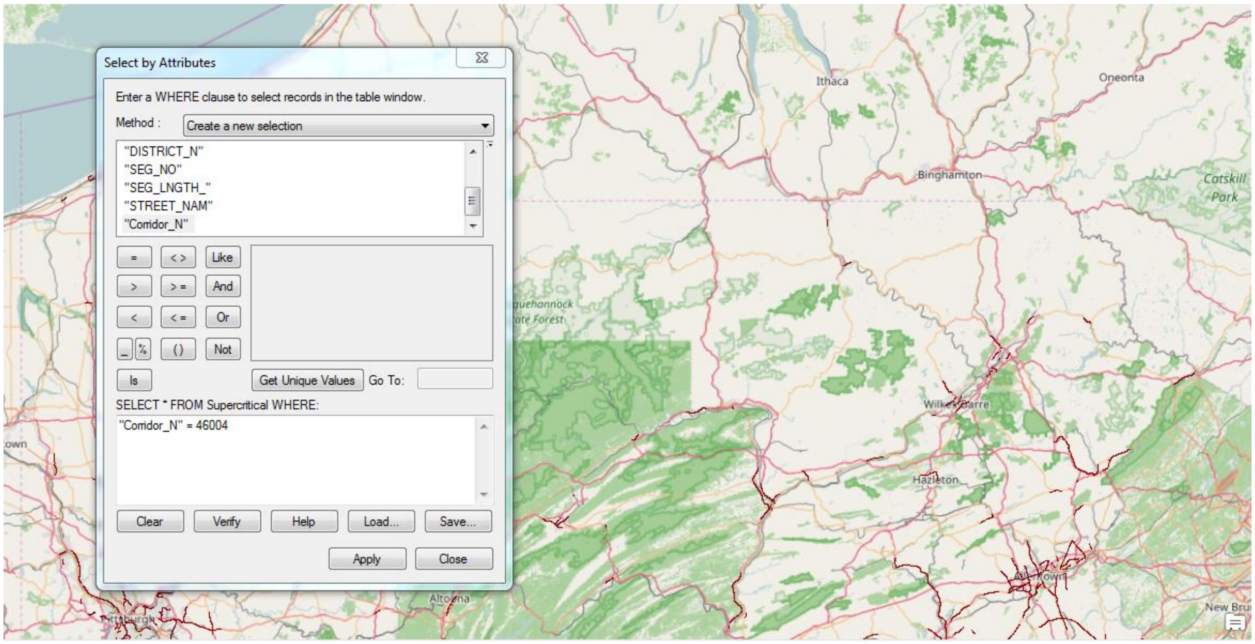


Open the attribute table and Select by Attributes

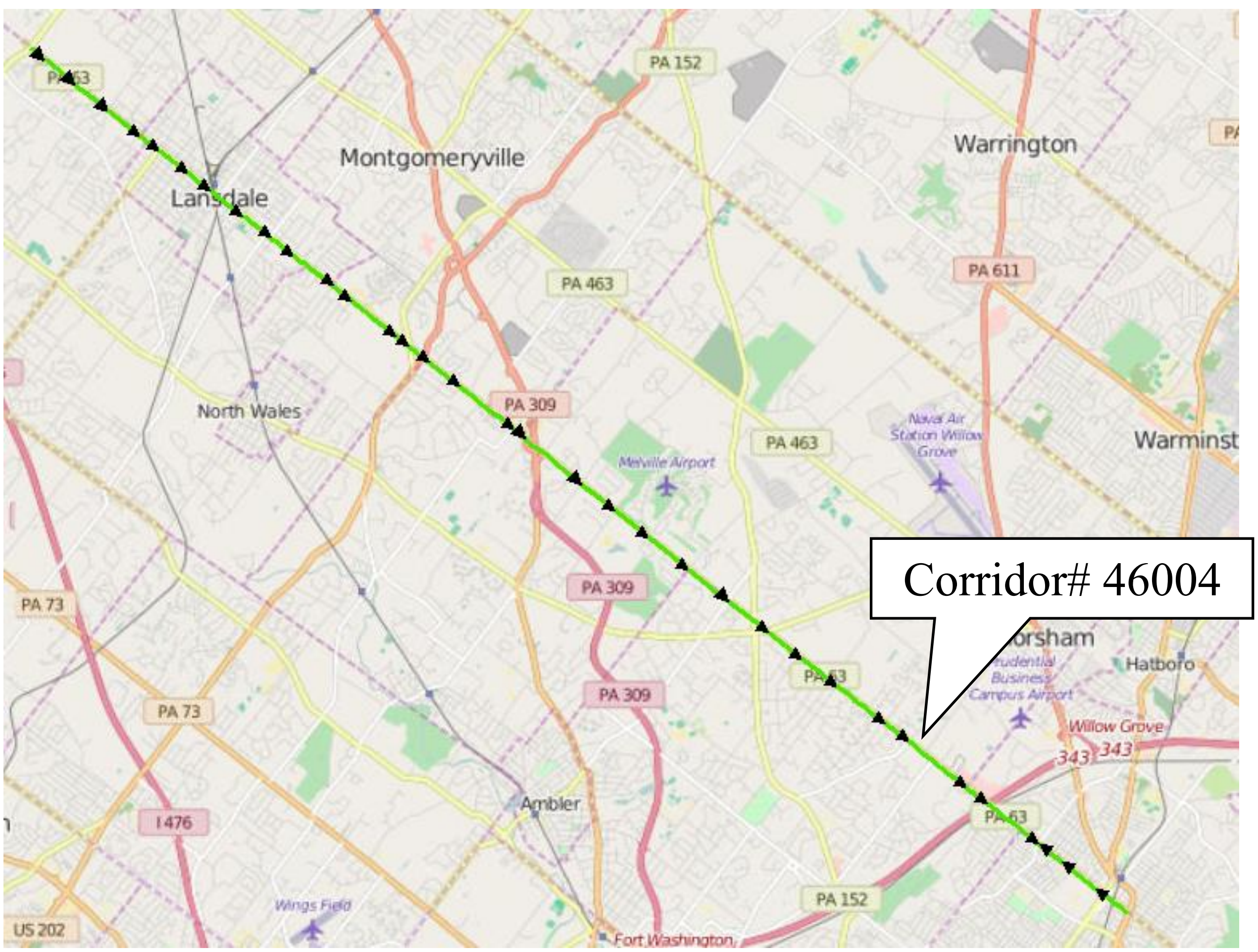




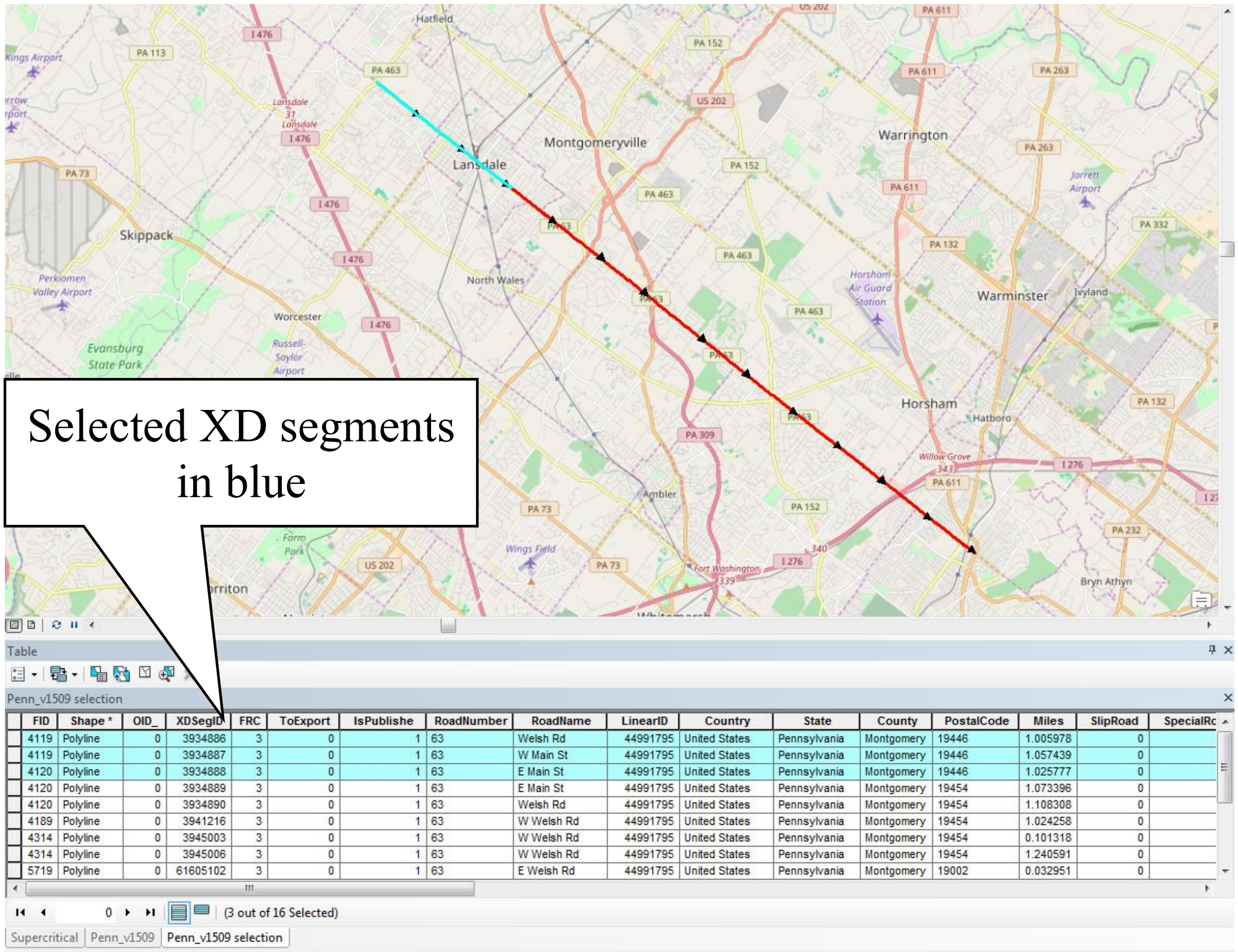
Input the *Corridor Number* to select the required corridor.



Zoom to the selected corridor.



Import the INRIX Shapefile into ArcMap, Map INRIX XD Segments for the Corridor



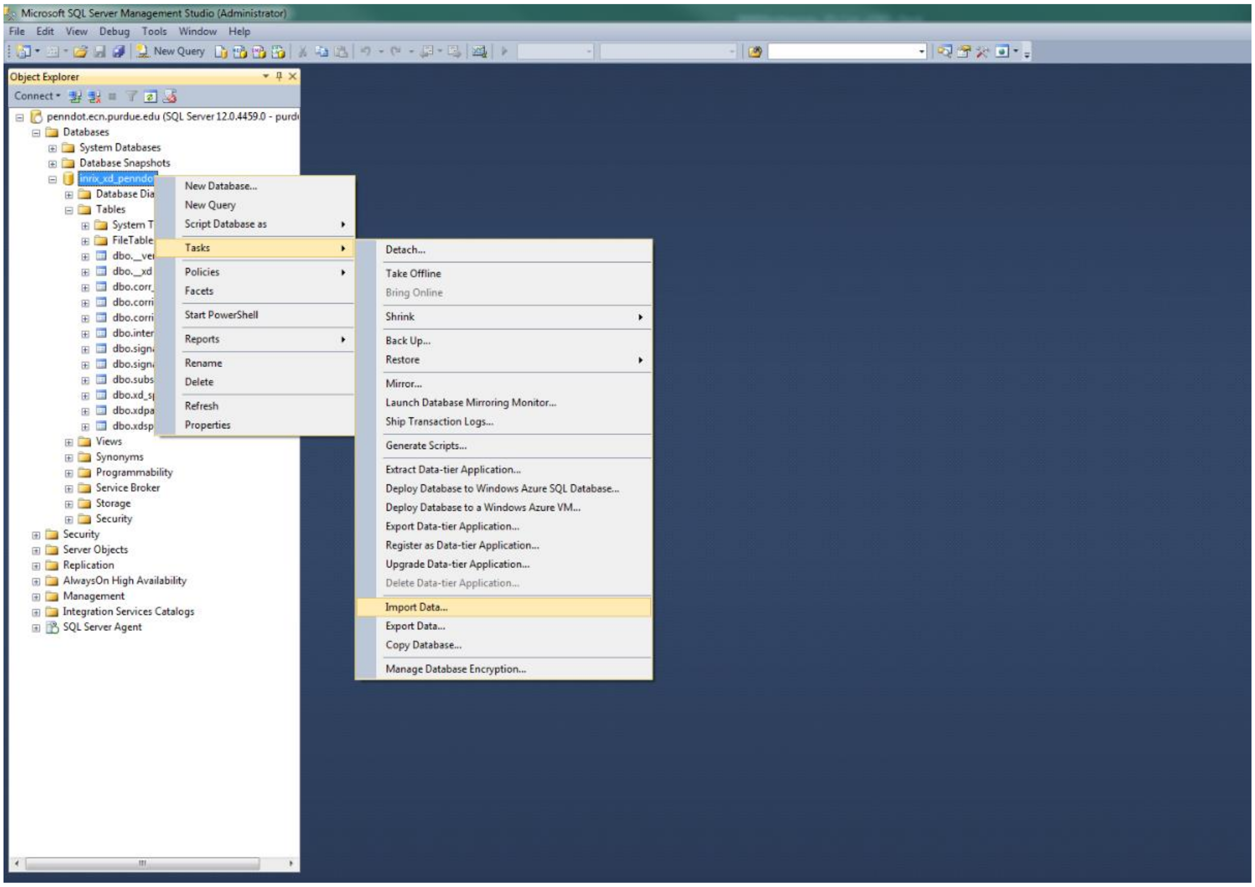
FID	Shape *	OID_	XDSegID	FRC	ToExport	IsPublishe	RoadNumber	RoadName	LinearID	Country	State	County	PostalCode	Miles	SlipRoad	SpecialRc
4119	Polyline	0	3934886	3	0	1	63	Welsh Rd	44991795	United States	Pennsylvania	Montgomery	19446	1.005978	0	
4119	Polyline	0	3934887	3	0	1	63	W Main St	44991795	United States	Pennsylvania	Montgomery	19446	1.057439	0	
4120	Polyline	0	3934888	3	0	1	63	E Main St	44991795	United States	Pennsylvania	Montgomery	19446	1.025777	0	
4120	Polyline	0	3934889	3	0	1	63	E Main St	44991795	United States	Pennsylvania	Montgomery	19454	1.073396	0	
4120	Polyline	0	3934890	3	0	1	63	Welsh Rd	44991795	United States	Pennsylvania	Montgomery	19454	1.108308	0	
4189	Polyline	0	3941216	3	0	1	63	W Welsh Rd	44991795	United States	Pennsylvania	Montgomery	19454	1.024258	0	
4314	Polyline	0	3945003	3	0	1	63	W Welsh Rd	44991795	United States	Pennsylvania	Montgomery	19454	0.101318	0	
4314	Polyline	0	3945006	3	0	1	63	W Welsh Rd	44991795	United States	Pennsylvania	Montgomery	19454	1.240591	0	
5719	Polyline	0	61605102	3	0	1	63	E Welsh Rd	44991795	United States	Pennsylvania	Montgomery	19002	0.032951	0	

Copy selected XD segments to Excel and provide *County*, *Corridor Number*, *Corridor Name*, and *Bearing* information. For each corridor, order the XD records in the direction of travel in a *position* column (*xd_pos* below). In some cases the XD segments and supercritical corridors may not have the same end points. Add number of feet to *trim* the XD segments to match the corridor definition. Complete the Excel sheet for all corridors desired.

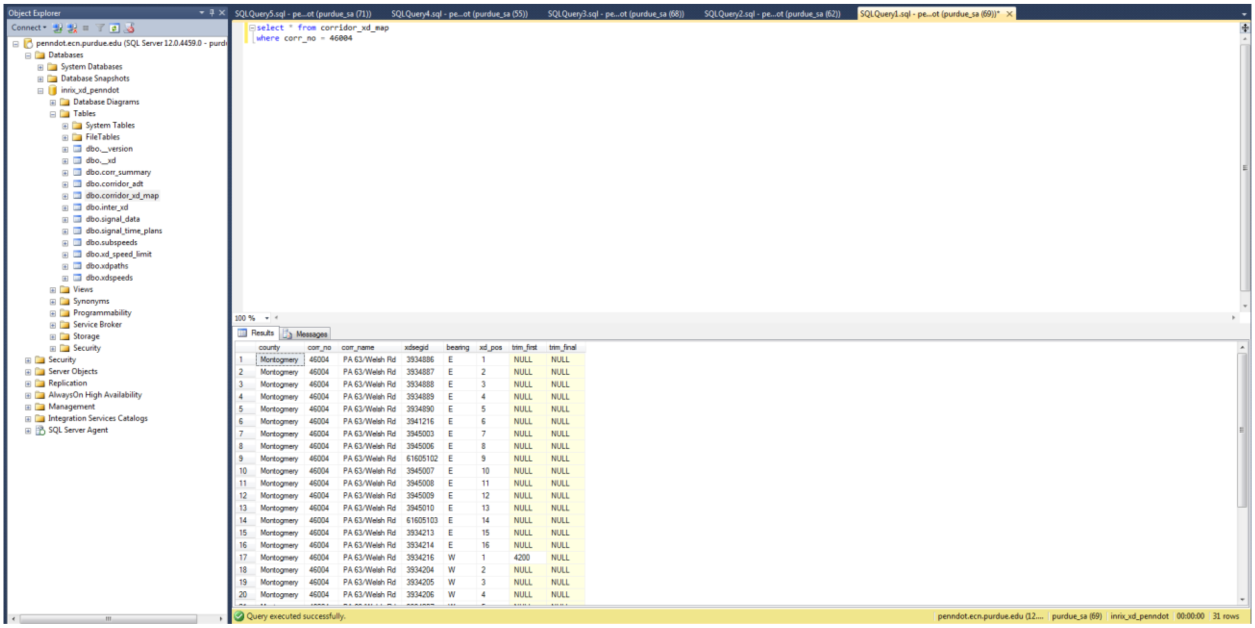
1	County	Corr #	Corr Name	XDSegID	Bearing	xd_pos	Trim first	Trim Final
230	Montogmery	46019	Matsonford Rd	3936211	N/E	4		
231	Montogmery	46019	Matsonford Rd	46420652	N/E	5		
232	Montogmery	46019	Matsonford Rd	3934571	N/E	6	4790	
233	Montogmery	46004	PA 63/Welsh Rd	3934216	W	1	4200	
234	Montogmery	46004	PA 63/Welsh Rd	3934204	W	2		
235	Montogmery	46004	PA 63/Welsh Rd	3934205	W	3		
236	Montogmery	46004	PA 63/Welsh Rd	3934206	W	4		
237	Montogmery	46004	PA 63/Welsh Rd	3934207	W	5		
238	Montogmery	46004	PA 63/Welsh Rd	3934208	W	6		
239	Montogmery	46004	PA 63/Welsh Rd	3934209	W	7		
240	Montogmery	46004	PA 63/Welsh Rd	3934210	W	8		
241	Montogmery	46004	PA 63/Welsh Rd	3934211	W	9		
242	Montogmery	46004	PA 63/Welsh Rd	3934212	W	10		
243	Montogmery	46004	PA 63/Welsh Rd	3934882	W	11		
244	Montogmery	46004	PA 63/Welsh Rd	3934883	W	12		
245	Montogmery	46004	PA 63/Welsh Rd	3934884	W	13		
246	Montogmery	46004	PA 63/Welsh Rd	3934885	W	14		
247	Montogmery	46004	PA 63/Welsh Rd	28301857	W	15		1900
248	Montogmery	46004	PA 63/Welsh Rd	3934886	E	1		
249	Montogmery	46004	PA 63/Welsh Rd	3934887	E	2		
250	Montogmery	46004	PA 63/Welsh Rd	3934888	E	3		
251	Montogmery	46004	PA 63/Welsh Rd	3934889	E	4		
252	Montogmery	46004	PA 63/Welsh Rd	3934890	E	5		
253	Montogmery	46004	PA 63/Welsh Rd	3941216	E	6		
254	Montogmery	46004	PA 63/Welsh Rd	3945003	E	7		
255	Montogmery	46004	PA 63/Welsh Rd	3945006	E	8		
256	Montogmery	46004	PA 63/Welsh Rd	61605102	E	9		
257	Montogmery	46004	PA 63/Welsh Rd	3945007	E	10		
258	Montogmery	46004	PA 63/Welsh Rd	3945008	E	11		
259	Montogmery	46004	PA 63/Welsh Rd	3945009	E	12		
260	Montogmery	46004	PA 63/Welsh Rd	3945010	E	13		
261	Montogmery	46004	PA 63/Welsh Rd	61605103	E	14		
262	Montogmery	46004	PA 63/Welsh Rd	3934213	E	15		
263	Montogmery	46004	PA 63/Welsh Rd	3934214	E	16		
264	Montogmery	46022	Gulph Rd	3927477	E	1	1970	
265	Montogmery	46022	Gulph Rd	3927478	E	2		
266	Montogmery	46022	Gulph Rd	3935990	E	3		

Import Corridor Data into SQL Server

Import the Excel sheet into the *corridor_xd_map* table in the database.



