

EVALUATING SPEED DIFFERENCES BETWEEN PASSENGER VEHICLES AND HEAVY TRUCKS FOR TRANSPORTATION-RELATED EMISSIONS MODELING

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EXECUTIVE SUMMARY

Heavy-duty trucks make up slightly more than 3% of the on-road vehicle fleet. In contrast, they account for more than 7% of vehicle miles traveled (VMT) on roadways in the United States. Even more significantly, they are estimated to contribute a significant proportion of regulated ambient emissions, which includes particulate matter (PM), carbon monoxide (CO), oxides of nitrogen (NO_x), and volatile organic compounds (VOC).

Heavy vehicles emit emissions at different rates than passenger vehicles. They may behave differently on the road as well, yet they are often treated similarly to passenger vehicles in emissions modeling. Although not frequently considered in calculating emission rates, differences in the operating speeds of passenger vehicles and heavy trucks may influence emissions. Emission rates from the MOBILE software model are correlated to average speed. Depending on the pollutant, emissions rates are generally higher at lower average speeds, less sensitive for mid-range speeds, and higher as speeds increase. Typically, average speeds are output for a roadway link or facility type from travel demand forecasting models and a single average speed is input to MOBILE to represent all vehicle types. However, since emission rates are correlated to average vehicle speed, systematic differences in operating speed between heavy vehicles and passenger vehicles have the potential to adversely affect emissions and the ability to estimate and reduce pollution levels.

The main goal of this research project was to evaluate whether heavy trucks typically travel at significantly different operating speeds than passenger vehicles and what impact differences in on-road speeds would have on emissions. Average speeds and spot speeds were collected for heavy trucks and passenger vehicles for four arterial segments and spot speeds were collected for two freeway segments in Des Moines, Iowa. Average and spot speeds were collected for four arterial segments and three freeway segments in the Minneapolis/St. Paul, Minnesota metropolitan area.

Average and spot speeds were compared for heavy trucks and passenger vehicles by facility. Average heavy-truck speeds were lower than passenger vehicle speeds for all arterial segments in Des Moines. Average speed differences ranged from 0.8 mph to 15.1 mph; although, not all differences were statistically significant at the 95% confidence level. Average speeds for passenger vehicles were higher than average speeds for heavy trucks for all segments in Minneapolis/St. Paul, with differences ranging from 5.9 mph to 11.4 mph. All differences were significant at the 5% level of significance.

Spot speeds for heavy trucks were also lower in all cases than for passenger vehicles. Passenger vehicle speeds were higher and statistically different from heavy-duty truck spot speeds at the 95% confidence level for all Des Moines locations except for the Interstate 35 site. Heavy-truck speeds were 0.8 mph to 6.1 mph lower than passenger vehicle speeds. Spot speeds for passenger vehicles were also higher than for heavy trucks

for all Minneapolis/St. Paul locations. Speed differences ranged from 0.2 mph to 3.9 mph; although, not all differences were statistically significant.

The impact that differences in on-road speeds would have on emissions was also evaluated using MOBILE version 6.2. Misspecification of average truck speed is the most significant at lower and higher speed ranges. For instance, if average speeds for heavy trucks were actually 10 mph lower than average passenger vehicle speeds, using the average speed for passenger vehicles at 26 mph to estimate heavy-duty truck emissions would result in emission rates that are 66%, 14%, and 47% lower for CO, NO_x, and VOC than the actual emission rates would be if trucks speeds were modeled separately at 16 mph.

