Application of Global Positioning System (GPS) to Travel Time and Delay Measurements

By

ARDESHIR FAGHRI
MINGXIN LI

Assisted by

MORTEZA TABATABAIE SHOURIJEH
SEAN HUMPHREY
DREW PAVLICK
REBECCA FREY

Department of Civil and Environmental Engineering
University of Delaware

April 2012

Delaware Center for Transportation
University of Delaware
355 DuPont Hall
Newark, Delaware 19716
(302) 831-1446
The Delaware Center for Transportation is a university-wide multi-disciplinary research unit reporting to the Chair of the Department of Civil and Environmental Engineering, and is co-sponsored by the University of Delaware and the Delaware Department of Transportation.

**DCT Staff**

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ardeshr Faghri</td>
<td>Director</td>
<td></td>
</tr>
<tr>
<td>Jerome Lewis</td>
<td>Associate Director</td>
<td></td>
</tr>
<tr>
<td>Ellen Pletz</td>
<td>Assistant to the Director</td>
<td></td>
</tr>
<tr>
<td>Earl “Rusty” Lee</td>
<td>T² Program Coordinator</td>
<td></td>
</tr>
<tr>
<td>Matheu Carter</td>
<td>T² Engineer</td>
<td></td>
</tr>
<tr>
<td>Sandra Wolfe</td>
<td>Event Coordinator</td>
<td></td>
</tr>
</tbody>
</table>

**DCT Policy Council**

- Natalie Barnhart, Co-Chair
  *Chief Engineer, Delaware Department of Transportation*

- Babatunde Ogunnaike, Co-Chair
  *Dean, College of Engineering*

- Delaware General Assembly Member
  *Chair, Senate Highways & Transportation Committee*

- Delaware General Assembly Member
  *Chair, House of Representatives Transportation/Land Use & Infrastructure Committee*

- Ajay Prasad
  *Professor, Department of Mechanical Engineering*

- Harry Shenton
  *Chair, Civil and Environmental Engineering*

- Michael Strange
  *Director of Planning, Delaware Department of Transportation*

- Ralph Reeb
  *Planning Division, Delaware Department of Transportation*

- Stephen Kingsberry
  *Executive Director, Delaware Transit Corporation*

- Shannon Marchman
  *Representative of the Director of the Delaware Development Office*

- James Johnson
  *Executive Director, Delaware River & Bay Authority*

- Holly Rybinski
  *Project Manager-Transportation, AECOM*

Delaware Center for Transportation  
University of Delaware  
Newark, DE  19716  
(302) 831-1446
Application of Global Positioning System (GPS) to Travel Time And Delay Measurements

Fall 2011

By:
Ardeshir Faghri
Mingxin Li

Assisted by:
Morteza Tabatabaie Shourijeh
Sean Humphrey
Drew Pavlick
Rebecca Frey

Department of Civil & Environmental Engineering
University of Delaware

April 2012
Introduction
Traffic congestion is a growing problem in many jurisdictions across the country. In order to quantify
the severity of congestion, Global Positioning System (GPS) applications have been utilized to collect
travel time and delay data for many of Delaware’s principal and minor arterials, collectors, and
freeways. Since 1996, the Delaware Department of Transportation (DelDOT), with the help of the Civil
and Environmental Engineering Department at the University of Delaware, has been using GPS
technology for this purpose. The GPS data has proven to be at least as accurate as the data collected by
conventional methods, and is 50% more efficient in terms of manpower. For these reasons, DelDOT has
continued to request this annual data each subsequent year. Annual reports documenting the data
collection process, its applicability and accuracy, and the collected data have been compiled over the
years. The Application of Global Positioning System (GPS) to Travel Time and Delay Measurements-1997
Phase report describes the testing of the applicability and accuracy of the GPS system, while the report
of the 1998 Phase provides a step-by-step procedure for the data collection. The following report
describes the data collection methodology, as well as a summary of the collected and processed Fall
2011 data.

Methodology
In an effort to quantify congestion related to commuter traffic, travel time and delay data have been
collected during morning (7AM – 9AM) and afternoon (4PM – 6PM) peak-hour travel times between
September 13, 2011 and November 11, 2011. Part of the data for Kent County has been collected
between March 5, 2012 and March 15, 2012. Data was collected by 2 two-person teams, each operating
a separate vehicle. Each team consisted of one driver and one data collector. The driver’s responsibility
is to maintain the vehicle’s speed to represent that of the average driver on the road. The data collector
is responsible for operating the computer and creating features in the data as the vehicle crosses each specified control point along the route and as the vehicle encounters delay sources. This separation of duties provides for optimal driving safety during data collection and allows each individual to fully concentrate on their respective responsibilities. Each team utilizes a Trimble GPS unit and a laptop computer with Trimble TerraSync and GPS Pathfinder Office softwares installed. Because of equipment failures experienced in past years, new laptops, updated TerraSync software, new GPS receivers, and new cables were purchased following data collection in the Fall of 2005. For the Fall 2011 project, all the equipment were checked again and the cables were replaced to ensure undisturbed data collection and as a result, no manual data collection was performed in course of this project which is somewhat remarkable.

All major routes surrounding large population centers in Delaware were covered. Those routes can be found below subdivided by county:


- **Kent County:** SR 1, US 13, US 113, SR 6, SR 8, SR 10, SR 12, SR 14, SR 15, SR 300, State St

- **Sussex County:** SR 1, US 13, US 113, SR 16, SR 404

With a minimum confidence level of 95% and with permitted errors of 1 to 5 miles per hour in velocity, a minimum of two runs was determined to be sufficient to achieve accurate results. Based on these findings, each direction of a roadway segment was traveled at least four times: twice during the morning peak hours, and twice during the afternoon peak hours. This was done to ensure that the effects of the
traffic directional and temporal fluctuations were captured. Furthermore, as started in 2000, data collection was expanded to include the TMC critical miles.

For data collection, all routes and associated control points have been printed onto index cards. Each card contains the route’s name, the direction of the road, all control points of that route, and any applicable notes regarding route navigation. A complete set of all 48 studied roads was included in each vehicle for use by the data collection teams. The index card serves two purposes: It can be used to prepare a run and familiarize data collectors with the features of the road, or it may serve as a backup in the event of equipment failure or insufficient GPS signal. The index cards have proven both successful and useful throughout the years of data collection.