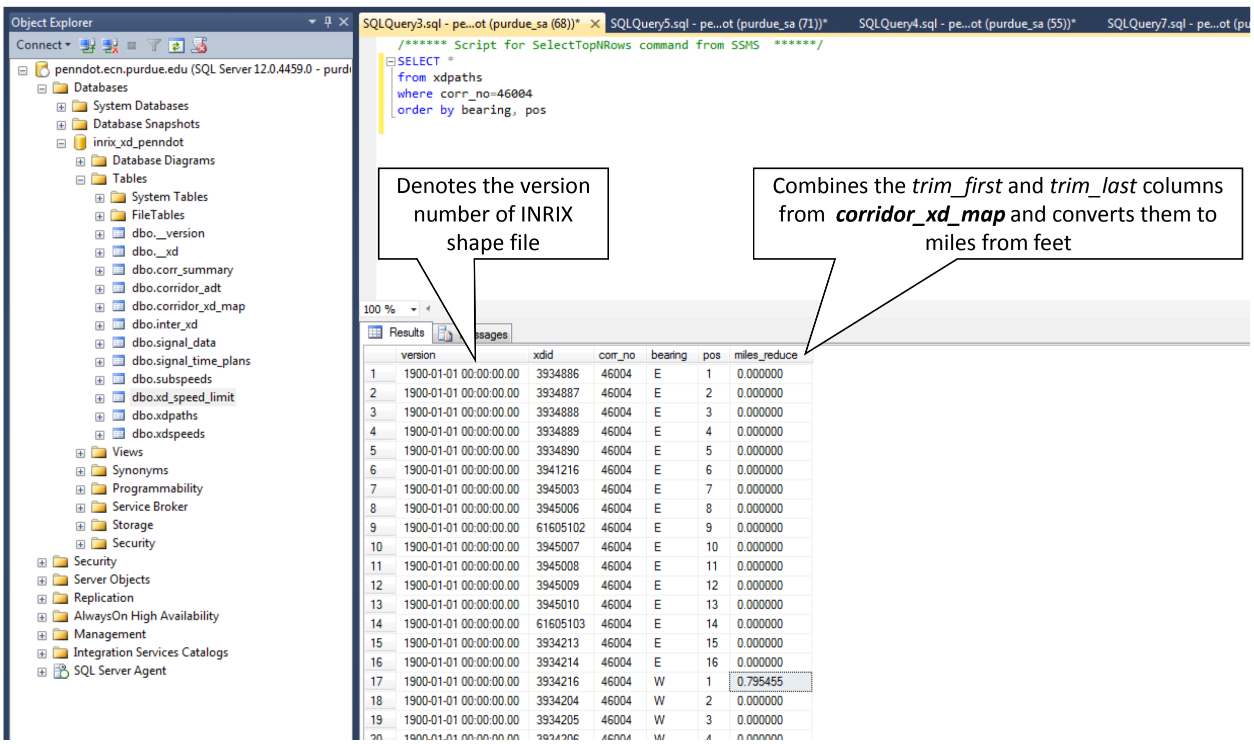
Import result: selected from the *corridor_xd_map* table.



Copy Corridor Data to [xdpaths] Table

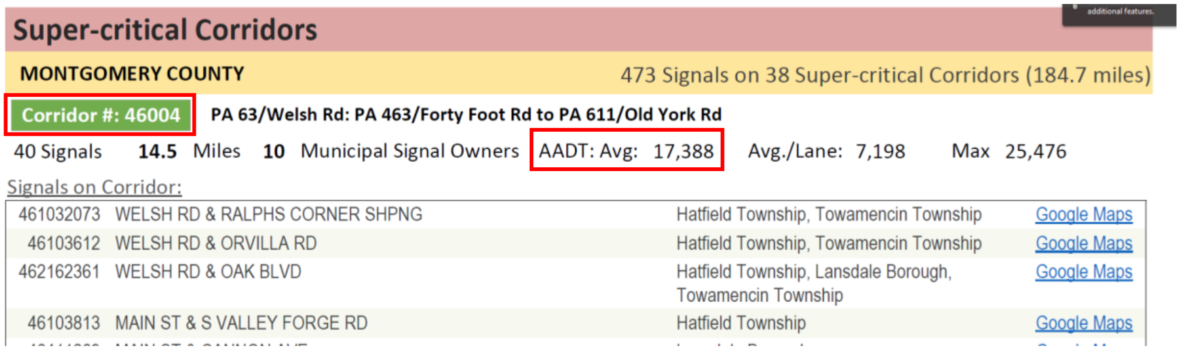
Run the following query from the SQL Management Studio console, replacing <version> with the correct version map (default is *'1900-01-01'*):

```
INSERT INTO xdpaths
SELECT
	<version>,
	xdsegid, corr_no, bearing, xd_pos,
	(CAST(CASE WHEN trim_first IS NULL THEN 0 ELSE trim_first END AS float) +
	CAST(CASE WHEN trim_final IS NULL THEN 0 ELSE trim_final END AS float)) / 5280
FROM
	corridor_xd_map
```



Adding Corridor AADT Data

Generate the *corridor AADT* table (Excel) from the *statewide supercritical corridor report*.



Super-critical Corridors

MONTGOMERY COUNTY — 473 Signals on 38 Super-critical Corridors (184.7 miles)

Corridor #: 46004 — PA 63/Welsh Rd: PA 463/Forty Foot Rd to PA 611/Old York Rd

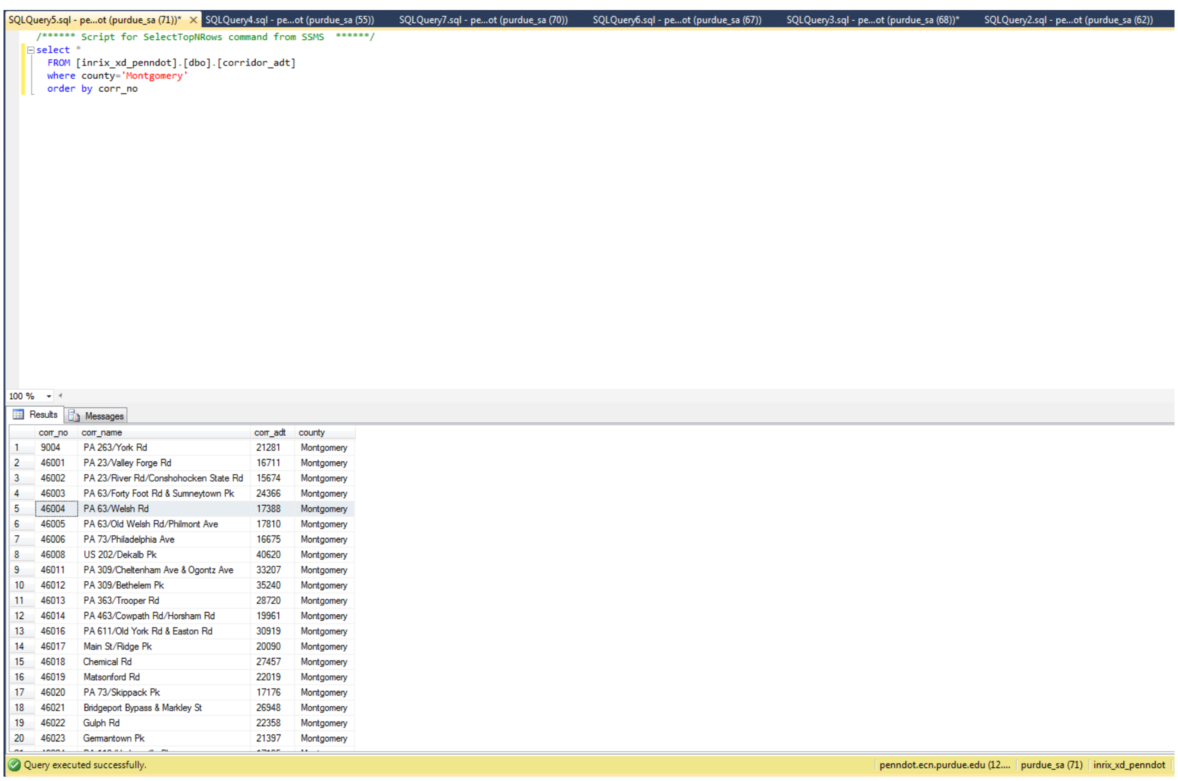
40 Signals 14.5 Miles 10 Municipal Signal Owners AADT: Avg: 17,388 Avg./Lane: 7,198 Max 25,476

Signals on Corridor:

461032073	WELSH RD & RALPHS CORNER SHPNG	Hatfield Township, Towamencin Township	Google Maps
46103612	WELSH RD & ORVILLA RD	Hatfield Township, Towamencin Township	Google Maps
462162361	WELSH RD & OAK BLVD	Hatfield Township, Lansdale Borough, Towamencin Township	Google Maps
46103813	MAIN ST & S VALLEY FORGE RD	Hatfield Township	Google Maps

1	ID #	Corr Name	ADT	County
2	9004	PA 263/York Rd	21281	Montogmery
3	9024	Old US 202/Butler Ave	17552	Montogmery
4	46001	PA 23/Valley Forge Rd	16711	Montogmery
5	46002	PA 23/River Rd/Conshohocken State Rd	15674	Montogmery
6	46003	PA 63/Forty Foot Rd & Sumneytown Pk	24366	Montogmery
7	46004	PA 63/Welsh Rd	17388	Montogmery
8	46005	PA 63/Old Welsh Rd/Philmont Ave	17810	Montogmery
9	46006	PA 73/Philadelphia Ave	16675	Montogmery
10	46008	US 202/Dekalb Pk	40620	Montogmery
11	46011	PA 309/Cheltenham Ave & Ogontz Ave	33207	Montogmery

Import Excel sheet to the *corridor_adt* table in the database (results shown below).



```
/****** Script for SelectTopNRows command from SSMS  ******/
select *
  FROM [inrix_xd_penndot].[dbo].[corridor_adt]
  where county='Montgomery'
  order by corr_no
```

	corr_no	corr_name	corr_adt	county
1	9004	PA 263/York Rd	21281	Montgomery
2	46001	PA 23/Valley Forge Rd	16711	Montgomery
3	46002	PA 23/River Rd/Conshohocken State Rd	15674	Montgomery
4	46003	PA 63/Forty Foot Rd & Sumneytown Pk	24366	Montgomery
5	46004	PA 63/Welsh Rd	17388	Montgomery
6	46005	PA 63/Old Welsh Rd/Philmont Ave	17810	Montgomery
7	46006	PA 73/Philadelphia Ave	16675	Montgomery
8	46008	US 202/Dekalb Pk	40620	Montgomery
9	46011	PA 309/Cheltenham Ave & Ogontz Ave	33207	Montgomery
10	46012	PA 309/Bethelem Pk	35240	Montgomery
11	46013	PA 363/Trooper Rd	28720	Montgomery
12	46014	PA 463/Cowpath Rd/Horsham Rd	19961	Montgomery
13	46016	PA 611/Old York Rd & Easton Rd	30919	Montgomery
14	46017	Main St/Ridge Pk	20090	Montgomery
15	46018	Chemical Rd	27457	Montgomery
16	46019	Matsonford Rd	22019	Montgomery
17	46020	PA 73/Skippack Pk	17176	Montgomery
18	46021	Bridgeport Bypass & Markley St	26948	Montgomery
19	46022	Gulph Rd	22358	Montgomery
20	46023	Germantown Pk	21397	Montgomery

Query executed successfully.

Add Speed Limit data into the [xd_speed_limit] Table

The xd_speed_limit table is used to generate the base/speed limit travel time. Speed limit data for most of the corridors were available from the given data.

- SpatInt – Lines from the shapefile *2015_06_25_PA_GIS_(Arterial_Evaluation).shp* contains the speed limit data;
- Spatial join speed limit data with available XD segments using *STBuffer(), STIntersection()* and *STOverlaps()* functions. Query is listed below:

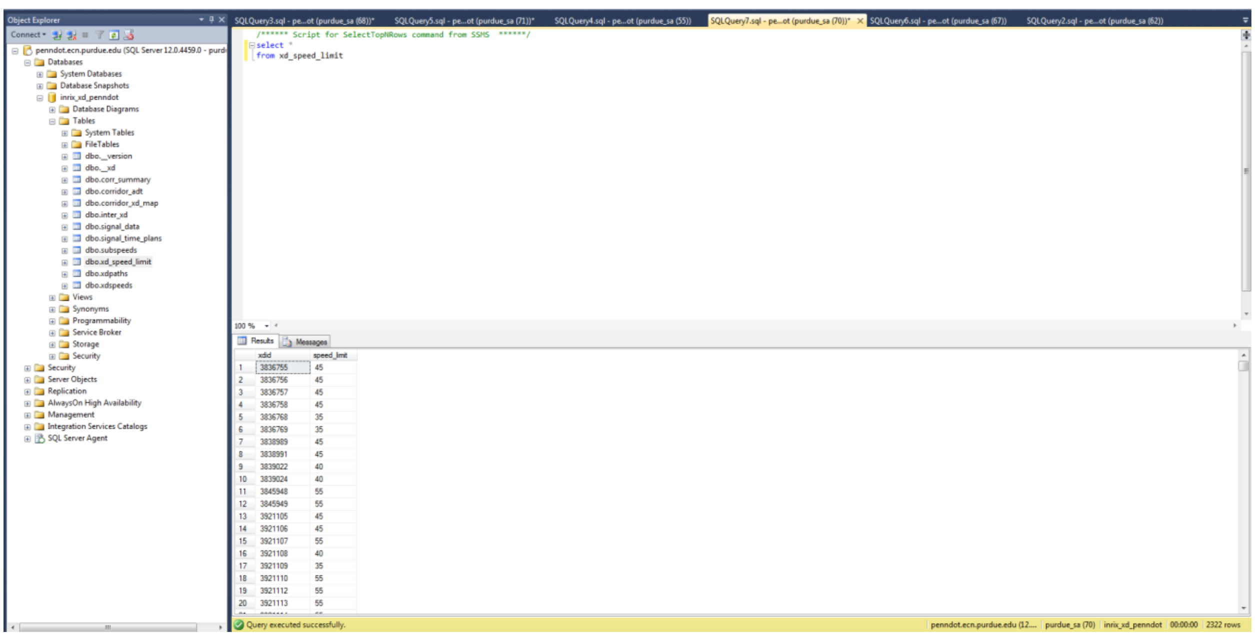
```
SELECT
       p.xdid, OBJECTID, SPEED_LIMI,
       x.geog.STBuffer(100).STIntersection(l.Shapeg).STLength() AS intersecting_length, l.Shapeg.STLength() AS speed_limit_length
FROM
       xdpaths p
INNER JOIN
       __xd x ON x.[version]=p.[version] AND x.XDSegID=p.xdid
LEFT JOIN
(
       SELECT
              OBJECTID, Shapeg, SPEED_LIMI
       FROM
              SPAT_INT2
) AS l ON l.Shapeg.STIntersects(x.geog.STBuffer(100))=1;
```

For XD segments where speed limit data are not available, use *Google Street View*.

For XD segments with multiple speed limit values, a *distance weighted measurement* was used to compute final speed limit value.

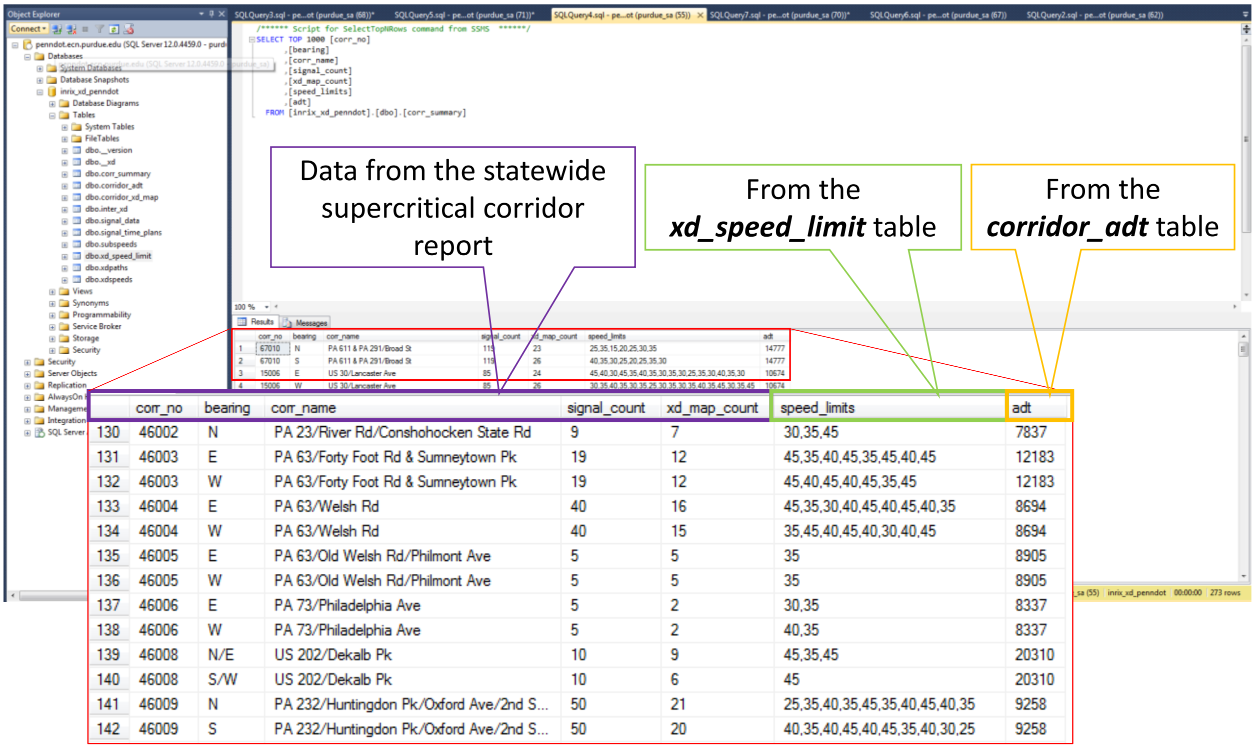
Final speed limit = (45*0.8 + 30*0.5)/(0.8+0.5) = 39.23 ~ 40mph

Then, generate an Excel sheet with the speed limit values for each XD segment obtained from the previous steps and import to the xd_speed_limit table in the SQL Server database.