1. INTRODUCTION

1.1 Background

Heavy-duty trucks make up slightly more than 3% of the on-road vehicle fleet. In contrast, they account for more than 7% of vehicle miles traveled (VMT) on roadways in the United States. Even more significantly, they are estimated to contribute a significant proportion of regulated ambient emissions, which includes particulate matter (PM), carbon monoxide (CO), oxides of nitrogen (NO_x), and volatile organic compounds (VOC). United States Environmental Protection Agency (USEPA 2000) estimates that highway vehicles contribute 32% of NO_x emissions, with heavy trucks producing up to 38% of that amount. Another source indicates that heavy trucks contribute as much NO_x as passenger vehicles (Sawyer et al. 2000). The total estimated highway vehicle contribution to VOCs is 30%, 9% of which comes from heavy trucks. They also contribute 13% of the carbon monoxide emissions attributed to highway vehicles. Nationally, heavy trucks are also responsible for 65% and 75% of the highway vehicle contribution to PM₁₀ and PM_{2.5} respectively (USEPA 2000).

Kirchstetter et al. (1999) reported on an emissions study in the Caldecott tunnel near San Francisco that compared heavy-duty diesel and light-duty vehicles in two tunnel bores. The heavy-duty truck volume in Bore 1 was approximately 4.2%. An estimated 56% of the trucks had three or more axles. The second tunnel had only 0.3% heavy-duty trucks. Emissions were monitored and the resulting information used to create estimates of the on-road contribution of heavy trucks. Study results indicated that heavy-duty diesel trucks emit 15 to 20 times the number of particles per unit mass of fuel burned than light-duty vehicles. Using the results and values for the number of heavy trucks on the road and diesel fraction of fuel sales, they estimated that in California, heavy duty diesel trucks emit 80% of PM_{2.5} and 45% of the on-road vehicle contribution to NO_x.

Heavy vehicles emit emissions at different rates than passenger vehicles. They may behave differently on the road as well, but they are often treated similarly to passenger vehicles in emissions modeling. The USEPA's emission factor model MOBILE requires use of default values or specification of local values for a number of vehicle activity variables. Agencies frequently collect variables to tailor MOBILE to reflect local conditions. However, variables such as average speed, soak time distribution, or trip length distribution are often collected for passenger vehicles and then broadly applied to all vehicle categories since it is difficult to obtain data that are more representative of individual vehicle classes.

The most recent version of MOBILE is 6.2, which estimates average, in-use fleet emission factors for VOC, CO, and NO_x. Emission rates are correlated to average speed (USEPA 2002). Typically, average speeds are output for a roadway link or facility type from travel demand forecasting models or measured in the field for project level analysis. A single average speed is typically specified to represent all vehicle activity for a facility without differentiating between vehicle types. Consequently, the methodology to estimate average speeds is the same for both heavy trucks and passenger vehicles due to a lack of more refined data to differentiate vehicle activity.

Differences in heavy trucks and passenger vehicle operation are usually considered in design of highway facilities and other aspects of transportation engineering, such as calculation of intersection clearance time. The effect of steep upgrades or downgrades on heavy-truck speeds is well documented. Truck speeds may be significantly below those of passenger vehicles depending on the magnitude and length of the upgrade. AASHTO (2001) reports that trucks typically increase their average speed by up to 5% on downgrades and decrease speed by 7% or more on upgrades as compared to their normal operation on level grade. Trucks also have lower acceleration rates and require increased time to reach cruising speeds than passenger vehicles. Acceleration capability is more significantly influenced by grade than for passenger vehicles (Fancher and Gillespie 1997).

Differences in average speeds between heavy trucks and passenger vehicles, however, are not documented. Vehicle speeds are a crucial input to MOBILE, and emission factors are significantly influenced by the specified average speed (Chatterjee et al. 1997). Consequently, systematic differences in operating speed between heavy trucks and passenger vehicles have the potential to adversely affect emissions and the ability to estimate and reduce pollution levels (Ross et al. 1998). If speed inputs are mis-specified, there may be severe underestimates or overestimates of emissions since vehicle speeds are a crucial input to MOBILE (Chatterjee et al. 1997).