The Fall 2011 data collection was executed with a group of graduate students in the Transportation Engineering Department and undergraduate students in the Civil and Mechanical Engineering Departments. Prior to the start of the data collection, all data collectors were familiarized with the designated routes and the use of the data collection equipment. The training consisted of preprocessing, a test-run data collection, and postprocessing. Preprocessing included a review of the route to be measured and associated control points, as well as preparation of the laptops, GPS hardware, and related software. Postprocessing included a transfer of the data from the laptops to a main computer, as well as an examination of the data for errors and logged inaccuracies.

The data collectors also conducted a test-run data collection using the manual collection method in the event of equipment failure. To aid in manual data collection, both vehicles were provided with the necessary references and equipment (e.g. manuals, instruction sheets, stopwatches, and printed maps) related to the different procedures and safety measures that would apply. Data collection was closely monitored on a day to day basis, and results were immediately processed after data collection.
Interpretation of 2011 Fall Data

This report includes a set of six summary tables containing the collected data segmented by county and time of day. The data in each table is arranged by route name, roadway segments, and direction of travel. The table contains the information explained below:

- **Distance (Miles)** – the length of the given route segment. The distance of each segment is listed and the total of those are summed in the last line of each route.

- **Mean Peak Travel Time (Seconds)** – the average time in seconds that was taken to travel the length of the segment. Again, the mean peak travel time of all segments are summed in the last line of each route.

- **Mean Peak Travel Speed (mph)** – the average speed of the test vehicle traveling from one control point to the next. This value is obtained by dividing the distance of the segment by the mean peak travel time.

- **Total Peak Delay (Seconds)** – the time spent in delay traveling through the given segment. *By definition, delay is the time when vehicle speed drops below 5 miles per hour.*

- **Peak Delay Source** – the reason for the delay noted in the previous column. Reasons for delay can be due to traffic signals, construction, accidents, congestion, pedestrian crossing, train crossing, etc. Traffic signals are the main cause of delay.

- **Mean Peak Running Speed (mph)** – the average speed that a vehicle would travel through the route segment if delay were not experienced. This value is obtained by the following equation:

\[
\text{MPRS} = \frac{\text{Distance}}{\text{Mean Peak Travel Time} - \text{Total Peak Delay}}
\]
• **Percent Time in Delay** – the percentage of time spent in delay for that route segment. The percentage is obtained by dividing the total peak delay by the mean peak travel time, then multiplying the quantity by 100.

\[
\text{Percent Time in Delay} = \left( \frac{\text{Total Peak Delay}}{\text{Mean Peak Travel Time}} \right) \times 100
\]

• **Number of Lanes** – the number of lanes for the given route segment. Route segments that have more than one value shown designate that the number of lanes change during that segment. This does not include turning bays at intersections.

• **Posted Speed (mph)** – the posted speed limit for the given route segment. Again, for those that have more than one posted speed in this column, this means that the posted speed changes during that segment.

**Project Observations and Conclusions**
The 2011 data collection was able to be completed accurately within the prescribed time periods. Data collection was never interrupted and thus during the whole Fall 2011 period no manual data was collected.

Appendix A shows the ten most degraded, the ten most improved, and the 20 worst route segments. These segments are ranked based on changes between the 2010 and 2011 data relating to difference between posted speed and average travel speed. These charts can be used to track changes in land use, system performance, and effects of construction or other improvements.

Appendix B shows a GIS map of full road coverage in the state of Delaware.
Appendix C shows GIS maps of the mean peak travel speed for the routes covered in Delaware for both the AM and PM peak periods. The GIS maps are color-coded based on a range of values.

Appendix D shows GIS maps of the mean peak delay in the AM and PM peak periods. The mean peak delay is the average amount of time, in seconds, that the test vehicle was in delay for a particular segment. The length of delay corresponds to the length of time the test vehicle was traveling at a speed of 5 mph or less.

Appendix E shows GIS maps of the percentage difference between the posted speed and the average travel speed for the AM and PM peak periods. This map is helpful when trying to determine congestion along a particular segment. Even if a particular segment has a low average delay, it does not always mean that there are free-flow conditions. The maps in Appendix E will help to determine additional traffic flow information.

Appendix F and Appendix G show GIS maps of the LOS for the AM and PM peak periods in both 2010 and 2011. LOS was computed based on the following criteria for the percent difference between posted speed and average speed, computed as:

\[
\left( \frac{\text{Posted Speed} - \text{Average Speed}}{\text{Posted Speed}} \right) \times 100\%
\]

<table>
<thead>
<tr>
<th>Interstate/Freeways (% time under speed limit)</th>
<th>Arterials: (% under speed limit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS A: 0-14%</td>
<td>LOS A: 0-10%</td>
</tr>
<tr>
<td>LOS B: 14-18%</td>
<td>LOS B: 10-30%</td>
</tr>
<tr>
<td>LOS C: 18-20%</td>
<td>LOS C: 30-45%</td>
</tr>
<tr>
<td>LOS D: 20-30%</td>
<td>LOS D: 45-60%</td>
</tr>
<tr>
<td>LOS E: 30-50%</td>
<td>LOS E: 60-70%</td>
</tr>
<tr>
<td>LOS F: 50% +</td>
<td>LOS F: 70% +</td>
</tr>
</tbody>
</table>
Finally, Appendix H consists of a summary of the data for each county, as well as the state, in an excel spreadsheet format. Appendix I is the data for the TMC 250 critical miles in an excel spreadsheet format.
Appendix A

Explanation:
This is a listing of the ten most degraded, ten most improved, and 20 worst route segments in the state as determined by comparing data from 2011 to that of 2010. For all degraded and improved charts \( \%_{D \text{ PS TS}} \) is the percent difference between the posted speed and travel speed between the years 2010 and 2011. The higher the percentage (positive number) the more degraded segment is, and the lower the percentage the more improved segment is. The ten most degraded and 20 worst segments may require further examination.