Adding Corridor Summary Information to corr_summary Table

The **corr_summary** table is used to generate the corridor summary during mouse hover on the dashboard. Data for this table should be inserted with the format as follows:



	corr_no	bearing	corr_name	signal_count	xd_map_count	speed_limits	adt
130	46002	N	PA 23/River Rd/Conshohocken State Rd	9	7	30,35,45	7837
131	46003	E	PA 63/Forty Foot Rd & Sumneytown Pk	19	12	45,35,40,45,35,45,40,45	12183
132	46003	W	PA 63/Forty Foot Rd & Sumneytown Pk	19	12	45,40,45,40,45,35,45	12183
133	46004	E	PA 63/Welsh Rd	40	16	45,35,30,40,45,40,45,40,35	8694
134	46004	W	PA 63/Welsh Rd	40	15	35,45,40,45,40,30,40,45	8694
135	46005	E	PA 63/Old Welsh Rd/Philmont Ave	5	5	35	8905
136	46005	W	PA 63/Old Welsh Rd/Philmont Ave	5	5	35	8905
137	46006	E	PA 73/Philadelphia Ave	5	2	30,35	8337
138	46006	W	PA 73/Philadelphia Ave	5	2	40,35	8337
139	46008	N/E	US 202/Dekalb Pk	10	9	45,35,45	20310
140	46008	S/W	US 202/Dekalb Pk	10	6	45	20310
141	46009	N	PA 232/Huntingdon Pk/Oxford Ave/2nd S...	50	21	25,35,40,35,45,35,40,45,40,35	9258
142	46009	S	PA 232/Huntingdon Pk/Oxford Ave/2nd S...	50	20	40,35,40,45,40,45,35,40,30,25	9258

Adding Signal Timing Plans to the signal_time_plans Table

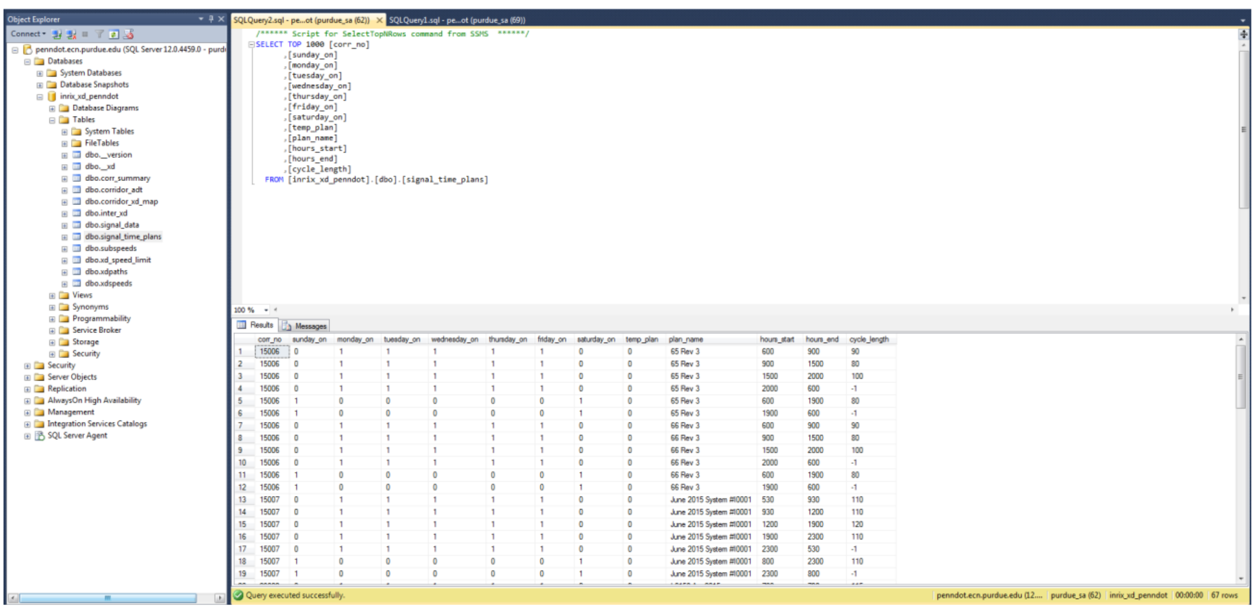
Data from this table is used to generate the signal time plans in the *Timing* menu of the *Travel Time Comparison* dashboard. Generate the below excel sheet with available timing plan information from all corridors:

1 if the timing plan runs on a particular day, else 0

Cycle length in seconds
-1 if it is free

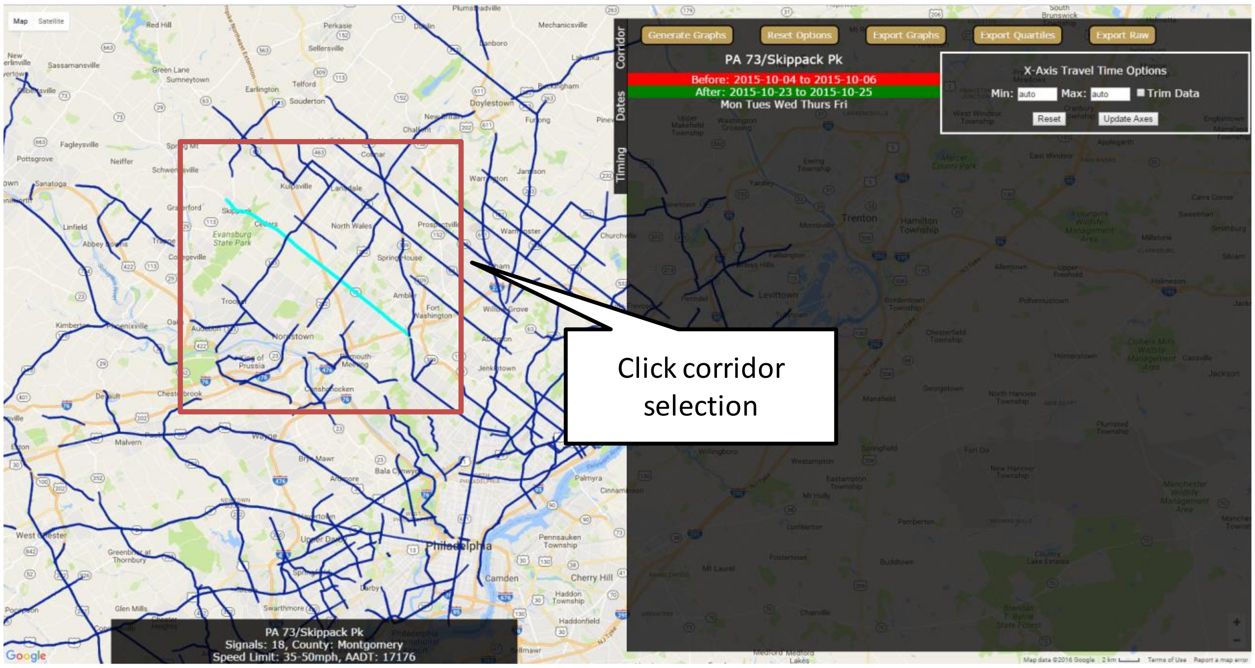
1	corr_no	sunday_on	monday_on	tuesday_on	wednesday_on	thursday_on	friday_on	saturday_on	temp_plan	plan_name	hours_start	hours_end	cycle_length
2	15006	0	1	1	1	1	1	0	0	65 Rev 3	0600	0900	90
3	15006	0	1	1	1	1	1	0	0	65 Rev 3	0900	1500	80
4	15006	0	1	1	1	1	1	0	0	65 Rev 3	1500	2000	100
5	15006	0	1	1	1	1	1	0	0	65 Rev 3	2000	0600	-1
6	15006	1	0	0	0	0	0	1	0	65 Rev 3	0600	1900	80
7	15006	1	0	0	0	0	0	1	0	65 Rev 3	1900	0600	-1
8	15006	0	1	1	1	1	1	0	0	66 Rev 3	0600	0900	90
9	15006	0	1	1	1	1	1	0	0	66 Rev 3	0900	1500	80
10	15006	0	1	1	1	1	1	0	0	66 Rev 3	1500	2000	100
11	15006	0	1	1	1	1	1	0	0	66 Rev 3	2000	0600	-1
12	15006	1	0	0	0	0	0	1	0	66 Rev 3	0600	1900	80
13	15006	1	0	0	0	0	0	1	0	66 Rev 3	1900	0600	-1
14	15007	0	1	1	1	1	1	0	0	June 2015 System #I0001	0530	0930	110
15	15007	0	1	1	1	1	1	0	0	June 2015 System #I0001	0930	1200	110
16	15007	0	1	1	1	1	1	0	0	June 2015 System #I0001	1200	1900	120
17	15007	0	1	1	1	1	1	0	0	June 2015 System #I0001	1900	2300	110
18	15007	0	1	1	1	1	1	0	0	June 2015 System #I0001	2300	0530	-1
19	15007	1	0	0	0	0	0	1	0	June 2015 System #I0001	0800	2300	110
20	15007	1	0	0	0	0	0	1	0	June 2015 System #I0001	2300	0800	-1
21	23002	0	1	1	1	1	1	0	0	I-0158 Apr 2015	0700	0730	115
22	23002	0	1	1	1	1	1	0	0	I-0158 Apr 2015	0730	0815	115
23	23002	0	1	1	1	1	1	0	0	I-0158 Apr 2015	0815	1000	115
24	23002	0	1	1	1	1	1	0	0	I-0158 Apr 2015	1000	1130	110

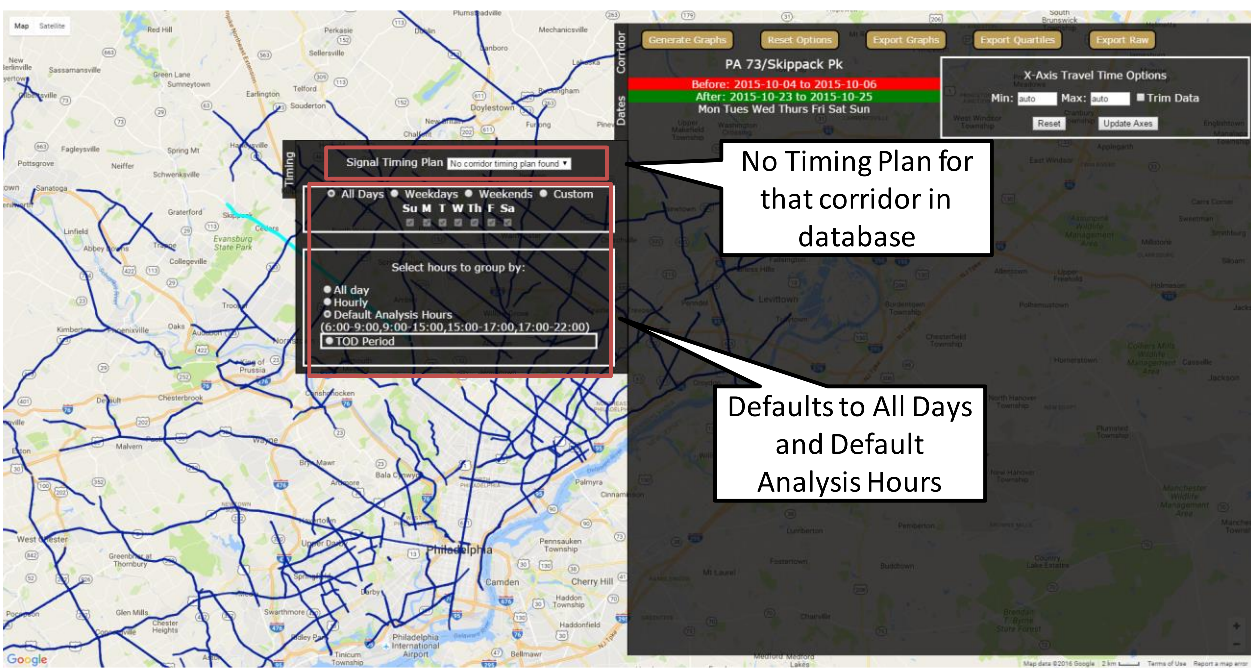
Import the Excel sheet to the *signal_time_plans* table in the SQL Server database.

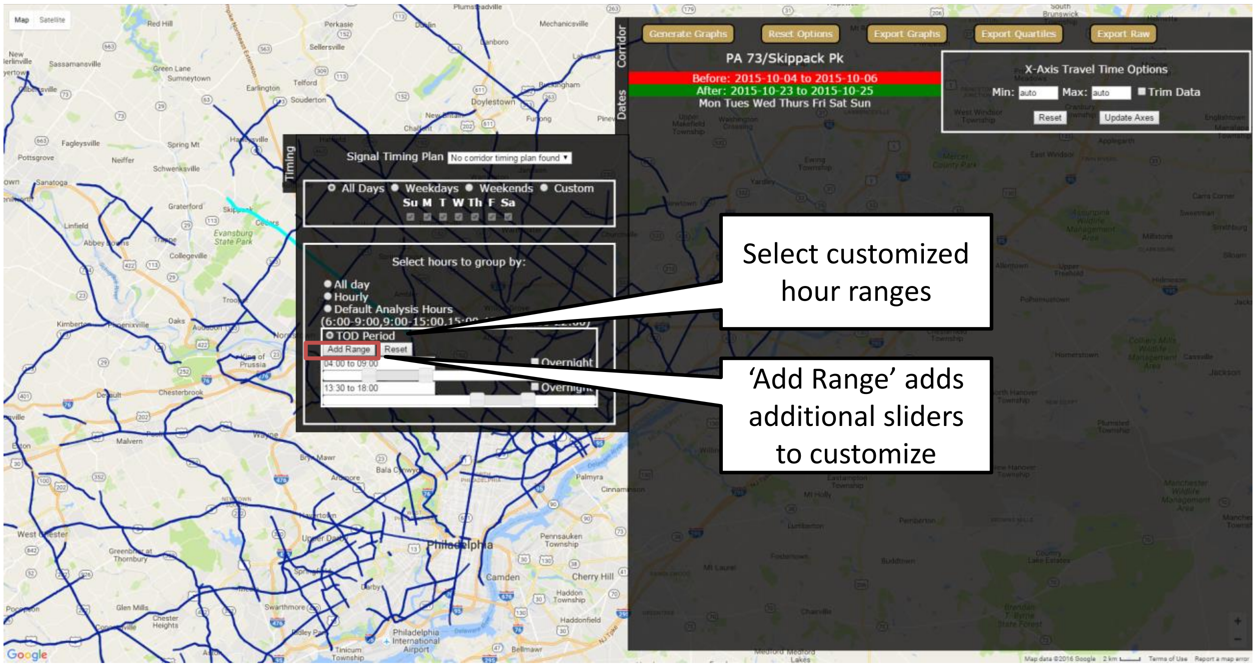


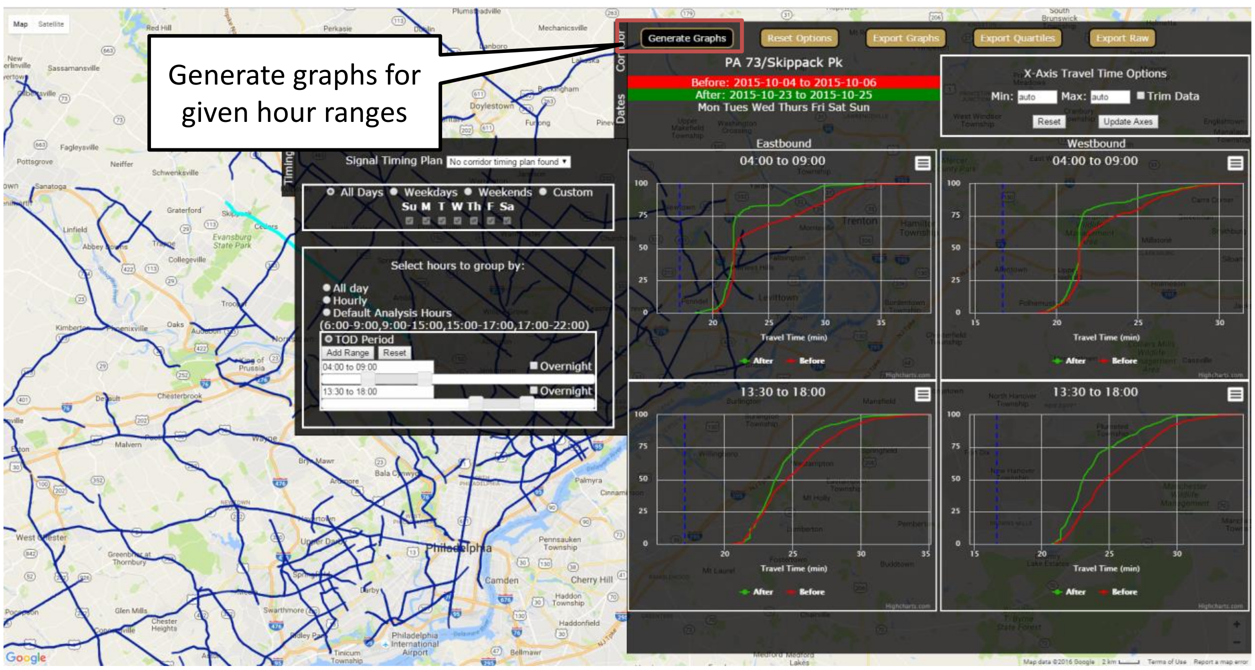
Timing Plan Selection in Travel Time Comparison Tool

For corridors without any timing plan information, **No corridor timing plan found** will be displayed in the *Signal Timing Plan* dropdown under the *Timing* menu. Select a corridor on the map, or from the *Corridor* dropdown menu. All days of the week will be selected by default, and the *Default Analysis Hours* will be selected. Optionally, custom *Time-of-Day (TOD) Periods* can be created using the options.