1.2 Project Objectives

The main goal of the research was to evaluate whether heavy trucks and passenger vehicles operated differently on the road. Average vehicle speeds, in particular, are critical inputs to MOBILE, and significant differences in the way different categories of vehicles are modeled could have important consequences in evaluating project level and regional emissions. Specifically, the objectives of the research were the following:

- Conduct field studies to compare on-road speeds of heavy trucks and passenger vehicles on arterials and freeways
- Evaluate differences in on-road average and spot speeds
- Evaluate the impact that differences in operating speeds would have on emissions

2. DATA COLLECTION

Differences in the on-road operating speeds of passenger vehicles and heavy trucks were evaluated by collecting and analyzing average speed and spot speed data for different categories of vehicles in the metropolitan Des Moines, Iowa and Minneapolis/St. Paul, Minnesota areas. Des Moines represents a medium-sized urban area and Minneapolis/St. Paul represents a major metropolitan area.

The speed input variable used for MOBILE is average link speed. Average speeds were collected for all arterial sections along with spot speeds. Spot speeds were only collected on freeways, because the use of average speed studies on freeway segments was not feasible. Although spot speeds cannot be used directly in current mobile source emission models, comparing differences in spot speeds provides a measure of whether there are significant differences in the way heavy trucks operate on the road in comparison to passenger vehicles. Additionally, future modal emissions models, such as USEPA's forthcoming MOVES model, will require instantaneous vehicle activity information.

Average speeds were collected using the chase car method where data collectors follow a specific vehicle over a study section and record the time for the vehicle to traverse the entire section. In order to accomplish this, the chase vehicle enters the traffic stream far enough upstream of the data collection location to select a vehicle to follow. The chase vehicle then follows the test vehicle over the length of the study section and then exits the traffic stream, turns around, and starts the procedure over. This method works well on arterials and lower functional class roadways because of the multiple access points to turn around and wait for a test vehicle. Freeway sections have limited access, so chase vehicles need to enter and leave the freeway significantly up- or downstream of the study location. The time to complete a "loop" is significant and requires either the use of a large number of chase vehicles or a very long data collection period. The use of a large number of different drivers was not feasible, and collecting data over a long period of time results in sample runs collected under changing traffic conditions. Additionally, it was assumed that under non-congested freeway conditions, spot speeds approximate average speeds over short sections.

2.1 Site Selection

Arterial and freeway locations were selected to facilitate data collection and to provide a representative sample of facility conditions. Roadway sections with truck volumes at 3% or higher of reported average daily traffic (AADT) volumes were selected. Locations with a significant volume of trucks were necessary to ensure that a sufficient sample of heavy trucks could be collected. Truck AADT volumes were based on Iowa Department of Transportation (DOT) or Minnesota DOT AADT counts. Locations with tangent sections and a flat grade with no significant vertical curves were selected to facilitate the use of a radar gun.

Arterial study locations consisted of sections of roadways between two adjacent signalized intersections. Arterial locations were on four-lane divided highways. Sites

were selected so that chase vehicles could turn around upstream and downstream of the study locations. It was also necessary to have adequate position for a vehicle to park so that data collectors could position the radar gun. Freeway study locations were selected so that spot speeds could be collected from overpasses. The locations were also selected to avoid horizontal or vertical curvature. Study locations are shown in Figures 1 and 2 for the Des Moines Area and Figure 3 for the Minneapolis/St. Paul area. Photos showing each location are provided in Appendix A.

2.2 Data Collection

Data were typically collected in the off-peak period. The times data were collected along with information such as speed limit, AADT, direction, section length, etc. and are presented in Tables 1 and 2. Average speeds and spot speeds were both collected at all arterial sections except Highway 65 in Minneapolis/St. Paul. Only average speeds were collected for Highway 65 due to technical difficulties with the radar gun. Spot speed studies were collected midblock, and average speed studies were always collected in the direction of the spot speed study along arterials. In several cases, average speeds were collected in the opposite direction as well. Results were recorded and analyzed separately when average speed data were collected in both directions.

The methodology used to collect average and spot speeds is described in the sections 2.3 and 2.4. Volume and vehicle classification counts were collected concurrently with speed studies as described in section 2.5. All speed and volume data were collected in metropolitan Des Moines and metropolitan Minneapolis/St. Paul between October 2003 and June 2004. Data were collected at four principal arterials and two freeway segments in Des Moines and four arterials and three freeway locations in Minneapolis/St. Paul.