Variables:
\[ \%_{PS \text{ TS}} = \text{The percentage difference between the posted speed and the average travel speed.} \]
\[ \%_{D \text{ PS TS}} = \text{The percentage difference between the posted speed and travel speed} \]
\[ \text{between years 2010 and 2011.} \]

Equations:
\[ \%_{PS \text{ TS}} = \frac{\text{MeanPeakTravelSpeed} - \text{WeightedAverageSpeed}}{\text{WeightedAverageSpeed}} \]
\[ \%_{D \text{ PS TS}} = \%_{PS \text{ TS}}^{2011} - \%_{PS \text{ TS}}^{2010} \]

A1: 10-Most Degraded Segments
Segments are selected by taking the difference between the LOS of 2011 and the LOS of 2010 and taking the segments which indicated the most drastic decline. If two or more segments had the same level of degradation, the segment with the least \( \%_{D \text{ PS TS}} \) took priority.
A₂: 10-Most Improved Segments
Segments are selected by taking the difference between the LOS of 2011 and the LOS of 2010 and taking the segments which indicated the most notable improvement. If two or more segments had the same level of improvement, the segment with the greatest %_D_PS_TS took priority.

A₃: 20-Worst Segments
The 20 segments with the worst LOS are selected and displayed in this table.
### A1: 10-Most Degraded Segments AM/PM:

<table>
<thead>
<tr>
<th>ID</th>
<th>Route Number</th>
<th>Dir</th>
<th>Segment</th>
<th>2010 LOS</th>
<th>2011 LOS</th>
<th>%Diff – Posted vs. Travel Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>348</td>
<td>US 113</td>
<td>NB</td>
<td>SR 12 to Bowers</td>
<td>A</td>
<td>B</td>
<td>128.47%</td>
</tr>
<tr>
<td>347</td>
<td>US 113</td>
<td>SB</td>
<td>Bowers to SR 12</td>
<td>A</td>
<td>B</td>
<td>94.55%</td>
</tr>
<tr>
<td>309</td>
<td>SR 1</td>
<td>SB</td>
<td>Exit 98 to Exit 97</td>
<td>A</td>
<td>E</td>
<td>84.64%</td>
</tr>
<tr>
<td>310</td>
<td>SR 1</td>
<td>NB</td>
<td>Exit 97 to Exit 98</td>
<td>A</td>
<td>D</td>
<td>72.20%</td>
</tr>
<tr>
<td>5</td>
<td>SR 92</td>
<td>EB</td>
<td>I-95 to US 13</td>
<td>A</td>
<td>C</td>
<td>71.58%</td>
</tr>
<tr>
<td>55</td>
<td>I-495</td>
<td>NB</td>
<td>Exit 3 to Exit 4 (Rt. 3 Marsh Rd.)</td>
<td>A</td>
<td>D</td>
<td>67.11%</td>
</tr>
<tr>
<td>449</td>
<td>SR 41</td>
<td>SB</td>
<td>McKennans Church Rd to Hercules Rd</td>
<td>B</td>
<td>F</td>
<td>65.80%</td>
</tr>
<tr>
<td>162</td>
<td>SR 273</td>
<td>EB</td>
<td>SR 58 to US 13</td>
<td>B</td>
<td>F</td>
<td>61.55%</td>
</tr>
<tr>
<td>19</td>
<td>I-95</td>
<td>NB</td>
<td>Exit 11 (Naamans Rd) to PA Line</td>
<td>A</td>
<td>E</td>
<td>58.34%</td>
</tr>
<tr>
<td>20</td>
<td>I-95</td>
<td>SB</td>
<td>PA Line to Exit 11 (Naaman's Rd)</td>
<td>B</td>
<td>F</td>
<td>56.93%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ID</th>
<th>Route Number</th>
<th>Dir</th>
<th>Segment</th>
<th>2010 LOS</th>
<th>2011 LOS</th>
<th>%Diff – Posted vs. Travel Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>558</td>
<td>SR 15</td>
<td>NB</td>
<td>SR 12 to US 13</td>
<td>A</td>
<td>F</td>
<td>128.05%</td>
</tr>
<tr>
<td>544</td>
<td>SR 15</td>
<td>NB</td>
<td>SR 6 to Clayton Delany Rd</td>
<td>A</td>
<td>F</td>
<td>126.76%</td>
</tr>
<tr>
<td>562</td>
<td>SR 15</td>
<td>NB</td>
<td>SR 14 to Carpenter Bridge</td>
<td>A</td>
<td>F</td>
<td>108.34%</td>
</tr>
<tr>
<td>557</td>
<td>SR 15</td>
<td>SB</td>
<td>US 13 to SR 12</td>
<td>A</td>
<td>F</td>
<td>106.89%</td>
</tr>
<tr>
<td>543</td>
<td>SR 15</td>
<td>SB</td>
<td>Clayton Delany Rd to SR 6</td>
<td>A</td>
<td>F</td>
<td>104.19%</td>
</tr>
<tr>
<td>559</td>
<td>SR 15</td>
<td>SB</td>
<td>SR 12 to Carpenter Bridge</td>
<td>A</td>
<td>F</td>
<td>102.03%</td>
</tr>
<tr>
<td>561</td>
<td>SR 15</td>
<td>SB</td>
<td>Carpenter Bridge to SR 14</td>
<td>A</td>
<td>F</td>
<td>101.27%</td>
</tr>
<tr>
<td>560</td>
<td>SR 15</td>
<td>NB</td>
<td>Carpenter Bridge to SR 12</td>
<td>A</td>
<td>F</td>
<td>99.06%</td>
</tr>
<tr>
<td>548</td>
<td>SR 15</td>
<td>NB</td>
<td>SR 42/15 Split to SR 300</td>
<td>A</td>
<td>F</td>
<td>94.76%</td>
</tr>
<tr>
<td>550</td>
<td>SR 15</td>
<td>NB</td>
<td>Kenton &amp; Denneys to SR 42/15 Split</td>
<td>A</td>
<td>F</td>
<td>91.92%</td>
</tr>
</tbody>
</table>
### A2: 10-Most Improved Segments AM/PM:

<table>
<thead>
<tr>
<th>ID</th>
<th>Route Number</th>
<th>Dir</th>
<th>Segment</th>
<th>2010 LOS</th>
<th>2011 LOS</th>
<th>% Diff – Posted vs. Travel Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>428</td>
<td>SR 72</td>
<td>NB</td>
<td>Main St to Kirkwood Hwy</td>
<td>B</td>
<td>A</td>
<td>-138.91%</td>
</tr>
<tr>
<td>59</td>
<td>I-495</td>
<td>NB</td>
<td>Exit 5 (US 13) to PA Line</td>
<td>D</td>
<td>A</td>
<td>-100.72%</td>
</tr>
<tr>
<td>57</td>
<td>I-495</td>
<td>NB</td>
<td>Exit 4 (Marsh Rd.) to Exit 5 (Rt. 13)</td>
<td>A</td>
<td>A</td>
<td>-89.12%</td>
</tr>
<tr>
<td>346</td>
<td>US 113</td>
<td>NB</td>
<td>Rd 18 (Bowers) to SR 9</td>
<td>A</td>
<td>A</td>
<td>-71.61%</td>
</tr>
<tr>
<td>197</td>
<td>US 13</td>
<td>NB</td>
<td>SR 896 to SR1/US13 Merge</td>
<td>B</td>
<td>A</td>
<td>-69.90%</td>
</tr>
<tr>
<td>345</td>
<td>US 113</td>
<td>SB</td>
<td>SR 9 to Rd 18 (Bowers)</td>
<td>A</td>
<td>A</td>
<td>-67.43%</td>
</tr>
<tr>
<td>136</td>
<td>SR 2</td>
<td>EB</td>
<td>SR 141 to SR 100</td>
<td>C</td>
<td>A</td>
<td>-58.69%</td>
</tr>
<tr>
<td>234</td>
<td>SR 896</td>
<td>SB</td>
<td>Chrysler to SR 4</td>
<td>B</td>
<td>A</td>
<td>-57.02%</td>
</tr>
<tr>
<td>116</td>
<td>SR 52</td>
<td>SB</td>
<td>SR 141 to Overpass</td>
<td>D</td>
<td>A</td>
<td>-57.01%</td>
</tr>
<tr>
<td>9</td>
<td>US 202</td>
<td>NB</td>
<td>I-95 to Foulke Rd</td>
<td>B</td>
<td>A</td>
<td>-55.93%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ID</th>
<th>Route Number</th>
<th>Dir</th>
<th>Segment</th>
<th>2010 LOS</th>
<th>2011 LOS</th>
<th>% Diff – Posted vs. Travel Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>US 202</td>
<td>SB</td>
<td>Foulke Rd. to I-95</td>
<td>A</td>
<td>A</td>
<td>-74.61%</td>
</tr>
<tr>
<td>9</td>
<td>US 202</td>
<td>NB</td>
<td>I-95 to Foulke Rd</td>
<td>A</td>
<td>A</td>
<td>-52.86%</td>
</tr>
<tr>
<td>349</td>
<td>US 113</td>
<td>SB</td>
<td>SR 12 to SR 1</td>
<td>C</td>
<td>A</td>
<td>-46.15%</td>
</tr>
<tr>
<td>565</td>
<td>SR 6</td>
<td>WB</td>
<td>SR 300 to SR 15</td>
<td>A</td>
<td>A</td>
<td>-38.31%</td>
</tr>
<tr>
<td>405</td>
<td>US 113</td>
<td>SB</td>
<td>SR 404/18 to US 9</td>
<td>D</td>
<td>B</td>
<td>-35.59%</td>
</tr>
<tr>
<td>310</td>
<td>SR 1</td>
<td>NB</td>
<td>Exit 97 to Exit 98</td>
<td>A</td>
<td>A</td>
<td>-32.45%</td>
</tr>
<tr>
<td>340</td>
<td>US 113</td>
<td>NB</td>
<td>SR 10 to US 13</td>
<td>B</td>
<td>A</td>
<td>-30.81%</td>
</tr>
<tr>
<td>528</td>
<td>State St</td>
<td>NB</td>
<td>SR 10 to US 13</td>
<td>D</td>
<td>B</td>
<td>-28.60%</td>
</tr>
<tr>
<td>339</td>
<td>US 113</td>
<td>SB</td>
<td>US 13 to SR 10</td>
<td>B</td>
<td>A</td>
<td>-26.06%</td>
</tr>
<tr>
<td>343</td>
<td>US 113</td>
<td>SB</td>
<td>Exit 93 to SR 9</td>
<td>A</td>
<td>A</td>
<td>-23.92%</td>
</tr>
</tbody>
</table>
### A3: 20-Worst Segments AM/PM:

<table>
<thead>
<tr>
<th>ID</th>
<th>Route Number</th>
<th>Dir</th>
<th>Segment</th>
<th>2011 LOS</th>
<th>%Diff - Posted Spd vs Travel Spd</th>
<th>Avg Travel Spd</th>
</tr>
</thead>
<tbody>
<tr>
<td>421</td>
<td>SR 2</td>
<td>EB</td>
<td>SR 72 to SR 273</td>
<td>F</td>
<td>89.06%</td>
<td>3.83</td>
</tr>
<tr>
<td>422</td>
<td>SR 2</td>
<td>WB</td>
<td>SR 273 to SR 72</td>
<td>F</td>
<td>86.81%</td>
<td>4.62</td>
</tr>
<tr>
<td>449</td>
<td>SR 41</td>
<td>SB</td>
<td>McKennans Church Rd to Hercules Rd</td>
<td>F</td>
<td>87.54%</td>
<td>5.61</td>
</tr>
<tr>
<td>138</td>
<td>SR 2</td>
<td>EB</td>
<td>SR 100 to Rt. 48</td>
<td>F</td>
<td>71.69%</td>
<td>7.11</td>
</tr>
<tr>
<td>447</td>
<td>SR 41</td>
<td>SB</td>
<td>SR 48 to McKennans Church Rd</td>
<td>F</td>
<td>83.82%</td>
<td>7.28</td>
</tr>
<tr>
<td>162</td>
<td>SR 273</td>
<td>EB</td>
<td>SR 58 to US 13</td>
<td>F</td>
<td>83.51%</td>
<td>7.42</td>
</tr>
<tr>
<td>453</td>
<td>SR 41</td>
<td>SB</td>
<td>SR 34 to SR 2</td>
<td>F</td>
<td>78.53%</td>
<td>7.52</td>
</tr>
<tr>
<td>281</td>
<td>Paper Mill</td>
<td>SB</td>
<td>Cleveland Ave. To DE Ave.</td>
<td>F</td>
<td>80.29%</td>
<td>7.84</td>
</tr>
<tr>
<td>252</td>
<td>48/41</td>
<td>WB</td>
<td>SR 2 to SR 100</td>
<td>F</td>
<td>78.83%</td>
<td>8.23</td>
</tr>
<tr>
<td>282</td>
<td>Paper Mill</td>
<td>NB</td>
<td>DE Ave. to Cleveland Ave.</td>
<td>F</td>
<td>74.10%</td>
<td>9.06</td>
</tr>
<tr>
<td>240</td>
<td>SR 896</td>
<td>SB</td>
<td>Deer Park to Del. Ave @ South Coll</td>
<td>E</td>
<td>62.11%</td>
<td>9.47</td>
</tr>
<tr>
<td>239</td>
<td>SR 896</td>
<td>NB</td>
<td>Del. Ave @ South Coll. To Deer Park</td>
<td>D</td>
<td>58.86%</td>
<td>10.29</td>
</tr>
<tr>
<td>8</td>
<td>US 202</td>
<td>SB</td>
<td>I-95 to Market St.</td>
<td>D</td>
<td>55.69%</td>
<td>11.08</td>
</tr>
<tr>
<td>524</td>
<td>State St</td>
<td>NB</td>
<td>Water St to SR 8</td>
<td>D</td>
<td>55.28%</td>
<td>11.18</td>
</tr>
<tr>
<td>255</td>
<td>48/41</td>
<td>EB</td>
<td>I-95 to Market St.</td>
<td>D</td>
<td>55.28%</td>
<td>11.18</td>
</tr>
<tr>
<td>207</td>
<td>US 40</td>
<td>WB</td>
<td>SR 1 to SR 7</td>
<td>F</td>
<td>76.39%</td>
<td>11.80</td>
</tr>
<tr>
<td>523</td>
<td>State St</td>
<td>SB</td>
<td>SR 8 to Water St</td>
<td>D</td>
<td>50.68%</td>
<td>12.33</td>
</tr>
<tr>
<td>97</td>
<td>SR 141</td>
<td>NB</td>
<td>SR 52 to Brandywine</td>
<td>E</td>
<td>64.12%</td>
<td>12.56</td>
</tr>
<tr>
<td>423</td>
<td>SR 2</td>
<td>EB</td>
<td>SR 273 to Marrows Rd</td>
<td>E</td>
<td>63.91%</td>
<td>12.63</td>
</tr>
<tr>
<td>122</td>
<td>SR 52</td>
<td>SB</td>
<td>I-95 to Market St.</td>
<td>D</td>
<td>49.23%</td>
<td>12.69</td>
</tr>
<tr>
<td>ID</td>
<td>Route Number</td>
<td>Dir</td>
<td>Segment</td>
<td>2011 LOS</td>
<td>%Diff - Posted Spd vs Travel Spd</td>
<td>Avg Travel Spd</td>
</tr>
<tr>
<td>----</td>
<td>--------------</td>
<td>-----</td>
<td>---------</td>
<td>---------</td>
<td>---------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>422</td>
<td>SR 2</td>
<td>WB</td>
<td>SR 273 to SR 72</td>
<td>F</td>
<td>94.67%</td>
<td>1.87</td>
</tr>
<tr>
<td>282</td>
<td>Paper Mill</td>
<td>NB</td>
<td>DE Ave. to Cleveland Ave.</td>
<td>F</td>
<td>92.58%</td>
<td>2.60</td>
</tr>
<tr>
<td>421</td>
<td>SR 2</td>
<td>EB</td>
<td>SR 72 to SR 273</td>
<td>F</td>
<td>90.11%</td>
<td>3.46</td>
</tr>
<tr>
<td>424</td>
<td>SR 2</td>
<td>WB</td>
<td>Marrows Rd to SR 273</td>
<td>F</td>
<td>88.11%</td>
<td>4.16</td>
</tr>
<tr>
<td>239</td>
<td>SR 896</td>
<td>NB</td>
<td>Del. Ave @ South Coll. To Deer Park</td>
<td>F</td>
<td>81.05%</td>
<td>4.74</td>
</tr>
<tr>
<td>281</td>
<td>Paper Mill</td>
<td>SB</td>
<td>Cleveland Ave. To DE Ave.</td>
<td>F</td>
<td>83.69%</td>
<td>6.49</td>
</tr>
<tr>
<td>237</td>
<td>SR 896</td>
<td>NB</td>
<td>Park Place to Del. Ave @ South Coll.</td>
<td>F</td>
<td>72.31%</td>
<td>6.92</td>
</tr>
<tr>
<td>151</td>
<td>SR 4</td>
<td>WB</td>
<td>1st State to SR7</td>
<td>F</td>
<td>81.97%</td>
<td>6.99</td>
</tr>
<tr>
<td>91</td>
<td>SR 7</td>
<td>NB</td>
<td>SR 4 (Stanton) to SR 4 (Newport)</td>
<td>F</td>
<td>84.37%</td>
<td>7.45</td>
</tr>
<tr>
<td>173</td>
<td>SR 273</td>
<td>WB</td>
<td>Library Ave. to Deer Pk.</td>
<td>E</td>
<td>69.77%</td>
<td>7.56</td>
</tr>
<tr>
<td>240</td>
<td>SR 896</td>
<td>SB</td>
<td>Deer Park to Del. Ave @ South Coll</td>
<td>E</td>
<td>63.54%</td>
<td>9.11</td>
</tr>
<tr>
<td>523</td>
<td>State St</td>
<td>SB</td>
<td>SR 8 to Water St</td>
<td>E</td>
<td>61.08%</td>
<td>9.73</td>
</tr>
<tr>
<td>126</td>
<td>SR 2</td>
<td>EB</td>
<td>SR 72 to PollyD. Hill</td>
<td>F</td>
<td>76.78%</td>
<td>10.33</td>
</tr>
<tr>
<td>8</td>
<td>US202</td>
<td>SB</td>
<td>I-95 to Market St.</td>
<td>D</td>
<td>57.89%</td>
<td>10.53</td>
</tr>
<tr>
<td>207</td>
<td>US 40</td>
<td>WB</td>
<td>SR 1 to SR 7</td>
<td>F</td>
<td>78.51%</td>
<td>10.75</td>
</tr>
<tr>
<td>519</td>
<td>State St</td>
<td>SB</td>
<td>US 13 Dover to Governors Blvd Split</td>
<td>E</td>
<td>68.83%</td>
<td>10.91</td>
</tr>
<tr>
<td>106</td>
<td>SR 141</td>
<td>SB</td>
<td>SR 4 to I-95</td>
<td>F</td>
<td>77.58%</td>
<td>11.21</td>
</tr>
<tr>
<td>284</td>
<td>SR 72</td>
<td>NB</td>
<td>SR 4 to Main St.</td>
<td>E</td>
<td>69.02%</td>
<td>11.85</td>
</tr>
<tr>
<td>254</td>
<td>48/41</td>
<td>WB</td>
<td>I-95 to SR 2</td>
<td>D</td>
<td>52.20%</td>
<td>11.95</td>
</tr>
<tr>
<td>268</td>
<td>SR 2</td>
<td>WB</td>
<td>SR 72 to Paper Mill</td>
<td>E</td>
<td>64.53%</td>
<td>12.41</td>
</tr>
</tbody>
</table>
Appendix B:

Fall 2011 Coverage:

The following GIS drawing displays all routes that have been covered in the Fall 2011 data collection.
Appendix C:

Mean Peak Travel Speed AM & PM:
The following GIS drawing displays the mean peak travel time in miles per hour in both directions for every segment of the Fall 2011 data collection. This is the average travel speed of the test vehicle across a particular segment.

Methodology:
The mean peak travel speed for every segment is calculated by averaging the total time required to travel the length of each segment of all runs (mean peak travel time), and dividing the segment length by that time.

Equations:

\[
MeanPeakTravelTime = \frac{\sum_{1}^{n} TotalTravelTimeofRun(x)}{n}
\]

\[
MeanPeakTravelSpeed = \frac{SegmentLength(Miles)}{MeanPeakTravelTime(Seconds)} \times \frac{3600(Seconds)}{1(hour)}
\]

C1: Fall 2011 Mean Peak Travel Speed Delaware AM
This GIS map displays the AM mean peak travel speed for the state of Delaware.

C2: Fall 2011 Mean Peak Travel Speed Delaware PM
This GIS map displays the PM mean peak travel speed for the state of Delaware.

C3: Fall 2011 Mean Peak Travel Speed New Castle AM
This GIS map displays the AM mean peak travel speed for New Castle County, DE.

C4: Fall 2011 Mean Peak Travel Speed New Castle PM
This GIS map displays the PM mean peak travel speed for New Castle County, DE.
**C₅: Fall 2011 Mean Peak Travel Speed Kent AM**
This GIS map displays the AM mean peak travel speed for Kent County, DE.

**C₆: Fall 2011 Mean Peak Travel Speed Kent PM**
This GIS map displays the PM mean peak travel speed for Kent County, DE.

**C₇: Fall 2011 Mean Peak Travel Speed Sussex AM**
This GIS map displays the AM mean peak travel speed for Sussex County, DE.

**C₈: Fall 2011 Mean Peak Travel Speed Sussex PM**
This GIS map displays the PM mean peak travel speed for Sussex County, DE.
C1: Fall 2011 Mean Peak Travel Speed Delaware AM

Travel Time & Delay Study – Fall 2011 – Delaware

Mean Travel Speed (mph) - AM

Legend
- 0-20
- 21-35
- 36-45
- 46-55
- >55
- Roadway Centrelines
- State Boundary

0 5 10 20 30 40 Miles
Travel Time & Delay Study – Fall 2011 – Delaware

Mean Travel Speed (mph) - PM

Legend
- 0-20
- 21-35
- 36-45
- 46-55
- >55

Roadway Centerline
State Boundary

Miles
0 5 10 20 30 40
C3: Fall 2011 Mean Peak Travel Speed New Castle AM

Travel Time & Delay Study – Fall 2011 – New Castle Co.

Mean Travel Speed (mph) - AM

Legend
- 0-20
- 21-35
- 36-45
- 46-55
- >55

Roadway Centerline
New Castle County Boundary

Miles
Travel Time & Delay Study – Fall 2011 – New Castle Co.

Mean Travel Speed (mph) - PM

Legend
- 0-20
- 21-35
- 36-45
- 46-55
- >55
- Roadway Centerline
- New Castle County Boundary
C6: Fall 2011 Mean Peak Travel Speed Kent PM

Travel Time & Delay Study – Fall 2011 – Kent Co.

Mean Travel Speed (mph) - PM

Legend
- 0-20
- 21-35
- 36-45
- 46-55
- >55

Roadway Centerline
Kent County Boundary

Miles
C7: Fall 2011 Mean Peak Travel Speed Sussex AM

Travel Time & Delay Study – Fall 2011 – Sussex Co.

Mean Travel Speed (mph) - AM

Legend
- 0-20
- 21-35
- 36-45
- 46-55
- >55
- Roadway Centerline
- Sussex County Boundary

Miles
0 2 4 8 12 16
C8: Fall 2011 Mean Peak Travel Speed Sussex PM

Travel Time & Delay Study – Fall 2011 – Sussex Co.

Mean Travel Speed (mph) - PM

Legend
- 0-20
- 21-35
- 36-45
- 46-55
- >55

Roadway Centerline
Sussex County Boundary

Miles
Appendix D:

Mean Peak Delay AM & PM:
The following GIS drawings display the average delay along each route segment in both directions for every segment of the Fall 2011 data collection. Mean peak delay is the average delay experienced by the test vehicle across a particular segment.