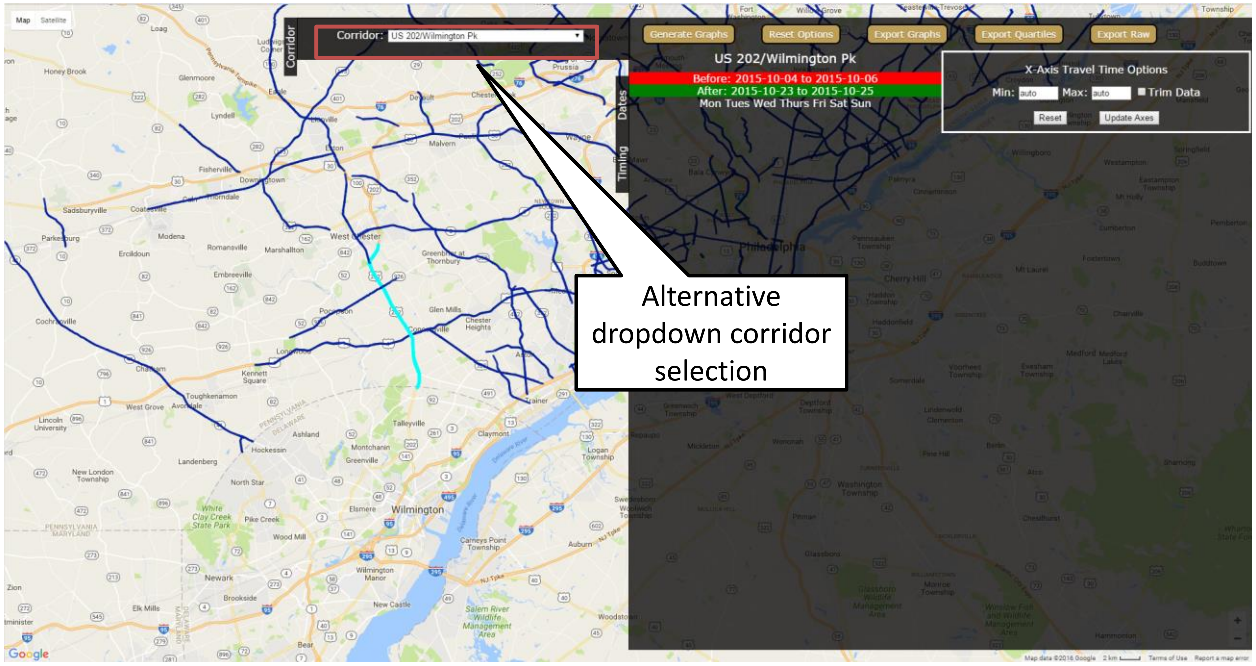


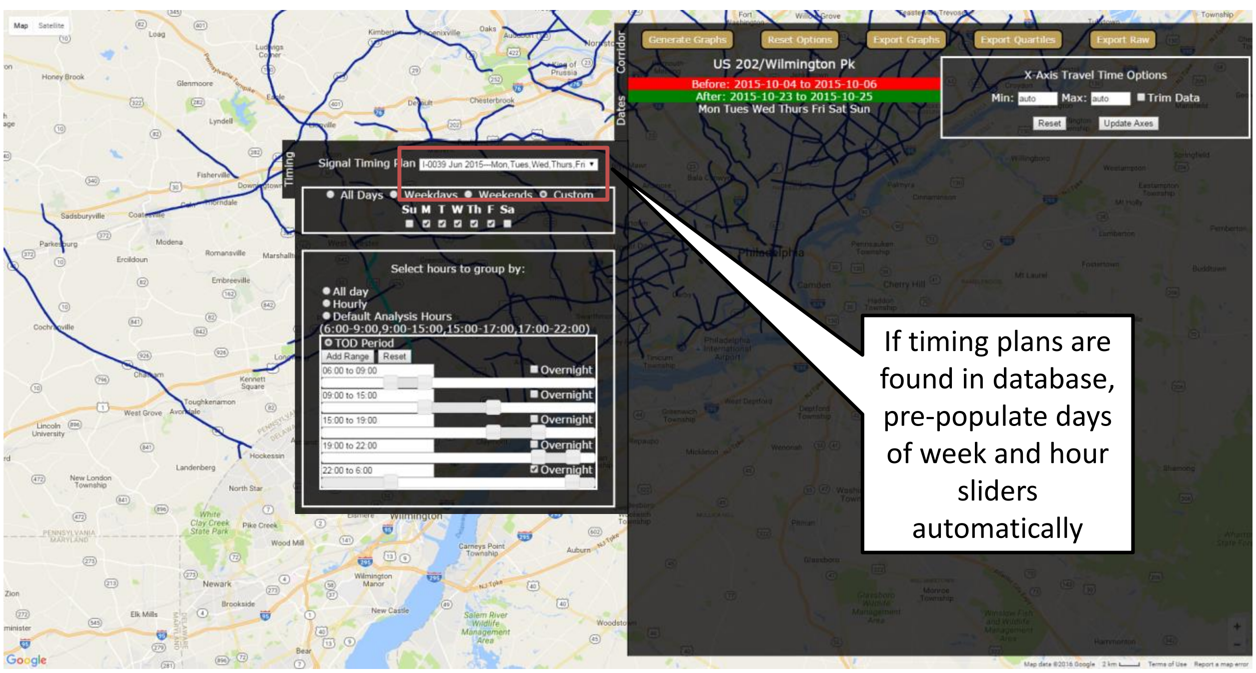



Generate Graphs
Reset Options
Export Graphs
Export Quartiles
Export Raw
PA 73/Skippack Pk
Before: 2015-10-04 to 2015-10-06
After: 2015-10-23 to 2015-10-25
Mon Tues Wed Thurs Fri Sat Sun
X-Axis Travel Time Options
Min: auto Max: auto Trim Data
Reset Update Axes
Signal Timing Plan No corridor timing plan found
All Days Weekdays Weekends Custom
Su M T W Th F Sa
Select hours to group by:
All day
Hourly
Default Analysis Hours
TOD Period
Add Range Reset
04:00 to 09:00 Overnight
13:30 to 18:00 Overnight
Select customized hour ranges
'Add Range' adds additional sliders to customize
Philadelphia

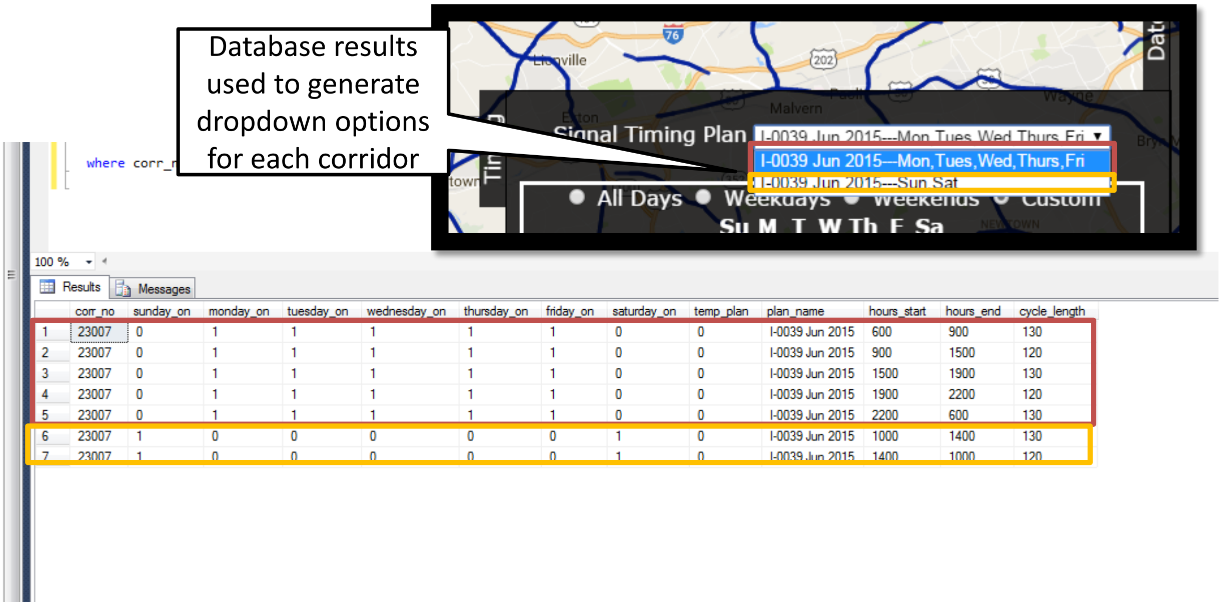

Generate graphs for given hour ranges
Generate Graphs
Reset Options
Export Graphs
Export Quartiles
Export Raw
PA 73/Skippack Pk
Before: 2015-10-04 to 2015-10-06
After: 2015-10-23 to 2015-10-25
Mon Tues Wed Thurs Fri Sat Sun
X-Axis Travel Time Options
Min: auto Max: auto Trim Data
Reset Update Axes
Signal Timing Plan No corridor timing plan found
All Days Weekdays Weekends Custom
Su M T W Th F Sa
Select hours to group by:
All day
Hourly
Default Analysis Hours
(6:00-9:00,9:00-15:00,15:00-17:00,17:00-22:00)
TOD Period
Add Range Reset
04:00 to 09:00 Overnight
13:30 to 18:00 Overnight
Eastbound
Westbound
04:00 to 09:00
13:30 to 18:00
Travel Time (min)
After Before
Philadelphia

For corridors with existing timing plan data loaded into the database, the *Signal Timing Plan* dropdown will be populated. In the below example, **US 202/Wilmington Pike** is selected from the "Corridor" menu dropdown. A preloaded timing plan is then loaded from the *Signal Timing Plan* dropdown, which populates a set of *TOD Period* ranges.



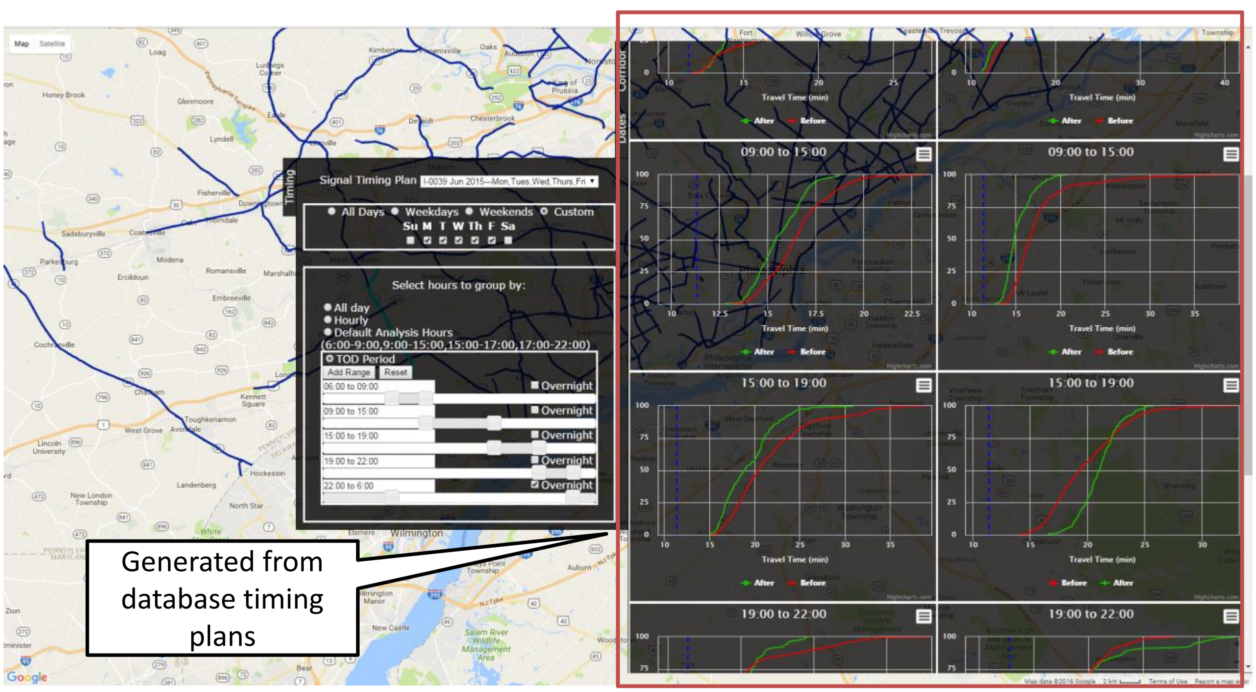


Below shows an example of two timing plans and their respective records in the SQL Server database.



	corr_no	sunday_on	monday_on	tuesday_on	wednesday_on	thursday_on	friday_on	saturday_on	temp_plan	plan_name	hours_start	hours_end	cycle_length
1	23007	0	1	1	1	1	1	0	0	I-0039 Jun 2015	600	900	130
2	23007	0	1	1	1	1	1	0	0	I-0039 Jun 2015	900	1500	120
3	23007	0	1	1	1	1	1	0	0	I-0039 Jun 2015	1500	1900	130
4	23007	0	1	1	1	1	1	0	0	I-0039 Jun 2015	1900	2200	120
5	23007	0	1	1	1	1	1	0	0	I-0039 Jun 2015	2200	600	130
6	23007	1	0	0	0	0	0	1	0	I-0039 Jun 2015	1000	1400	130
7	23007	1	0	0	0	0	0	1	0	I-0039 Jun 2015	1400	1000	120

Finally, select the dates and click the *Generate* button to display the graphs in the before and after period.



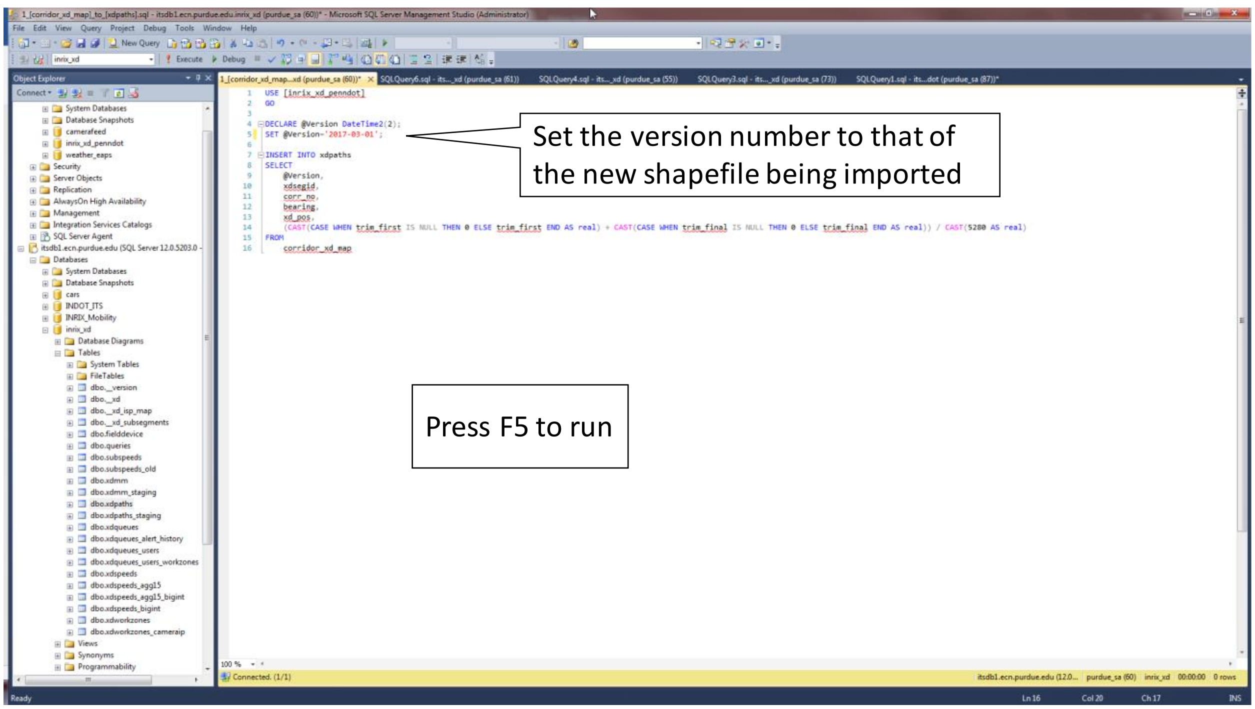
APPENDIX III – UPDATING SHAPEFILE VERSIONS

Remap all the corridors (as shown in Appendix II – Mapping Corridors, Timing Plans and Database Management (Webinar Topic)) for the new shapefile and generate the following csv files:

- corridor_xd_map.csv
- speed_limit.csv

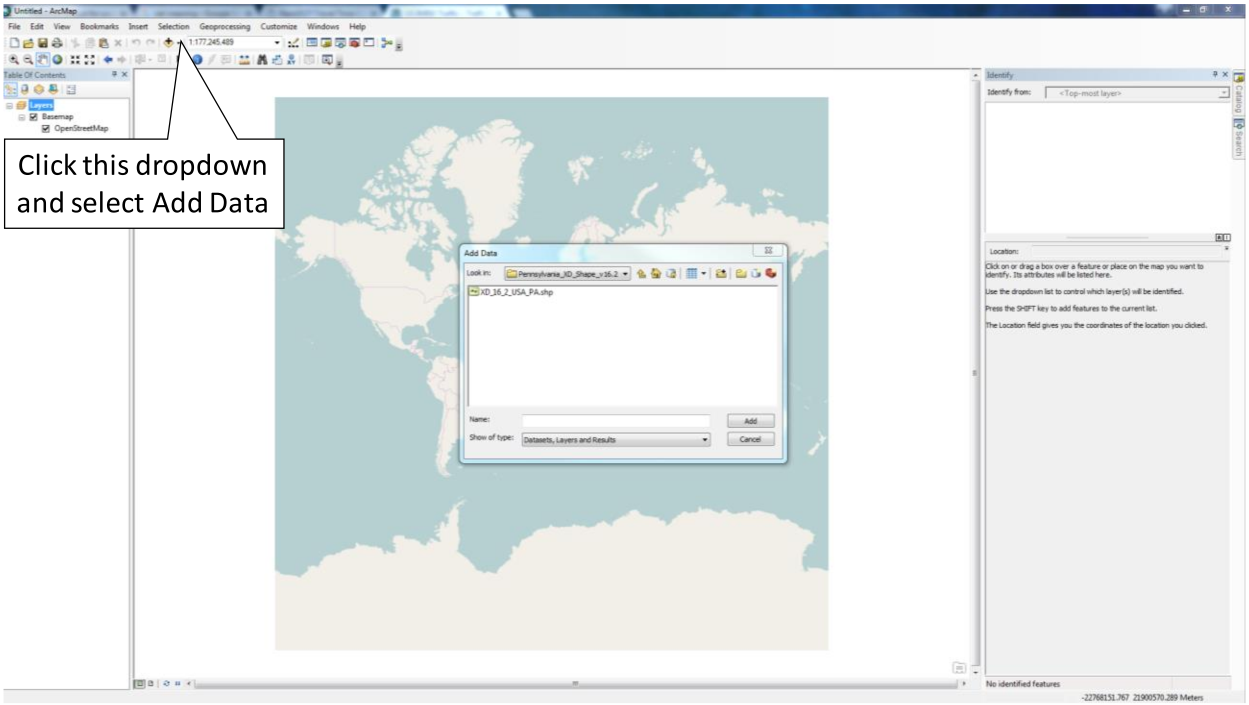
Import the above csv files to the SQL database (as shown in Appendix II) and append them to the corridor_xd_map and speed_limit tables respectively

Update the "xdpaths" table in the database by running the *1_[corridor_xd_map]_to_[xdpaths].sql* script. Please note that the version number on the script should match the version number of the new shapefile. For example, we will use the new shapefile version as "2016-09-20".

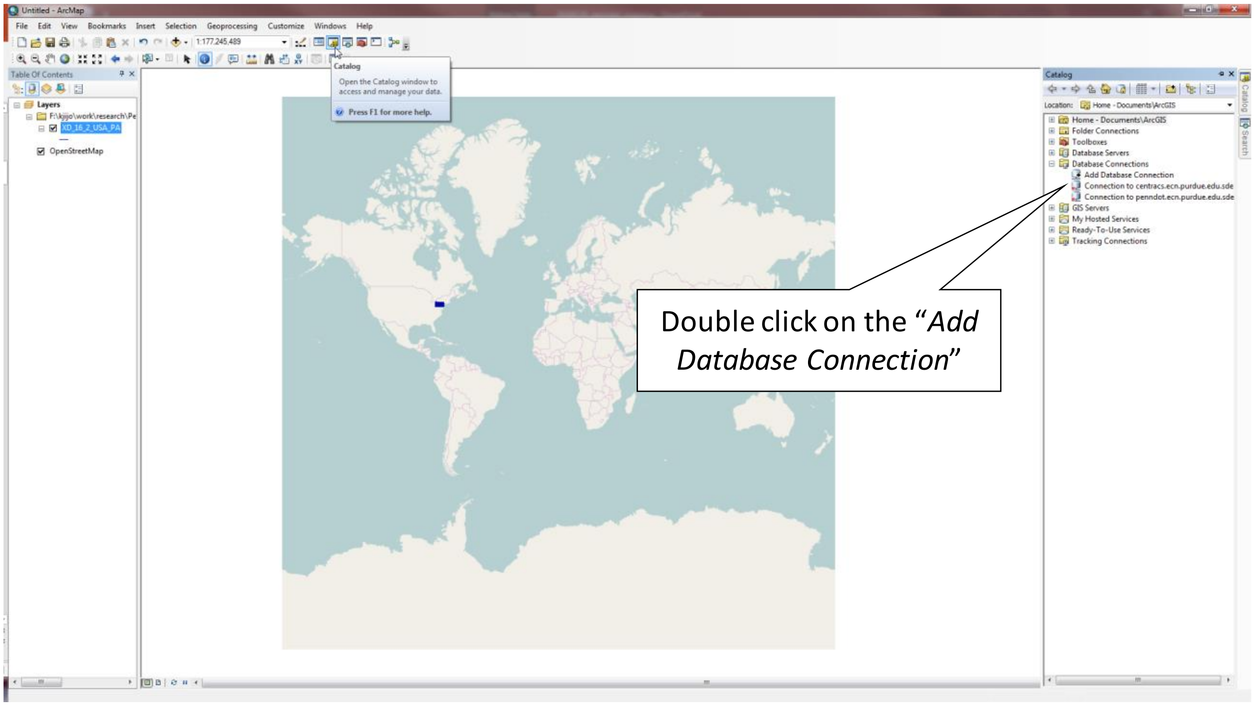


Import the shapefile data from ArcMap to the database by following the below steps:

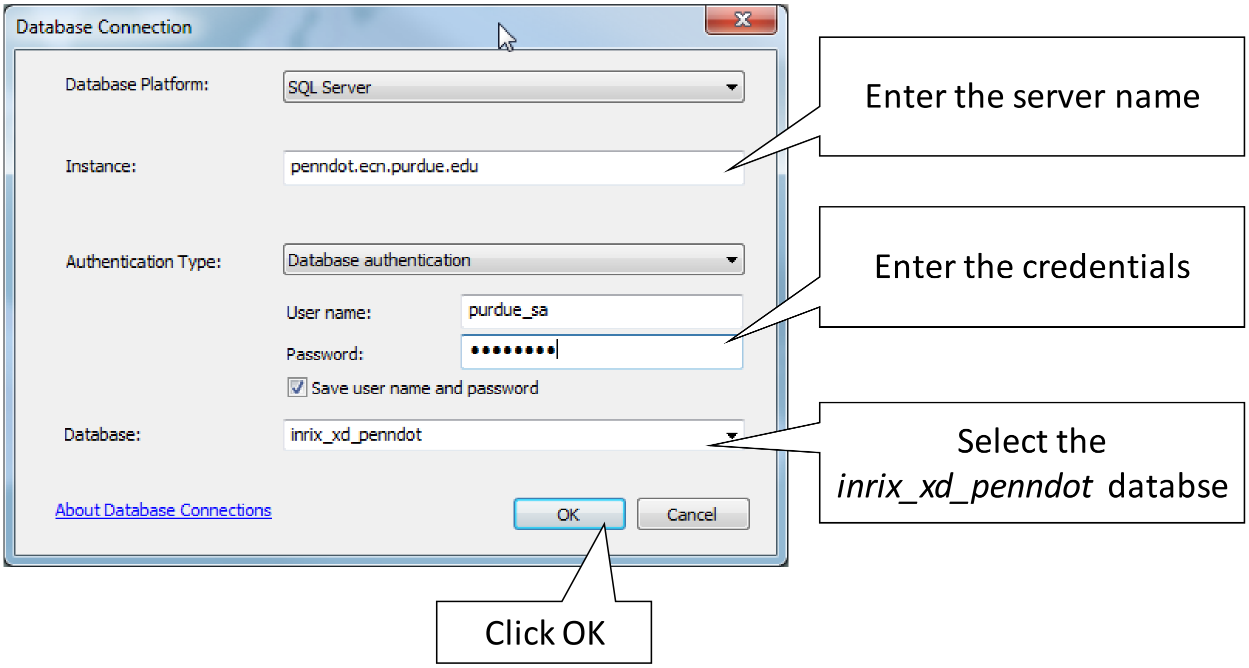
Open the new shapefile in ArcMap.