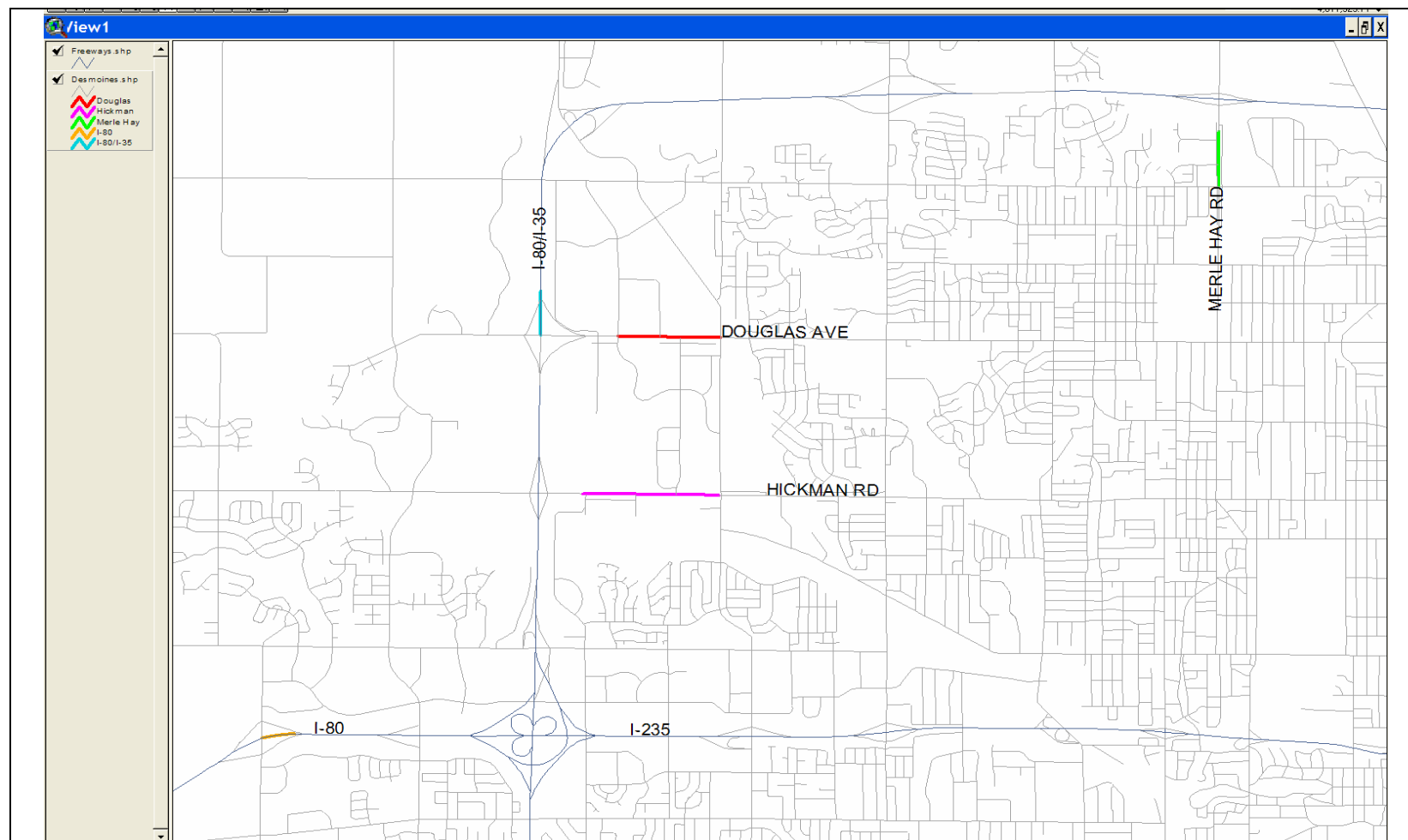


Figure 1. Data collection sites in Des Moines not including Highway 163

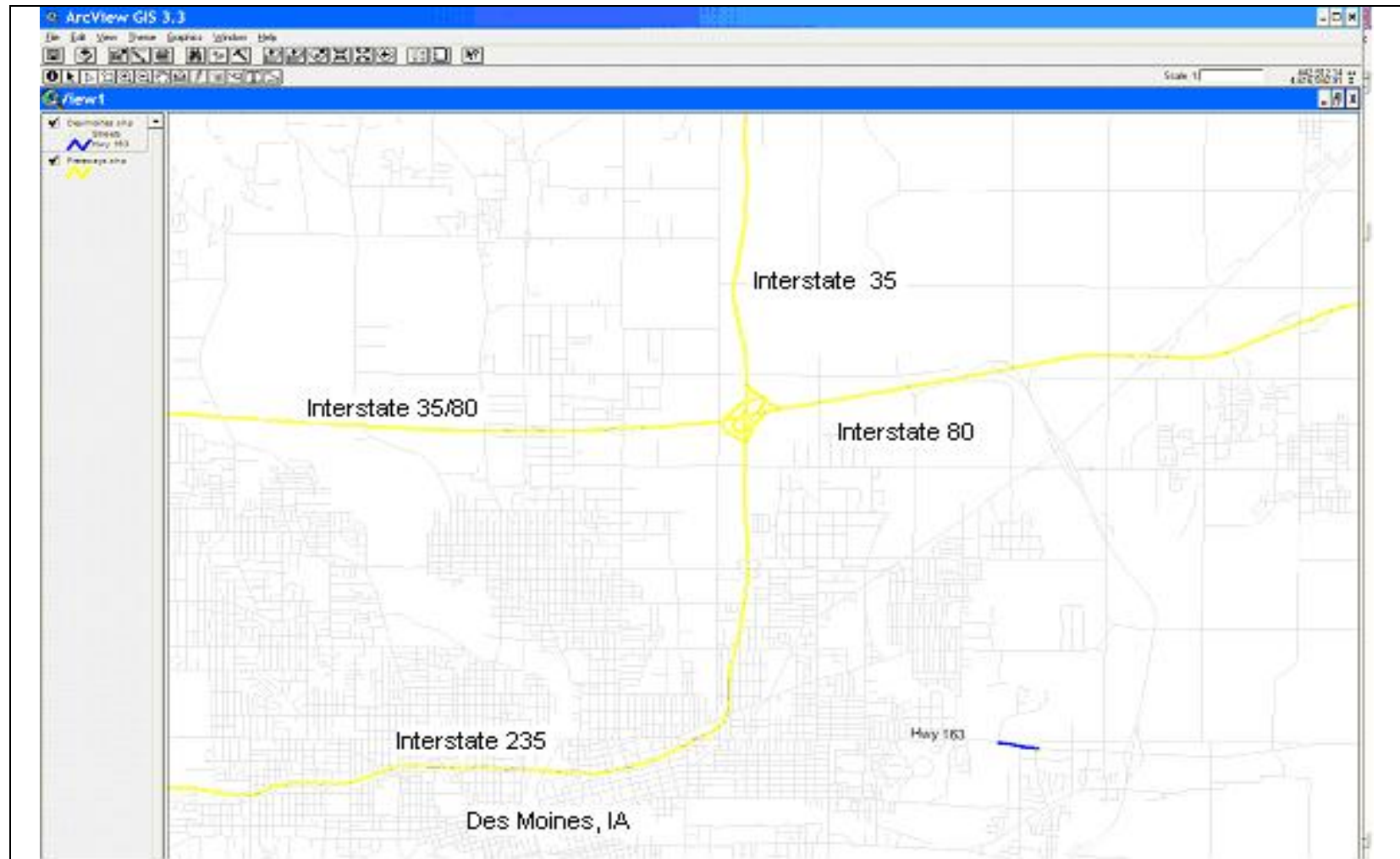


Figure 2. Data collection sites on Highway 163 in Des Moines

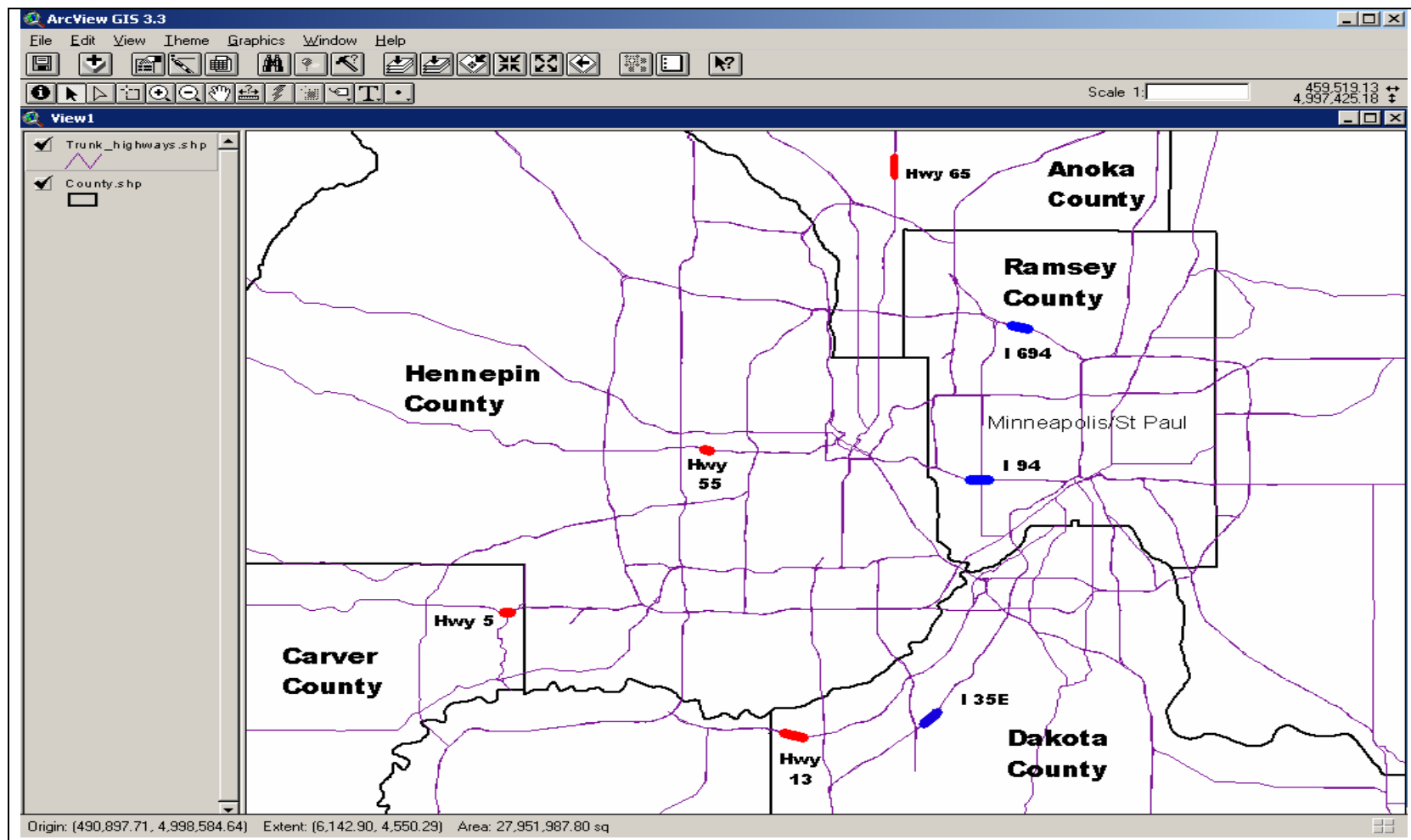


Figure 3. Data collection sites in Minneapolis/St. Paul

Table 1. Des Moines site specific information

<p>Hickman Road (US 6) from NW 114th St to NW 100th St <i>Date:</i> October 31, 2003 <i>Time:</i> 1:30 p.m. to 3:30 p.m. <i>Direction of spot speed study:</i> eastbound <i>Direction of average speed study:</i> eastbound <i>Functional class:</i> principal arterial (4-lane) <i>AADT:</i> 21,000 <i>Percent trucks:</i> 4% <i>Posted speed limit:</i> 50 mph <i>Section length:</i> 4,321 feet</p>	<p>Merle Hay Road (Highway 28) from Sutton Drive to Meredith Drive <i>Date:</i> November 