Methodology:
Average delay is calculated by adding together the delay measured in each run and dividing the total by the number of runs. The result is displayed in seconds of delay.

Equations:

\[
Average\text{Delay}\,(\text{seconds}) = \frac{\sum_{i=1}^{n} Delay(\text{Seconds})^{of\text{run}(x)}}{n}
\]

D₁: Fall 2011 Mean Peak Delay Delaware AM
This GIS map displays the AM mean peak delay for the state of Delaware.

D₂: Fall 2011 Mean Peak Delay Delaware PM
This GIS map displays the PM mean peak delay for the state of Delaware.

D₃: Fall 2011 Mean Peak Delay New Castle AM
This GIS map displays the AM mean peak delay for New Castle County, DE.

D₄: Fall 2011 Mean Peak Delay New Castle PM
This GIS map displays the PM mean peak delay for New Castle County, DE.

D₅: Fall 2011 Mean Peak Delay Kent AM
This GIS map displays the AM mean peak delay for Kent County, DE.

D₆: Fall 2011 Mean Peak Delay Kent PM
This GIS map displays the PM mean peak delay for Kent County, DE.
D7: Fall 2011 Mean Peak Delay Sussex AM
This GIS map displays the AM mean peak delay for Sussex County, DE.

D8: Fall 2011 Mean Peak Delay Sussex PM
This GIS map displays the PM mean peak delay for Sussex County, DE.
D2: Fall 2011 Mean Peak Delay Delaware PM
D3: Fall 2011 Mean Peak Delay New Castle AM

Travel Time & Delay Study – Fall 2011 – New Castle Co.

Mean Delay (sec) - AM

Legend
- 0 - 16
- 17 - 43
- 44 - 75
- 76 - 110
- 111 - 183
- Roadway Centerline
- New Castle County Boundary
D4: Fall 2011 Mean Peak Delay New Castle PM

Travel Time & Delay Study – Fall 2011 – New Castle Co.

Mean Delay (sec) - PM

Legend

- 0 - 19
- 20 - 49
- 50 - 80
- 81 - 131
- 132 - 335

Roadway Centerline

New Castle County Boundary

Miles

0 2 4 8 12 16
D5: Fall 2011 Mean Peak Delay Kent AM

Travel Time & Delay Study – Fall 2011 – Kent Co.

Mean Delay (sec) - AM

Legend
- 0 - 16
- 17 - 43
- 44 - 75
- 76 - 110
- 111 - 183
- Roadway Centerline
- Kent County Boundary

Miles
0 2 4 8 12 16
D6: Fall 2011 Mean Peak Delay Kent PM

Travel Time & Delay Study – Fall 2011 – Kent Co.

Mean Delay (sec) - PM

Legend
- 0 - 19
- 20 - 49
- 50 - 80
- 81 - 131
- 132 - 379
- Roadway Centerline
- Kent County Boundary

Miles
0  2  4  8  12  16
Travel Time & Delay Study – Fall 2011 – Sussex Co.

Mean Delay (sec) - AM

Legend
- 0 - 16
- 17 - 43
- 44 - 75
- 76 - 110
- 111 - 183
- Roadway Centerline
- Sussex County Boundary

Miles
Travel Time & Delay Study – Fall 2011 – Sussex Co.

Mean Delay (sec) - PM

Legend
- 0 - 19
- 20 - 49
- 50 - 80
- 81 - 131
- 132 - 379
- Roadway Centerline
- Sussex County Boundary

Miles
Appendix E:

Posted Speed vs. Average Speed Difference AM & PM:
The following GIS drawings display the percent difference between the posted speed and the average speed for every segment of the Fall 2011 data collection. This is the percentage difference between the posted speed of a segment and the average delay of the test vehicle across that segment.

Methodology:
The percent difference between the posted speed and the average speed is calculated by subtracting the average speed of all runs from the posted speed and dividing the difference by the posted speed. This is done for all segments.

Equations: (spd = speed)

\[
\text{AverageSpd} = \frac{\sum x \text{AverageSpd}_x}{n}
\]

\[
\text{Posted & AverageSpdDiff} \% = \left( \frac{\text{PostedSpd} - \text{AverageSpd}}{\text{PostedSpd}} \right) \times 100\%
\]

E1: Fall 2011 Percentage difference between average and posted speed Delaware AM
This GIS map displays the AM percentage difference between average and posted speed for the state of Delaware.

E2: Fall 2011 Percentage difference between average and posted speed Delaware PM
This GIS map displays the PM percentage difference between average and posted speed for the state of Delaware.
E3: Fall 2011 Percentage difference between average and posted speed New Castle AM
This GIS map displays the AM percentage difference between average and posted speed for New Castle County, DE.

E4: Fall 2011 Percentage difference between average and posted speed New Castle PM
This GIS map displays the PM percentage difference between average and posted speed for New Castle County, DE.

E5: Fall 2011 Percentage difference between average and posted speed Kent AM
This GIS map displays the AM percentage difference between average and posted speed for Kent County, DE.

E6: Fall 2011 Percentage difference between average and posted speed Kent PM
This GIS map displays the PM percentage difference between average and posted speed for Kent County, DE.

E7: Fall 2011 Percentage difference between average and posted speed Sussex AM
This GIS map displays the AM percentage difference between average and posted speed for Sussex County, DE.

E8: Fall 2011 Percentage difference between average and posted speed Sussex PM
This GIS map displays the PM percentage difference between average and posted speed for Sussex County, DE.
E1: Fall 2011 Percentage difference between average and posted speed
Delaware AM
E2: Fall 2011 Percentage difference between average and posted speed
Delaware PM
E3: Fall 2011 Percentage difference between average and posted speed New Castle AM
E4: Fall 2011 Percentage difference between average and posted speed New Castle PM
E5: Fall 2011 Percentage difference between average and posted speed Kent AM
$E_6$: Fall 2011 Percentage difference between average and posted speed Kent PM
E7: Fall 2011 Percentage difference between average and posted speed Sussex AM
E8: Fall 2011 Percentage difference between average and posted speed Sussex PM

Travel Time & Delay Study – Fall 2011 – Sussex Co.