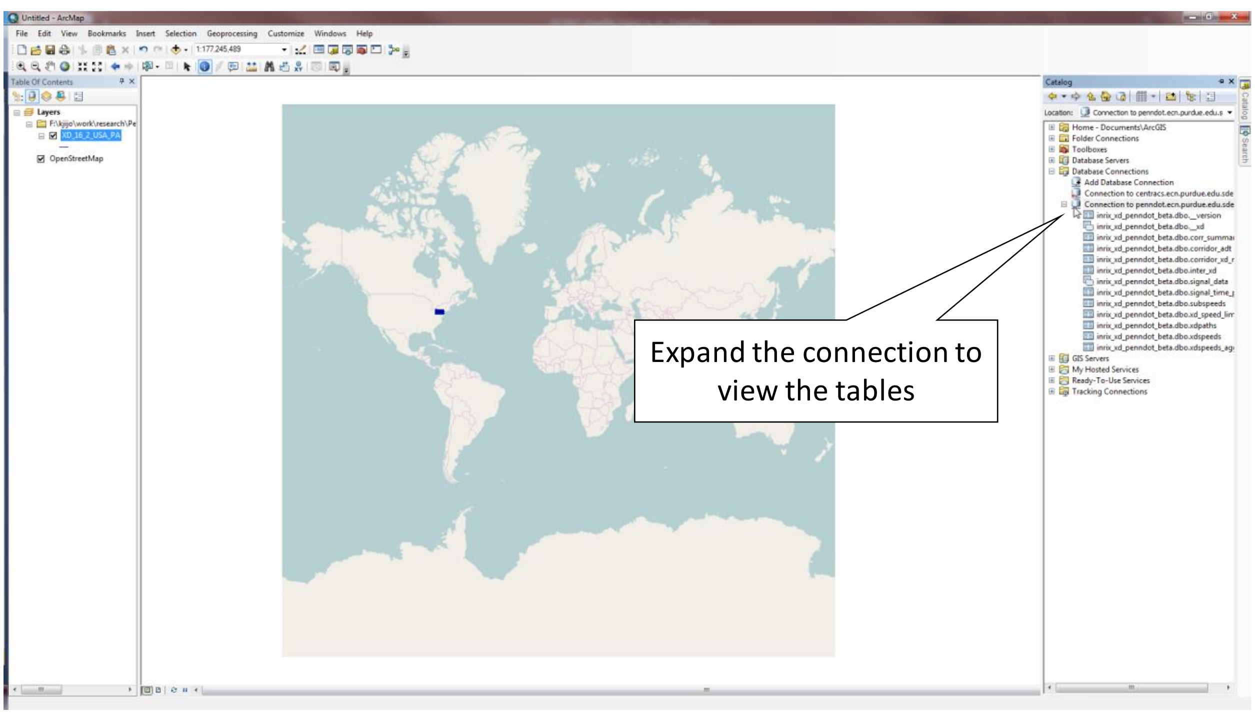
Open the Arc Catalog and establish the connection with the server.



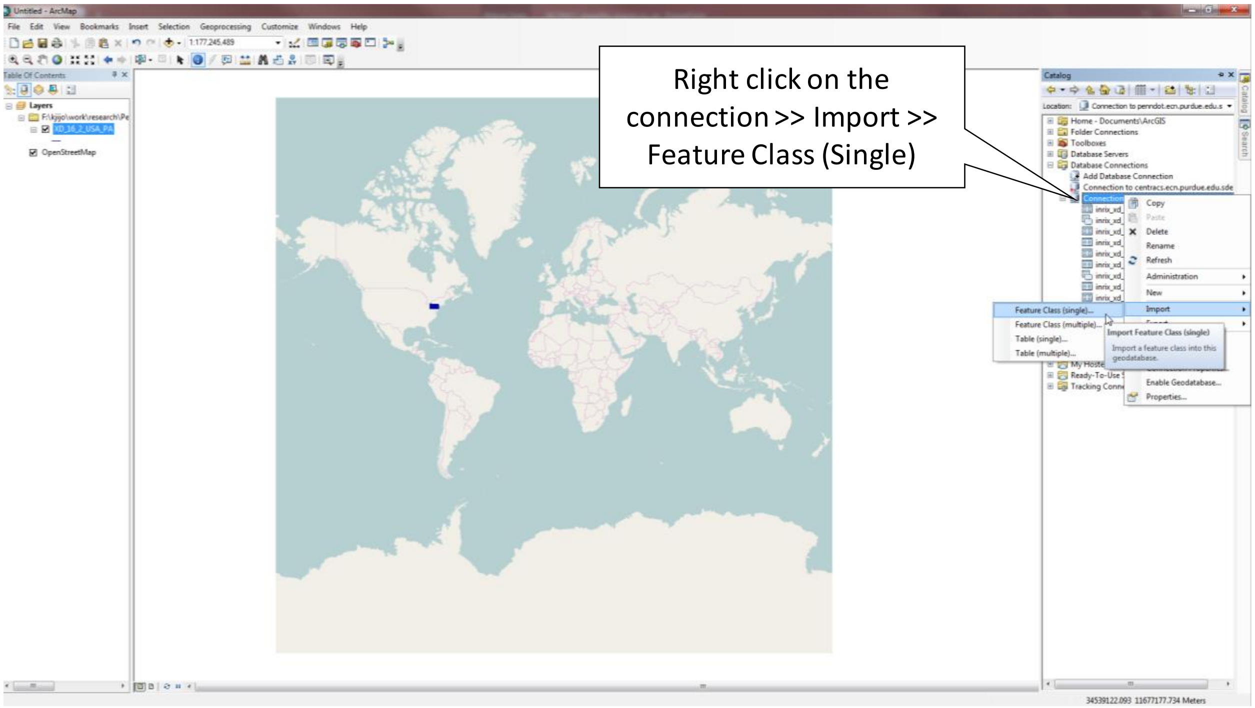
Enter the relevant credentials.



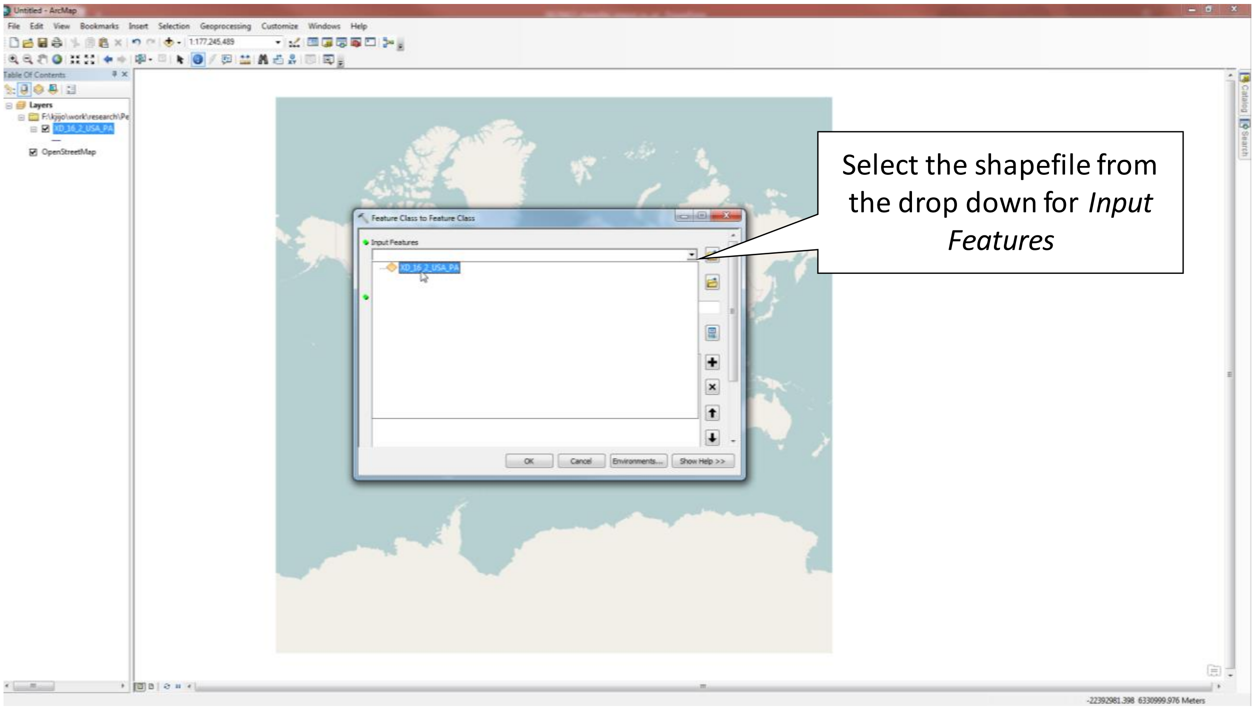
Expand the connection to view the tables in the database.



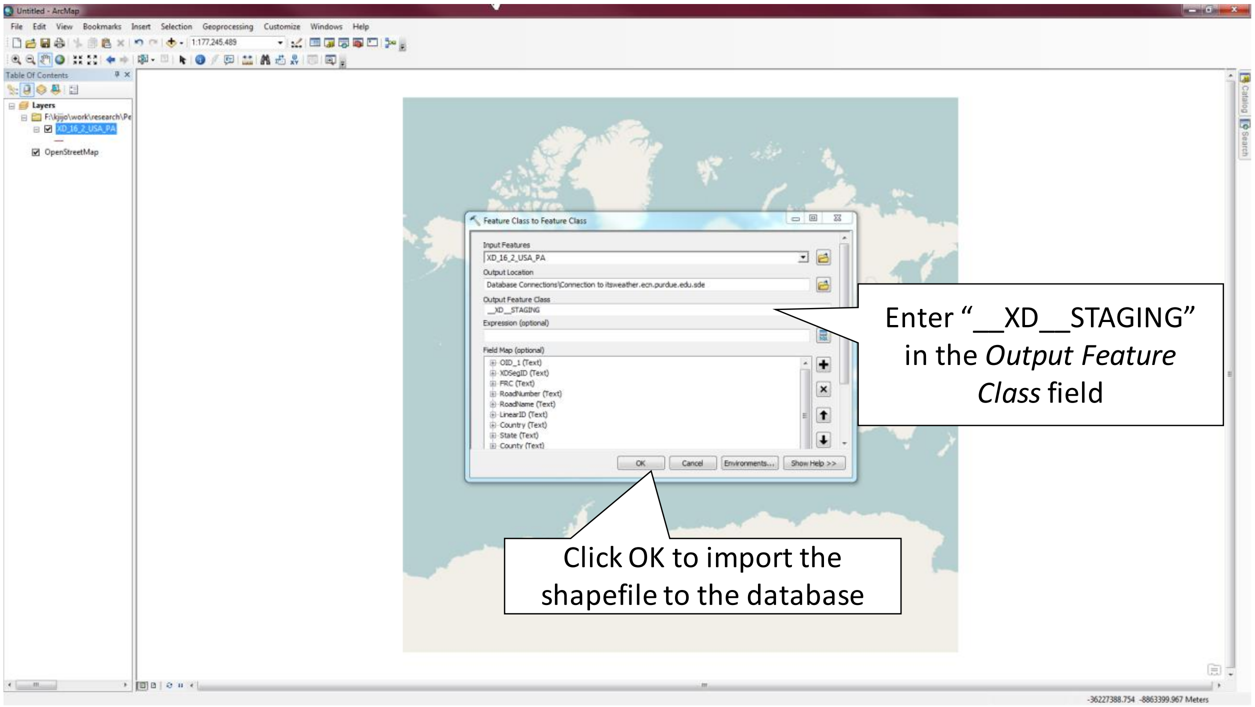
Right click on the connection >> Import >> Feature Class (Single).



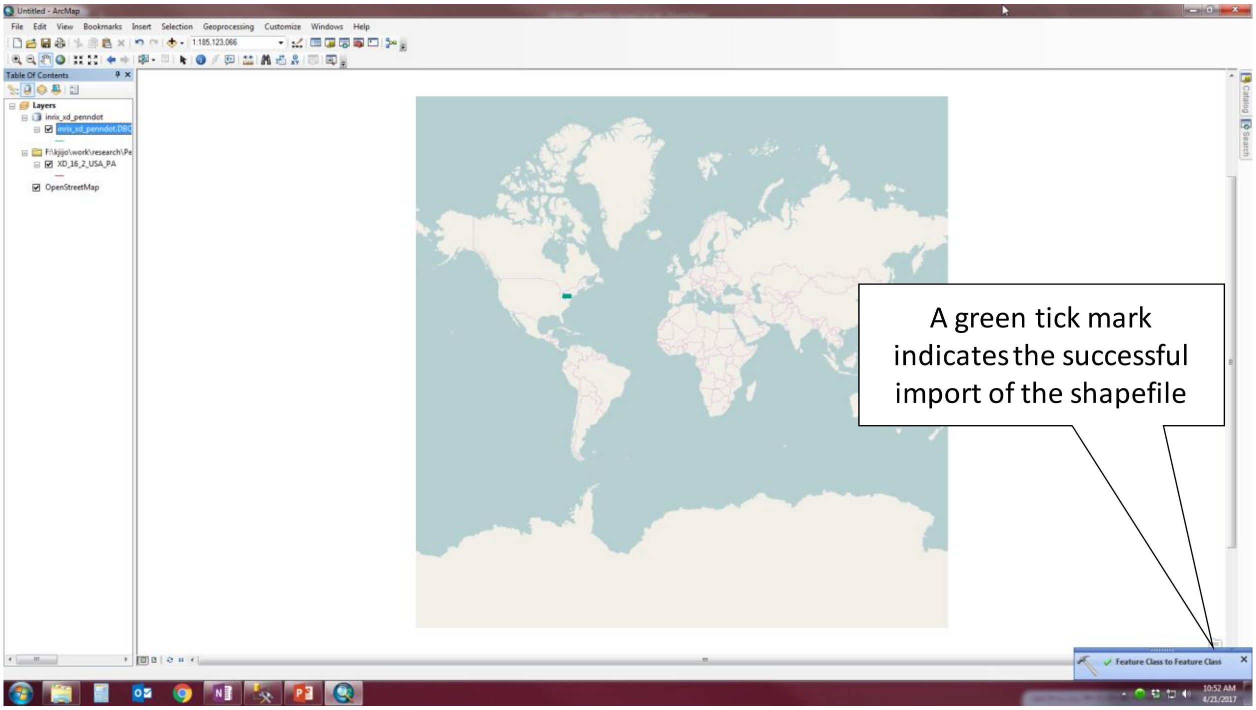
Select the shapefile from the drop down for Input Features.



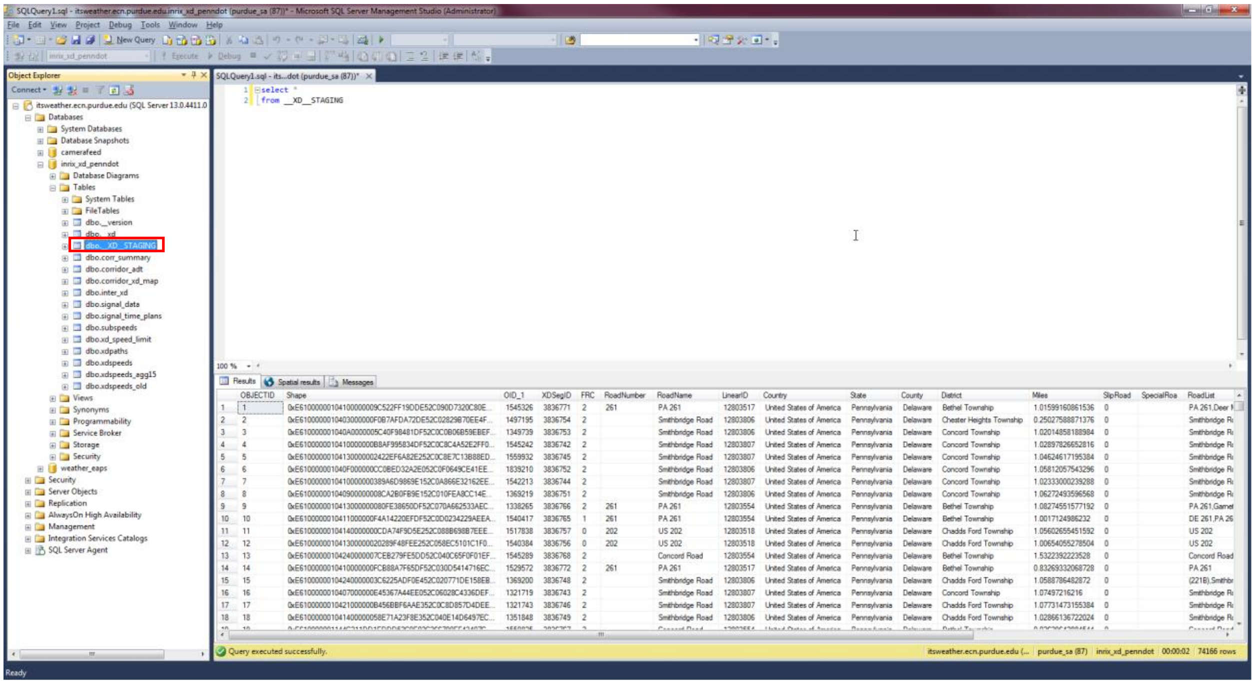
Name the output feature class to *[__xd__staging]*.



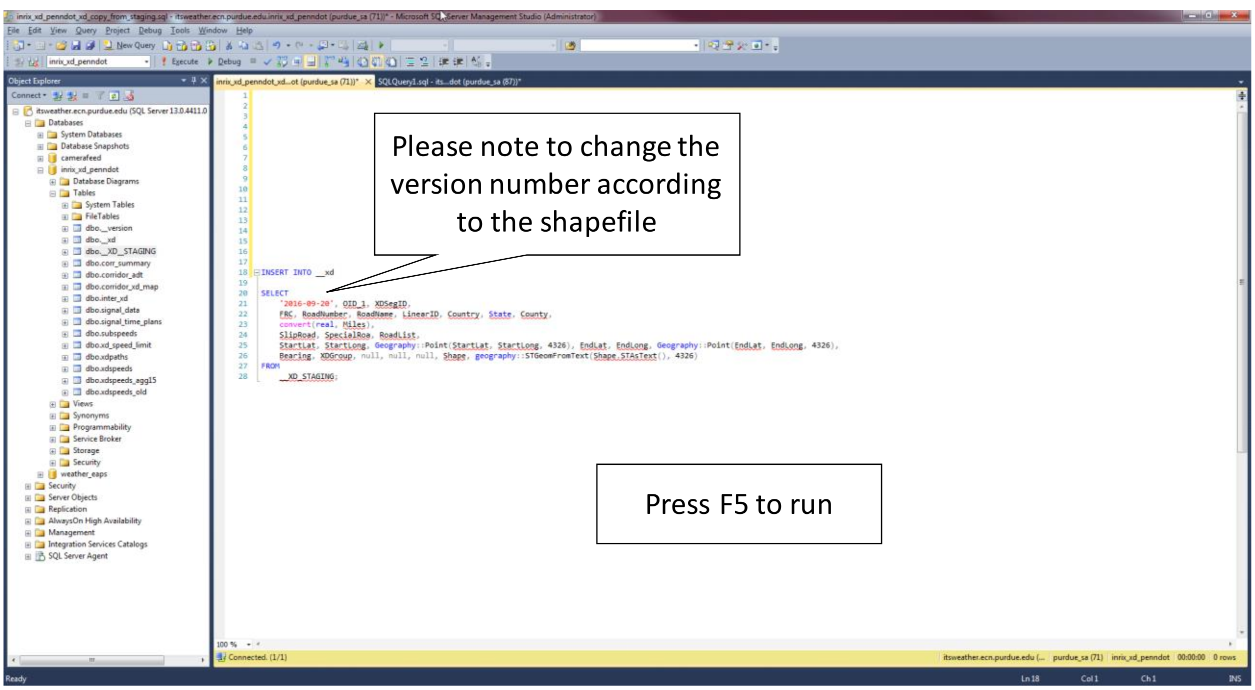
Please wait for a pop-up to indicate the successful import of the shapefile.



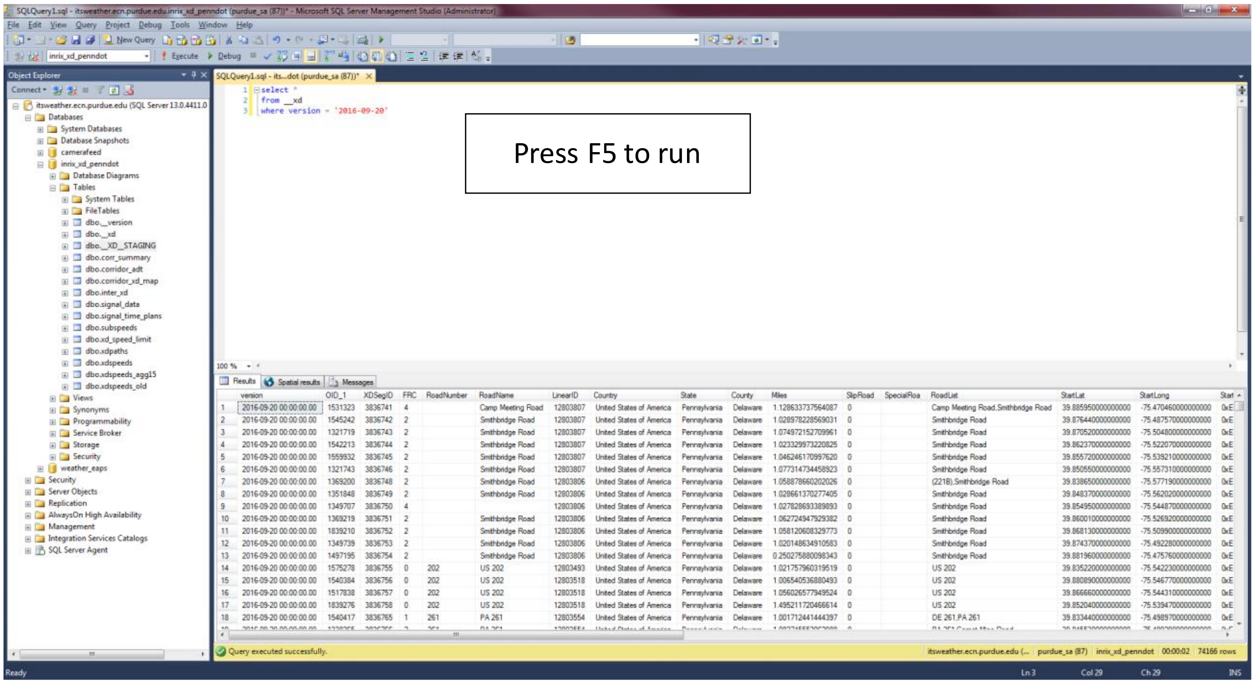
Refresh the tables on the SQL database to view the newly imported [__xd_staging] table.



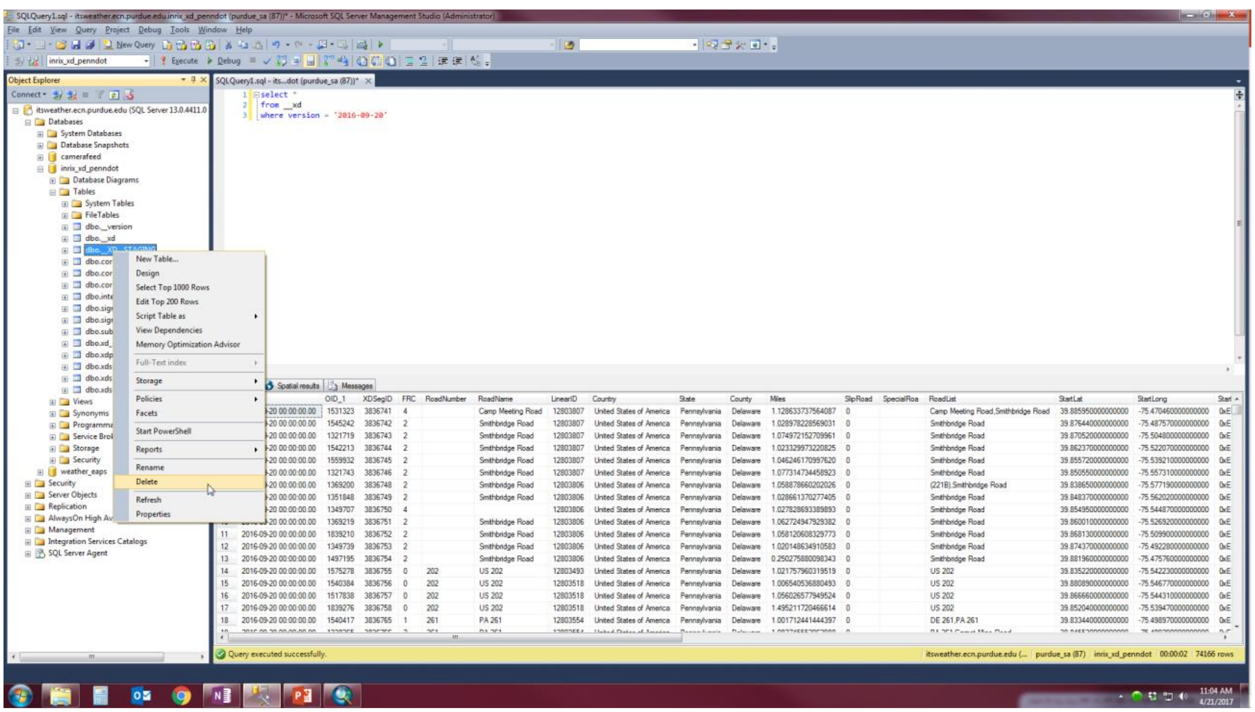
Append the data from [__xd__staging] table to [__xd] table by running the *inrix_xd_penndot_xd_copy_from_staging* script. Please make sure that the version number matches with that of the new shapefile (in this case "2016-09-20"). The version number should also be consistent with the one used earlier to update the [xdpaths] table.



Verify the appended data in the [__xd] table.

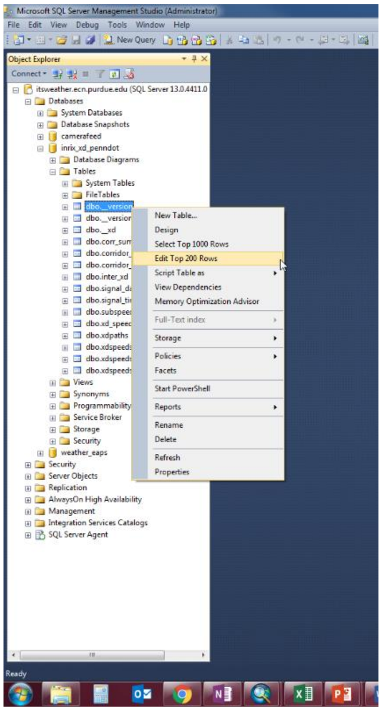


Delete the [__xd__staging] table.



Update the [__version] table

Right click on the [__version] table >> Edit Top 200 Rows



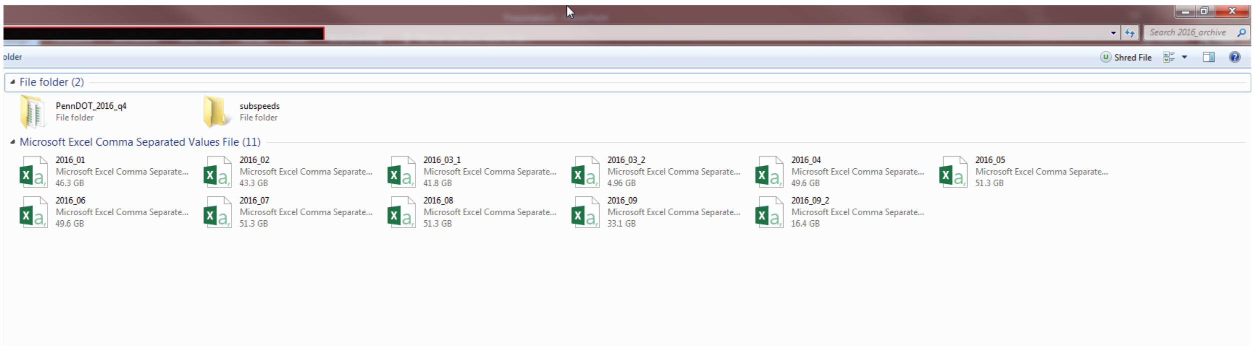
ver_start	ver_end
1900-01-01	2015-03-20
2016-09-20	2017-05-09
2015-09-20	2016-03-20
2015-03-20	2015-09-20
2016-03-20	2016-09-20
2017-05-09	2100-01-01
NULL	NULL

Update the [ver_start] and [ver_end] columns to include the new version

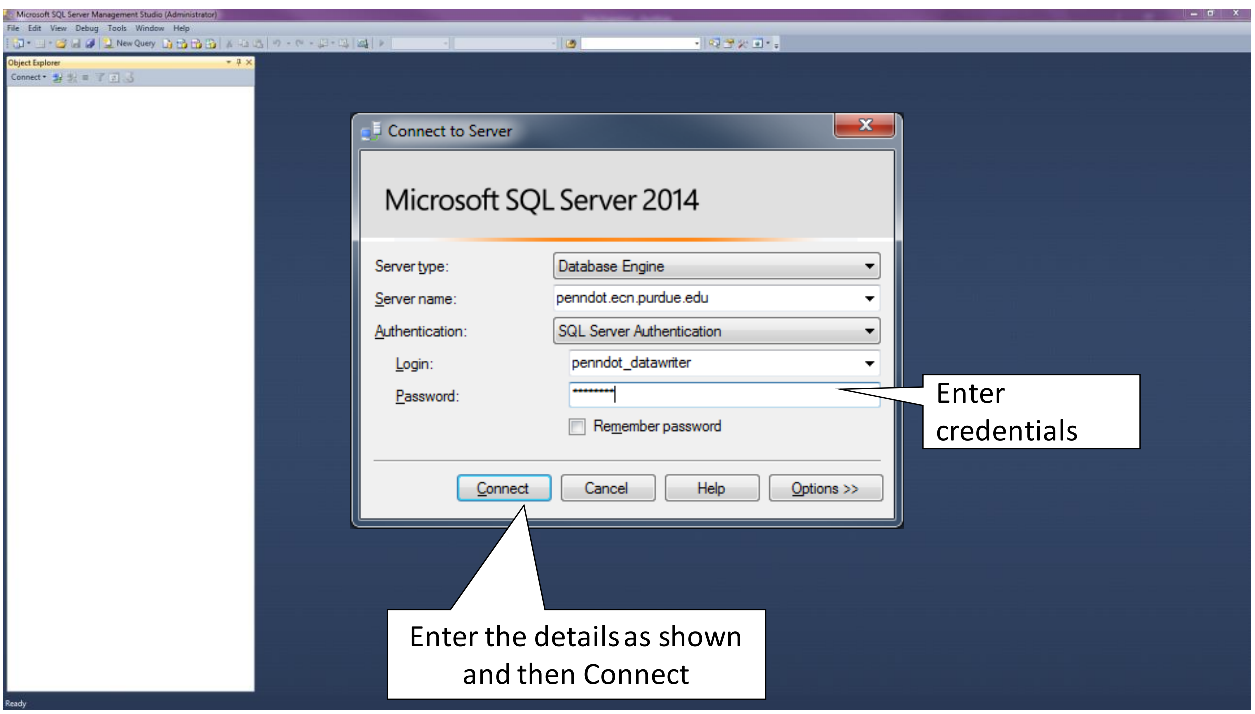
APPENDIX IV – ARCHIVED SPEED DATA IMPORT

Archive data should be requested from INRIX before the import is performed. Contact your INRIX Sales Engineer to request the archived speeds data.

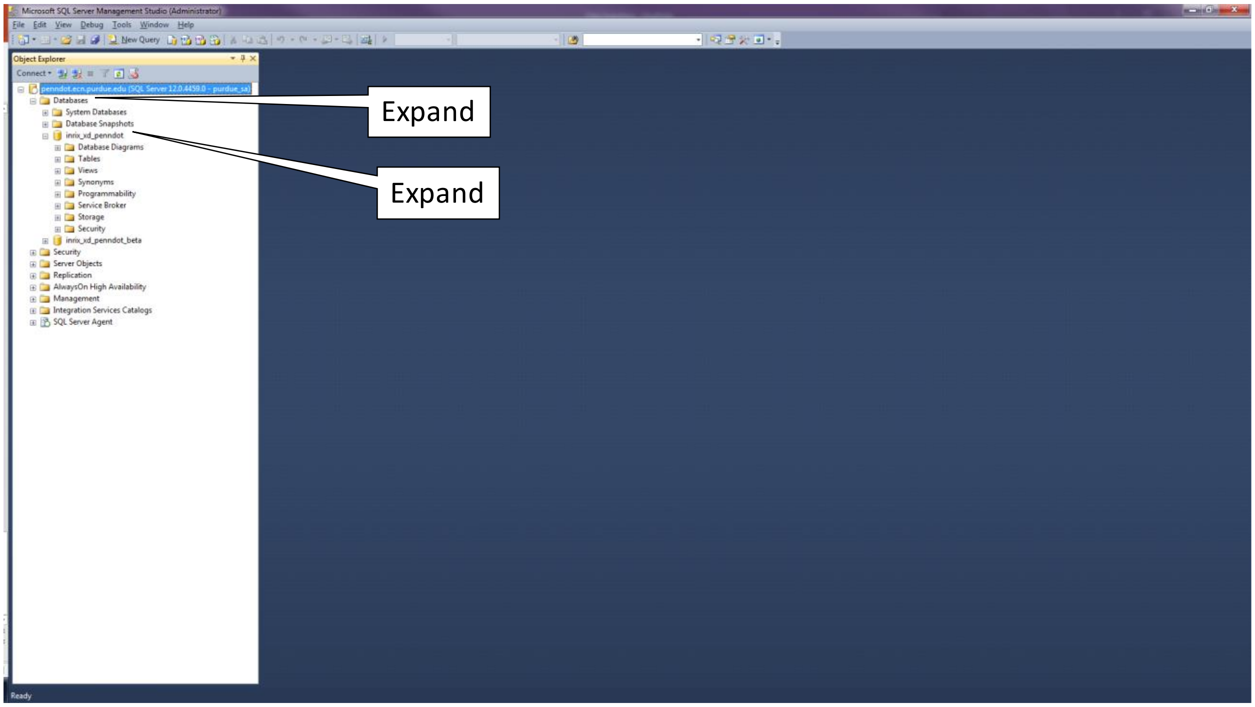
Download the CSV files to the desired location



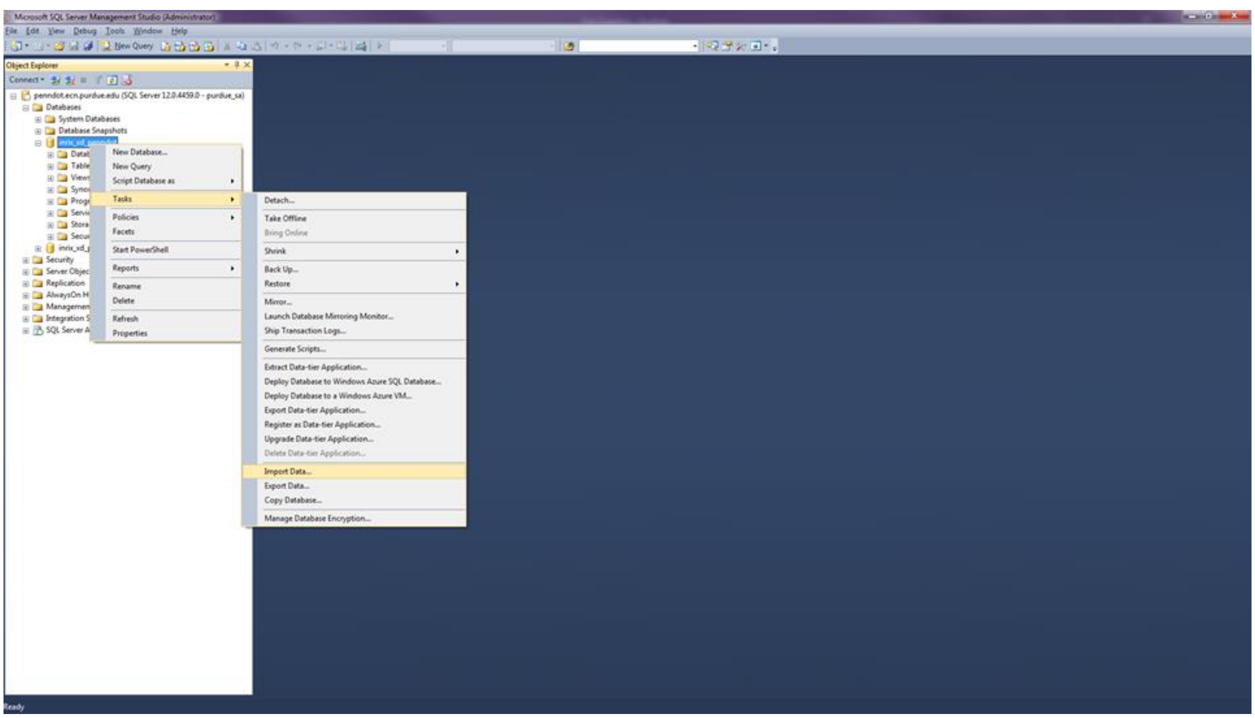
Open SQL Server Management Studio.