Percent Difference Between Posted Speed and Mean Speed - PM

Legend

- < -25%
- -25% - -10%
- -10% - 0
- 0 - 10%
- 10% - 25%
- > 25%
Roadway Centerline
Sussex County Boundary

Miles
Appendix F:

Level of Service 2010 AM and PM:
The following GIS drawings display the computed level of service for each segment in both directions for all Fall 2010 data collection.

Methodology:
Using the percent difference between the posted speed and average speed, the level of service is computed. By first identifying segments that are interstates or interstate/freeways and roads that are arterials in 2010, the following tables are used to classify the appropriate level of service.

\[
\frac{(\text{Posted Speed} - \text{Average Speed})}{\text{Posted Speed}} \times 100\%
\]

<table>
<thead>
<tr>
<th>Interstate/Freeways (% time under speed limit)</th>
<th>Arterials: (% under speed limit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS A: 0-14%</td>
<td>LOS A: 0-10%</td>
</tr>
<tr>
<td>LOS B: 14-18%</td>
<td>LOS B: 10-30%</td>
</tr>
<tr>
<td>LOS C: 18-20%</td>
<td>LOS C: 30-45%</td>
</tr>
<tr>
<td>LOS D: 20-30%</td>
<td>LOS D: 45-60%</td>
</tr>
<tr>
<td>LOS E: 30-50%</td>
<td>LOS E: 60-70%</td>
</tr>
<tr>
<td>LOS F: 50% +</td>
<td>LOS F: 70% +</td>
</tr>
</tbody>
</table>

F1: Fall 2010 LOS Delaware AM
This GIS map displays the AM LOS for the state of Delaware.

F2: Fall 2010 LOS Delaware PM
This GIS map displays the PM LOS for the state of Delaware.
Travel Time and Delay Study- Fall 2010- Delaware

Level of Service- AM

Legend

- A
- B
- C
- D
- E
- F

Roadway Centerline
State Boundry

Miles
0 5 10 20 30 40
Appendix G:

Level of Service Fall 2011 AM and PM:
The following GIS drawings display the computed level of service for each segment in both directions for all Fall 2011 data collection.

Methodology:
Using the percent difference between the posted speed and average speed, the level of service is computed. By first identifying segments that are interstates or interstate/freeways and roads that are arterials in 2011, the following tables are used to classify the appropriate level of service.

\[
\frac{(\text{Posted Speed} - \text{Average Speed})}{\text{Posted Speed}} \times 100\%
\]

<table>
<thead>
<tr>
<th>Interstate/Freeways (% time under speed limit)</th>
<th>Arterials: (% under speed limit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS A: 0-14%</td>
<td>LOS A: 0-10%</td>
</tr>
<tr>
<td>LOS B: 14-18%</td>
<td>LOS B: 10-30%</td>
</tr>
<tr>
<td>LOS C: 18-20%</td>
<td>LOS C: 30-45%</td>
</tr>
<tr>
<td>LOS D: 20-30%</td>
<td>LOS D: 45-60%</td>
</tr>
<tr>
<td>LOS E: 30-50%</td>
<td>LOS E: 60-70%</td>
</tr>
<tr>
<td>LOS F: 50% +</td>
<td>LOS F: 70% +</td>
</tr>
</tbody>
</table>

G1: Fall 2011 LOS Delaware AM
This GIS map displays the AM LOS for the state of Delaware.

G2: Fall 2011 LOS Delaware PM
This GIS map displays the PM LOS for the state of Delaware.

G3: Fall 2011 LOS New Castle AM
This GIS map displays the AM LOS for New Castle County, DE.
**G4: Fall 2011 LOS New Castle PM**
This GIS map displays the PM LOS for New Castle County, DE.

**G5: Fall 2011 LOS Kent AM**
This GIS map displays the AM LOS for Kent County, DE.

**G6: Fall 2011 LOS Kent PM**
This GIS map displays the PM LOS for Kent County, DE.

**G7: Fall 2011 LOS Sussex AM**
This GIS map displays the AM LOS for Sussex County, DE.

**G8: Fall 2011 LOS Sussex PM**
This GIS map displays the PM LOS for Sussex County, DE.
G1: Fall 2011 LOS Delaware AM

Travel Time & Delay Study – Fall 2011 – Delaware

Level of Service - AM
Travel Time & Delay Study – Fall 2011 – Delaware

Level of Service - PM

Legend
- A
- B
- C
- D
- E
- F

Roadway Centerline
State Boundary

Miles
0 5 10 15 20 25 30 35 40
Travel Time & Delay Study – Fall 2011 – Kent Co.

Level of Service - AM

Legend

A
B
C
D
E
F
Roadway Centerline
Kent County Boundary

Miles
Travel Time & Delay Study – Fall 2011 – Kent Co.

Level of Service - PM

Legend
- A
- B
- C
- D
- E
- F
- Roadway Centerline
- Kent County Boundary

Miles
0 2 4 8 12 16
Travel Time & Delay Study – Fall 2011 – Sussex Co.

Level of Service - AM

Legend

- A
- B
- C
- D
- E
- F

Roadway Centerline
Sussex County Boundary

Miles
Travel Time & Delay Study – Fall 2011 – Sussex Co.

Level of Service - PM

Legend

- A
- B
- C
- D
- E
- F

Roadway Centerline
Sussex County Boundary
Appendix H:

Peak Travel Time Data – Fall 2011:

The following table is the averaged data for all segments analyzed during Fall 2011 data collection. The table includes the route number, route name, segment direction, segment distance, mean peak travel time, mean peak delay, total delay, peak delay source, mean peak running speed, percent time in delay, number of lanes, and the posted speeds.
Appendix I:

250 Critical Miles – Peak Travel Time Data – Fall 2011:

The following table is a selection of the data for the most important segments analyzed during Fall 2011 data collection, the 250-Critical Miles. The table includes the route number, route name, segment direction, segment distance, mean peak travel time, mean peak delay, total delay, peak delay source, mean peak running speed, percent time in delay, number of lanes, and the posted speeds.