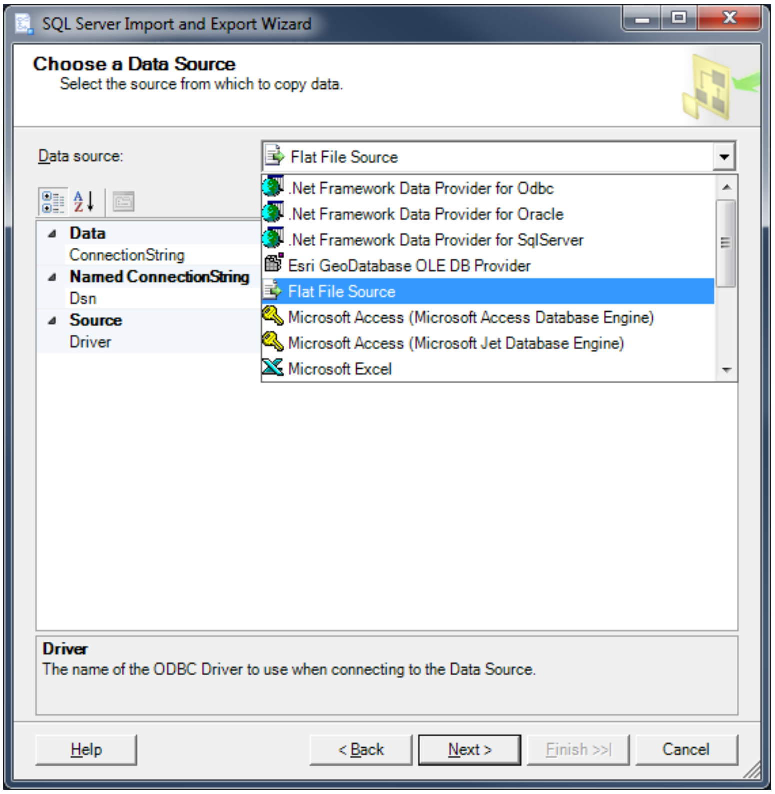
Expand "Databases" and then expand [inrix_xd_penndot]



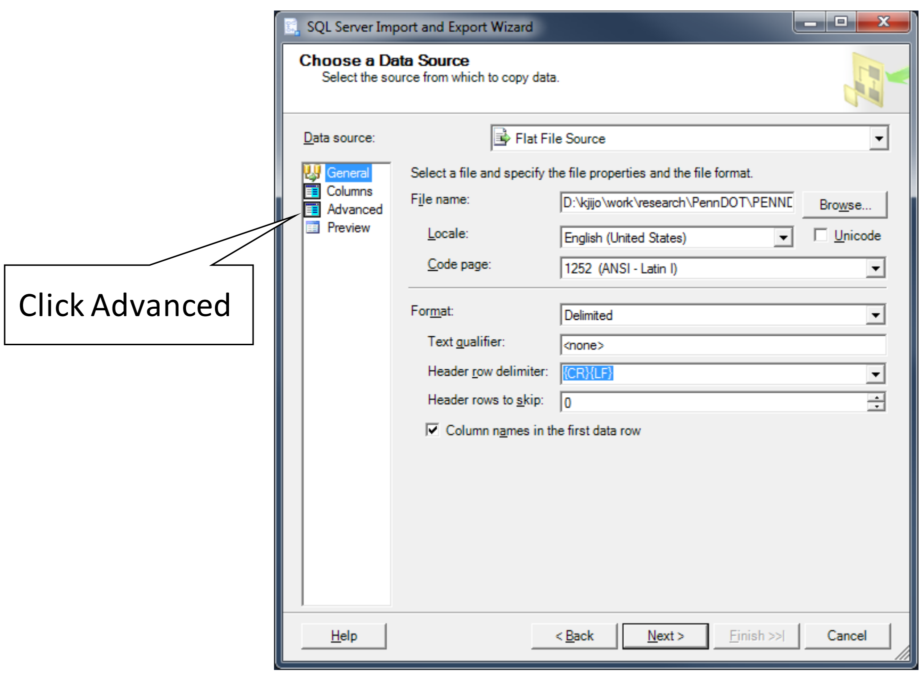
Right-click on "inrix_xd_penndot" -> "Tasks" -> "Import Data"



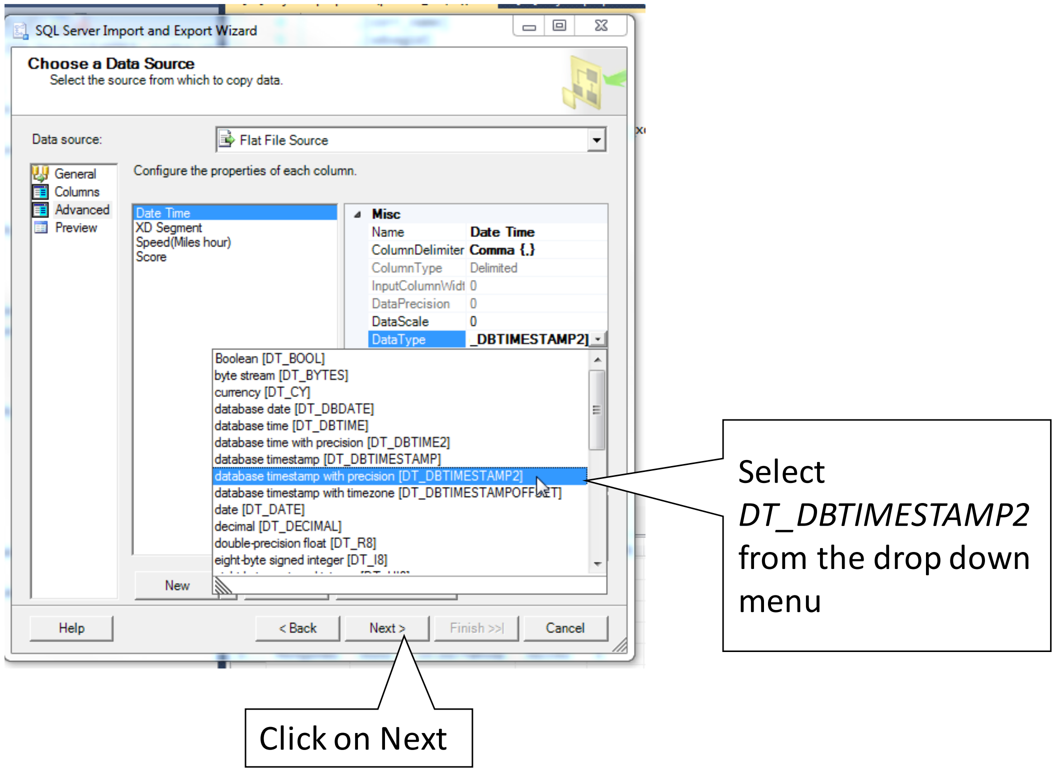
Select “Flat File Source” from the “Data Source” dropdown.



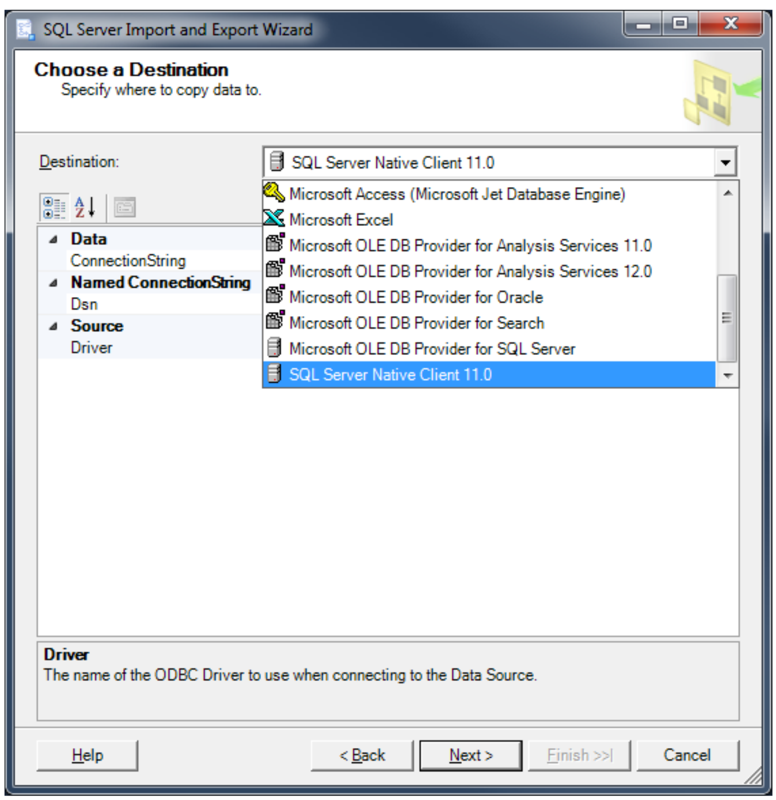
Use the “Browse” button to locate the archive. In this case, 2016_01.csv file.



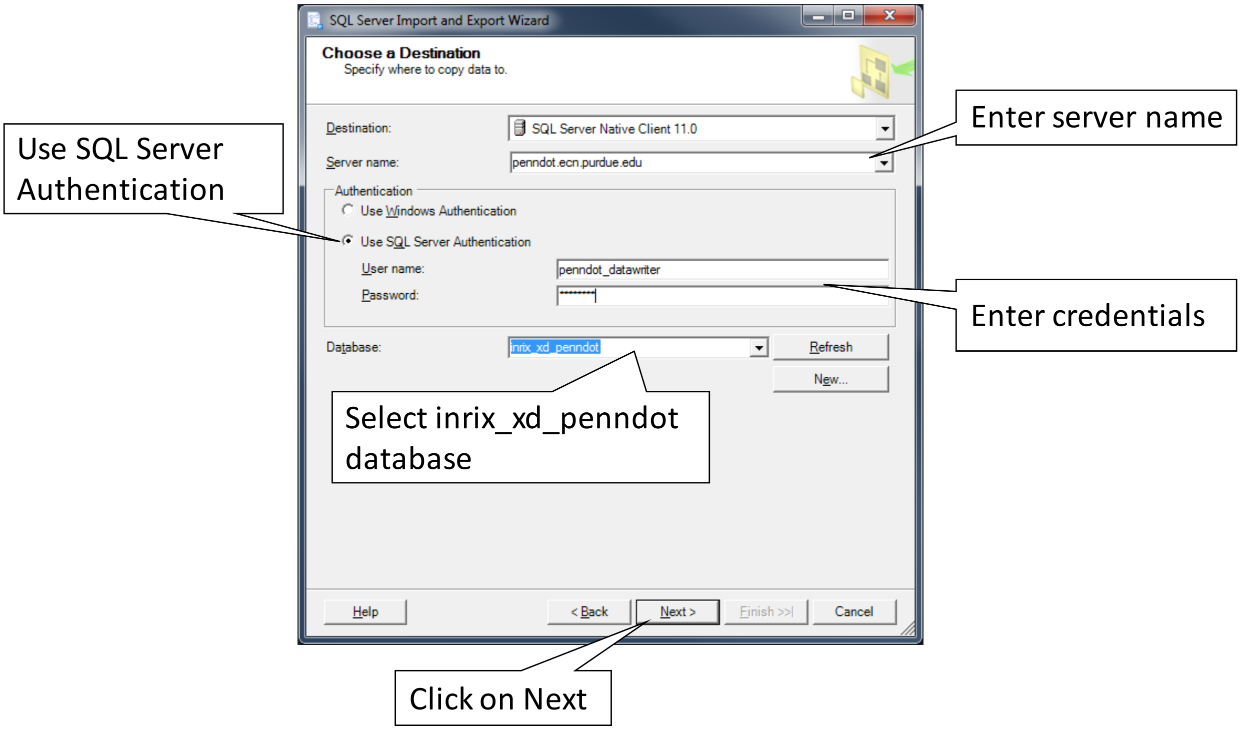
Select “DT_DBTIMESTAMP2” data type for the date and time.



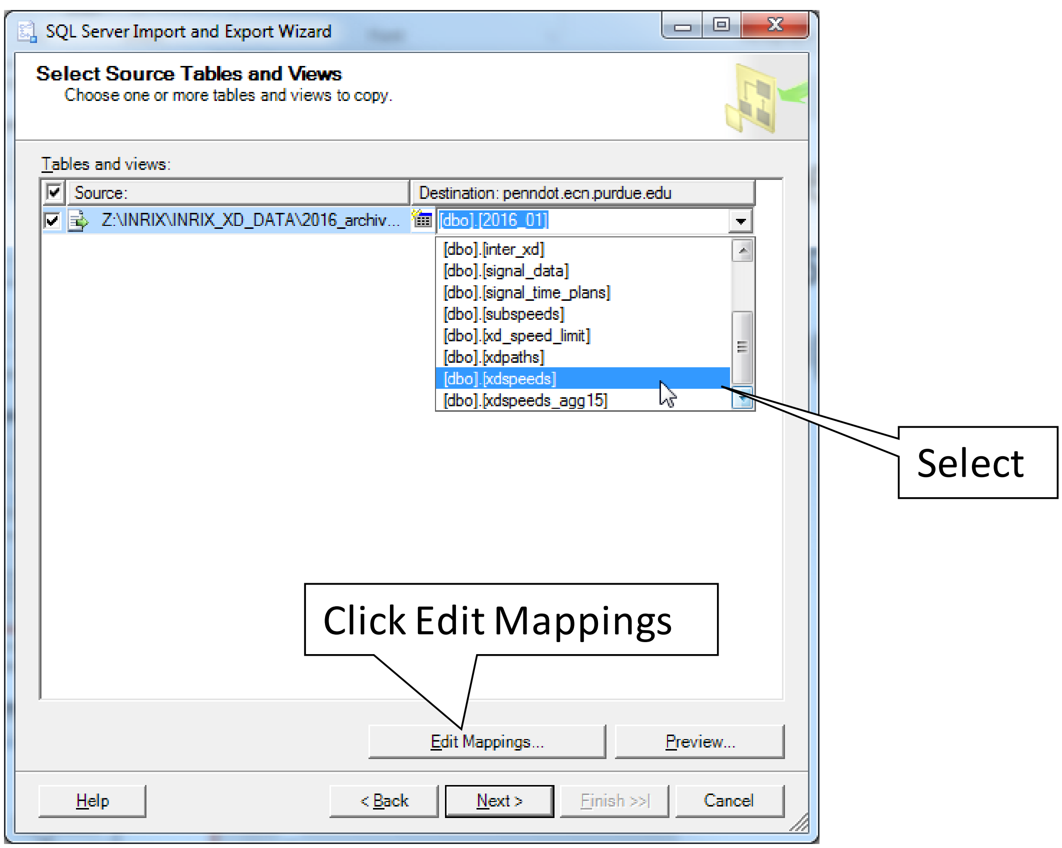
Select “SQL Server Native Client 11.0” from the “Destination” dropdown.



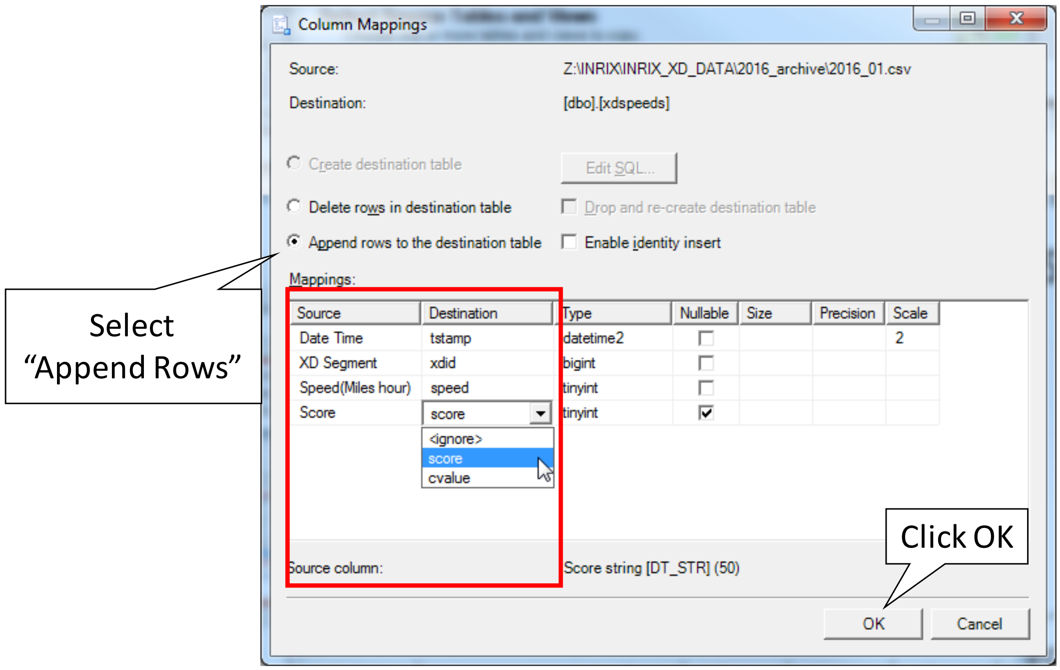
Select “SQL Authentication” and enter the credentials to the database.



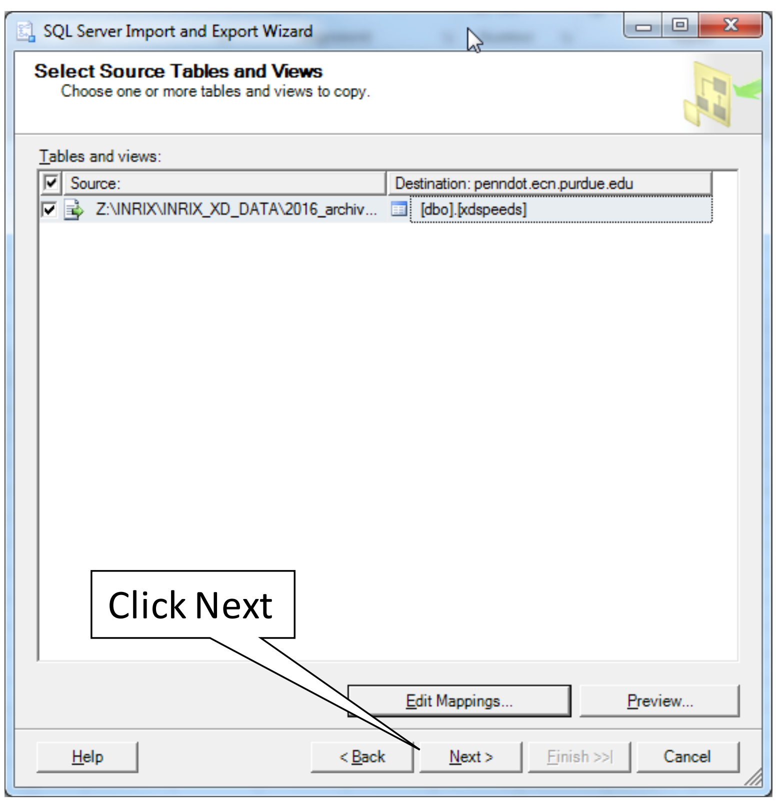
Select “[dbo].[xdspeeds]” from the “Destination” dropdown and click “Edit Mappings.”



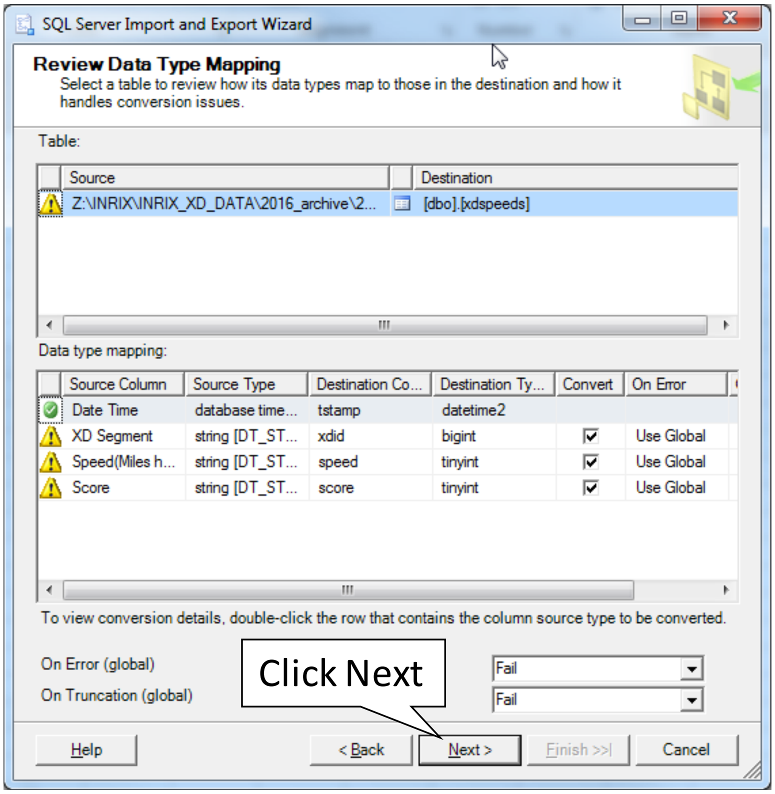
Ensure that the “Source” and “Destination” columns match. If not, use the dropdown from “Destination” to match the “Source.”



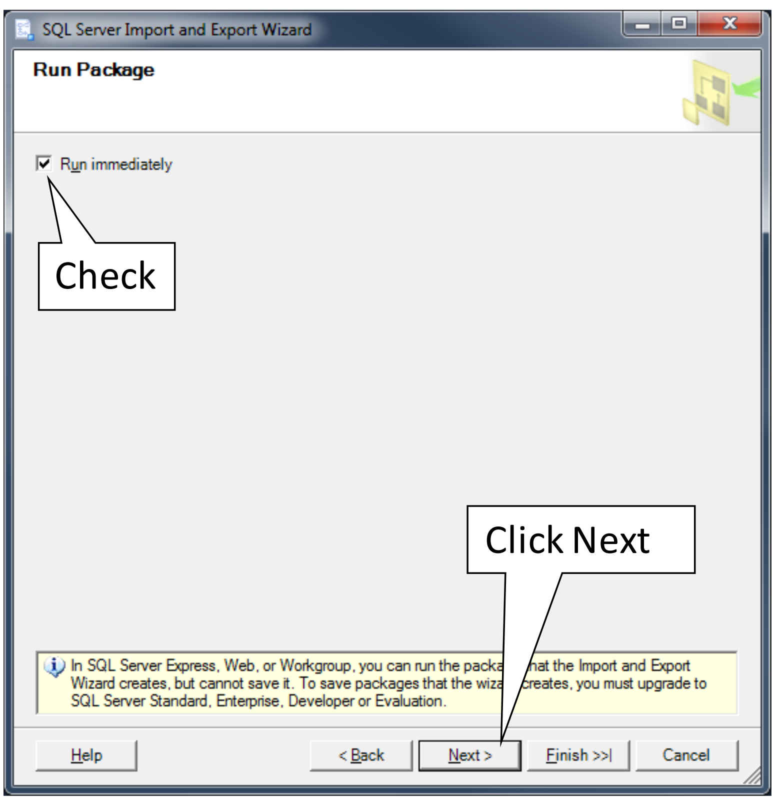
Click “Next.”



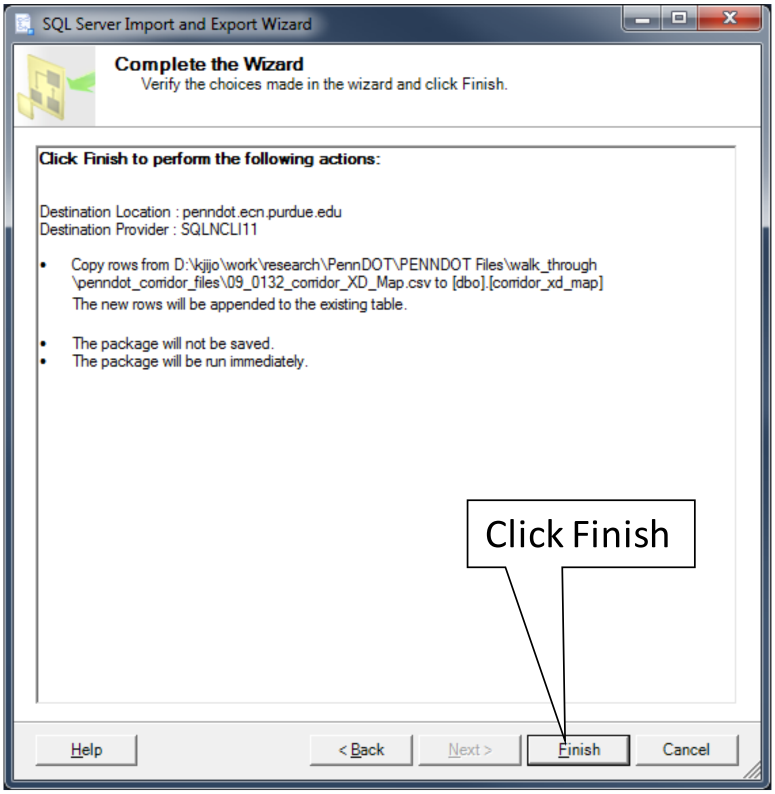
Click “Next” on the “Review Data Type Mapping” screen.



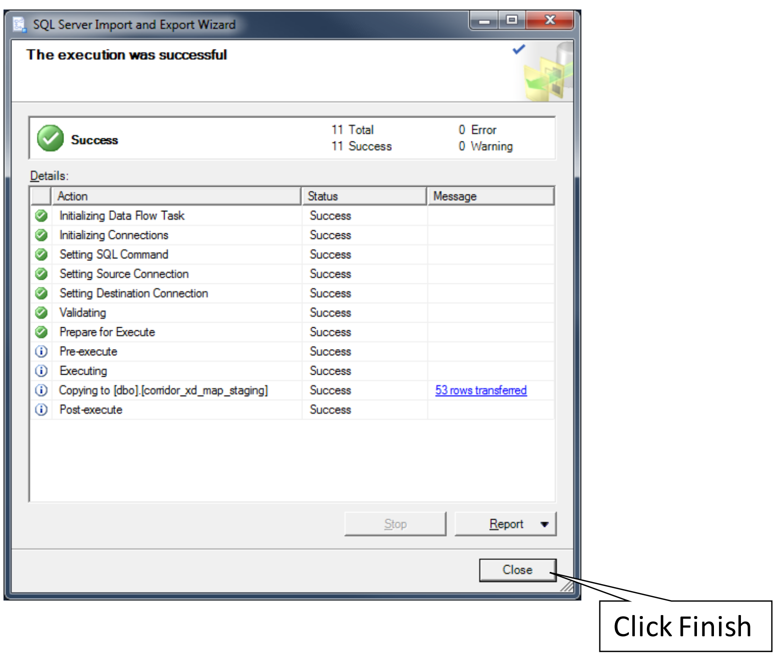
Check the “Run Immediately” option and hit “Next” in the “Run Package” menu.



Click “Finish” to start the import process.



A “Success” status indicates that all data have been imported successfully.



Repeat steps for the other CSV archive files.

APPENDIX V – CORRIDOR LIST AND ATTRIBUTES

Table 6. Bucks County Corridor Information

Bucks County Corridors						
	Corr Name	ID #	Length (mi)	AADT	Signals	Speed Limits
1	PA 132/Street Rd	09003	15.2	33965	49	40-45
2	PA 309/Bethlehem Pk & 3rd St	09006	11.9	37061	19	35-55
3	Oxford Valley Rd	09012	1.4	32735	7	40
4	Newtown Bypass	09007	4.8	35015	11	45-55
5	County Line Rd	09014	11.8	19895	26	40-45
6	PA 413/Veteran Hwy	09008	6.0	21787	14	35-55
7	Lincoln Hwy	09013	5.9	21310	16	35-45
8	PA 313/Dublin Pk/Swamp Rd	09009	18.0	17223	26	30-55
9	PA 663/John Fries Hwy	09011	6.5	20901	6	35-55
10	PA 332/Jacksonville Rd	09015	9.7	17655	13	35-45
11	Woodbourne Rd	09022	4.1	17781	8	35-45
12	Bristol Rd	09020	8.1	16851	8	40-45
13	US 202/Buckingham Rd & PA 179/Bridge St	09005	9.8	16769	11	35-55
14	PA 611/Easton Rd	09019	2.7	19120	5	45-55
15	PA 413/Newtown Langhorne Rd	09016	4.3	17723	5	35-45
16	PA 513/Hulmeville Rd	09018	4.0	15089	10	35-40
17	PA 413/Durham Rd	09017	2.8	15894	4	45
18	E Bristol Rd	09021	2.0	16454	2	35
19	Old Lincoln Hwy	09023	2.0	15452	4	45-50

Table 7. Chester County Corridor Information

Chester County Corridors						
	Corr Name	ID #	Length (mi)	AADT	Signals	Speed Limits
20	PA 3/West Chester Pk	23003	19.7	32033	76	25-55
21	US 1/Baltimore Pk	23001	15.8	33248	30	35-55
22	PA 100/Pottstown Pk	15007	32.7	23215	39	25-55
23	US 30/Lancaster Ave	15006	21.4	21348	85	25-45
24	PA 29/Morehall Rd	15004	2.6	25164	11	40-45
25	PA 724/Schuylkill Rd & PA 23/Valley Forge Rd	15002	13.8	16942	17	35-55
26	Bus 30/Lincoln Hwy/Lancaster Ave	15016	10.2	15995	37	25-45
27	Boot Rd	15014	2.7	19845	6	35-40
28	PA 113/Uwchlan Ave	15008	12.8	17197	17	35-55
29	PA 41/Gap Newport Pk	15003	22.2	16142	13	40-55
30	High St	15013	4.3	17962	10	25-55
31	PA 401/Conestoga Rd	15011	1.9	18486	3	45
32	US 322/Downingtown Pk	15009	5.1	17168	5	30-50
33	PA 10/Octorara Tr	15001	2.1	17678	2	35-45
34	US 322/Horseshoe Pk	15005	3.5	19194	3	35-45
35	Limestone Rd	15015	0.8	18154	1	40
36	PA 926/Street Rd	15012	5.5	13634	4	40-45

Table 8. Delaware County Corridor Information

Delaware County Corridors						
	Corr Name	ID #	Length (mi)	AADT	Signals	Speed Limits
37	US 1/State Rd/Twp Line Rd/City Ave	23002	10.0	35268	40	35-45
38	US 202/Wilmington Pk	23007	8.6	46553	16	35-55
39	Baltimore Pk	23018	8.4	23694	38	25-45
40	PA 420/Wanamaker Ave/Woodland Ave	23014	5.6	22492	15	25-45
41	PA 320/Sproul Rd	23010	4.5	25632	18	35-40
42	PA 252/Providence Rd/Newtown Street Rd	23008	13.5	21866	21	35-55
43	Lansdowne Ave	23015	2.9	22183	13	25-35
44	US 322/Conchester Hwy	23011	7.2	27926	5	30-45
45	Macdade Blvd	23016	5.1	22058	21	30-35
46	Kerlin St	23019	0.6	26506	4	25
47	PA 352/Edgemont Ave	23012	13.7	19741	27	35-45
48	Springfield Rd	23020	3.8	17804	12	30-35
49	84th St/Hook Rd	67021	1.3	34336	3	35
50	US 13/Chester Pk	23004	0.6	27986	4	40
51	Marshall Rd	67030	1.2	23573	7	35-40
52	PA 452/Pennell Rd	23013	5.8	18241	6	35-40
53	Church Ln/69th St	23024	1.0	16549	10	35-45
54	Eagle Rd	23017	2.6	18303	9	35
55	US 13/Macdade Blvd	23005	0.3	25267	3	35
56	South Ave	23023	1.3	16732	4	35
57	Chichester Ave	23028	1.9	17953	4	30-35
58	Oak Ave	23022	1.4	15901	4	35-45
59	State Rd	23026	3.5	16084	10	30-35
60	Providence Rd	23021	0.7	16133	3	30
61	Concord Rd	23027	2.5	15864	5	35-40
62	Bishop Ave/Garrett Rd	23025	3.0	17090	2	25-35

Table 9. Montgomery County Corridor Information

Montgomery County Corridors						
	Corr Name	ID #	Length (mi)	AADT	Signals	Speed Limits
63	PA 309/Bethelem Pk	46012	8.0	35240	23	40-50
64	PA 611/Old York Rd & Easton Rd	46016	16.3	30919	68	25-50
65	PA 63/Forty Foot Rd & Sumneytown Pk	46003	7.4	24366	19	35-45
66	US 202/Dekalb Pk	46008	2.4	40620	10	35-45
67	PA 309/Cheltenham Ave & Ogontz Ave	46011	2.2	33207	12	35
68	Germantown Pk	46023	4.7	21397	10	25-45
69	PA 463/Cowpath Rd/Horsham Rd	46014	11.3	19961	29	40-45
70	PA 73/Cottman Ave	67007	7.0	19461	39	30-45
71	US 202/Dekalb Pk	46027	7.6	19634	18	40-50
72	PA 263/York Rd	09004	10.2	21281	29	30-55
73	PA 363/Trooper Rd	46013	2.7	28720	5	35-45
74	Chemical Rd	46018	1.1	27457	5	35-50
75	Matsonford Rd	46019	1.4	22019	4	25-35
76	PA 63/Welsh Rd	46004	14.5	17388	40	30-45
77	Gulph Rd	46022	4.9	22358	17	35-40
78	Main St/Ridge Pk	46017	3.5	20090	8	35-45
79	Egypt Rd	46042	3.5	21233	8	35-45
80	Armand Hammer Blvd	46044	0.7	18167	4	40
81	PA 73/Skippack Pk	46020	12.5	17176	18	35-50
82	Old US 202/Butler Ave	09024	6.8	17552	13	35-45
83	Township Line Rd	46026	3.2	19732	8	30-45
84	Ridge Pk	46025	0.4	35955	2	35-40
85	Lewis Rd	46041	2.4	16705	7	35-45
86	Bethlehem Pk	46034	8.2	15589	19	35-50
87	PA 363/Valley Forge Rd	46028	8.9	17138	7	35-45
88	Bridgeport Bypass & Markley St	46021	1.9	26948	4	25-45
89	PA 63/Old Welsh Rd/Philmont Ave	46005	2.7	17810	5	35
90	Susquehanna Rd	46033	5.3	15808	16	30-45
91	Walton Rd	46039	0.9	18367	2	40
92	PA 23/River Rd/Conshohocken State Rd	46002	3.6	15674	9	30-45
93	PA 23/Valley Forge Rd	46001	1.7	16711	6	35-55
94	PA 113/Harleysville Pk	46024	4.3	17135	4	40-45
95	PA 73/Philadelphia Ave	46006	1.4	16675	5	30-40
96	Ridge Pk	46043	6.0	16048	8	40-45
97	Davisville Rd	46037	1.2	17362	3	35
98	Blair Mill Rd	46035	3.1	17445	3	40
99	Morris Rd	46030	4.9	14331	9	40-45
100	Paper Mill Rd	46036	1.4	16841	3	30-35
101	Allentown Rd	46029	3.1	14933	4	40-45
102	North Wales Rd	46031	1.1	15856	1	30-35

Table 10. Philadelphia County Corridor Information

Philadelphia County Corridors						
	Corr Name	ID #	Length (mi)	AADT	Signals	Speed Limits
103	Aramingo Ave/Harbison Ave	67019	6.3	27167	37	25-35
104	US 1/Roosevelt Blvd	67002	13.2	73305	50	35-50
105	PA 611 & PA 291/Broad St	67010	11.7	29554	119	15-35
106	Lincoln Dr	67034	1.2	29316	8	30-35
107	PA 3/Chestnut St & Walnut St	67003	3.8	32966	70	30-35
108	PA 532/Bustleton Ave	67009	7.6	26563	33	25-35
109	PA 232/Huntingdon Pk/Oxford Ave/2nd St Pk	46009	14.5	18516	50	25-45
110	Ben Franklin Pkwy & Kelly Dr	67024	5.5	34574	15	25-35
111	Cobbs Creek Pkwy/63rd St	67025	0.7	28622	7	25-35
112	Cheltenham Ave/Crescentville Rd/Adams Ave	67011	3.00	24457	16	25-40
113	US 13/Frankford Ave/Bristol Pk	09002	16.2	20895	37	25-50
114	52nd St	67028	0.3	33072	3	35
115	26th St & University Ave	67022	2.5	36545	6	25-40
116	Henry Ave & Ridge Ave	67032	5.2	28051	21	35
117	Academy Rd	67015	1.1	33219	4	30-35
118	Bartram Ave & Essington Ave & Passyunk Ave	67029	4.1	22560	21	25-40
119	Stenton Ave/Godfrey Ave	67041	6.0	18122	34	25-40
120	Delaware Ave (Columbus Blvd)	67018	4.0	22667	21	25-35
121	PA 291/Bartram Ave & Penrose Ave	67008	6.1	27222	14	25-45
122	Grant Ave/Welsh Rd	67016	2.7	31160	7	30-45
123	US 13 & US 30/Girard Ave	67004	1.5	21917	11	30-50
124	Welsh Rd	67038	2.0	20879	6	25-35
125	Island Ave	67026	1.2	33155	4	35
126	Castor Ave	67035	3.6	15898	18	25-35
127	Ridge Ave	67040	4.2	17366	21	30-35
128	Vine St	67020	0.5	25928	10	25
129	Princeton Ave	67037	0.4	18690	4	25
130	Belmont Ave	67023	3.8	18165	15	35-40
131	Roberts Ave	67042	0.8	17723	4	30-35
132	Rising Sun Ave	67013	3.3	15843	19	35
133	58th St	67027	0.2	25854	2	25
134	Verree Rd	67014	3.6	17211	10	30-35
135	Erie Ave/Torresdale Ave	67006	6.7	13904	45	25-30
136	Rhawn St	67039	4.0	15675	17	25-35
137	Levick St	67036	1.2	15784	10	25
138	Woodhaven Rd	67017	0.4	22104	0	55

APPENDIX VI – LIST OF PARTICIPANTS

1. Webinar on 15 November 2016

Name	Affiliation
Howell Li	Purdue University
Jijo Mathew	Purdue University
Lou Rymarscuk	Purdue University
Drake Krohn	Purdue University
Dan Farley	PennDOT BOMO
Michael Bindie	PennDOT Central Office
Ben Flanagan	PennDOT Central Office
Steve Gault	Michael Baker Int'l
Tony Tanzi	PennDOT
Adam Dunlap	PennDOT
Jon Bowman	PennDOT
Jim Saylor	PennDOT
Kevin Snyder	PennDOT
Mike Buckner	PennDOT
Jackie Baldwin	PennDOT
Ashwin Patel	PennDOT District 6
Matthew Anderson	PennDOT District 6
Ted Lucas	KMJ Consulting

2. Webinar on 20 November 2016

Name	Affiliation
Howell Li	Purdue University
Jijo Mathew	Purdue University
Lou Rymarscuk	Purdue University
Drake Krohn	Purdue University
Dan Farley	PennDOT BOMO
Michael Bindie	PennDOT Central Office
Ben Flanagan	PennDOT Central Office
Maurice Lee	PennDOT Central Office
Doug Smith	SPC Pittsburgh
Bridget Postlewaite	KMJ Consultants
Zoe Neaderland	DVRPC
Jesse	DVRPC
Ashwin Patel	PennDOT District 6
Matthew Anderson	PennDOT District 6

3. Workshop at PennDOT District 6 office on 12 January 2017

Name	Affiliation
Howell Li	Purdue University
Jijo Mathew	Purdue University
Dan Farley	PennDOT BOMO
Steve Gault	Michael Baker Int’l
Bridget Postlewaite	KMJ Consulting
Paul Lutz	PennDOT
Ted Lucas	KMJ Consulting
Dave Adams	PennDOT District 6
Nipul Patel	PennDOT District 6
Manny Anastasiadis	PennDOT District 6
Michael Crowley	PennDOT District 6
Brian Keaveney	Pennoni Associates
Lou Belmonte	PennDOT District 6
Ashwin Patel	PennDOT District 6
Matthew Anderson	PennDOT District 6