7, 2003 <i>Time:</i> 1:30 p.m. to 3:30 p.m. <i>Direction of spot speed study:</i> southbound <i>Direction of average speed study:</i> southbound and northbound <i>Functional class:</i> principal arterial (4-lane) <i>AADT:</i> 28,200 <i>Percent trucks:</i> 4% <i>Posted speed limit:</i> 40 mph <i>Section length:</i> 1,595 feet</p>
<p>Interstate 80 at 74th Street <i>Date:</i> November 13, 2003 <i>Time:</i> 1:30 p.m. to 3:30 p.m. <i>Direction of spot speed study:</i> westbound <i>Functional class:</i> Interstate (4-lane) <i>AADT:</i> 51,700 <i>Percent trucks:</i> 16% <i>Posted speed limit:</i> 65 mph</p>	<p>Interstate 80/35 at Douglas Avenue <i>Date:</i> November 19, 2003 <i>Time:</i> 11:30 a.m. to 1:30 p.m. <i>Direction of spot speed study:</i> northbound/eastbound <i>Functional class:</i> Interstate (6-lane) <i>AADT:</i> 72,200 <i>Percent trucks:</i> 18% <i>Posted speed limit:</i> 65 mph</p>
<p>Douglas Avenue from 100th to 109th Street <i>Date:</i> January 8, 2004 <i>Time:</i> 9:30 a.m. to 11:30 a.m. <i>Direction of spot speed study:</i> eastbound <i>Direction of average speed study:</i> eastbound and westbound <i>Functional class:</i> principal arterial (4-lane) <i>AADT:</i> 15,900 <i>Percent trucks:</i> 3% <i>Posted speed limit:</i> 45 mph <i>Section length:</i> 3,280 feet</p>	<p>Highway 163 from Copper Creek Drive to Hickory Blvd <i>Date:</i> January 8, 2004 <i>Time:</i> 1:30 p.m. to 3:30 p.m. <i>Direction of spot speed study:</i> westbound <i>Direction of average speed study:</i> eastbound and westbound <i>Functional class:</i> principal arterial (4-lane) <i>AADT:</i> 20,500 <i>Percent trucks:</i> 5% <i>Posted speed limit:</i> 50 mph <i>Section length:</i> 2,118 feet</p>

Table 2. Minneapolis/St. Paul site specific information

<p>Highway 13 from Washburn Avenue to CR 5, Burnsville, Dakota County <i>Date:</i> June 2, 2004 <i>Time:</i> 9:30 a.m. to 12 p.m. <i>Direction of spot speed study:</i> eastbound <i>Direction of average speed study:</i> eastbound <i>Functional class:</i> principal arterial (4-lane) <i>AADT:</i> 47,000 <i>Percent trucks:</i> 7% <i>Posted speed limit:</i> 55 mph <i>Section length:</i> 3,643 feet</p>	<p>Highway 5 from Great Plains Blvd to Market Blvd (Hwy 101 S), Chanhassen, Carver County <i>Date:</i> June 2, 2004 <i>Time:</i> 1:30 p.m. to 3:30 p.m. <i>Direction of spot speed study:</i> westbound <i>Direction of average speed study:</i> westbound and eastbound (collected on sidewalk with observers able to watch vehicles progress from one intersection to the next) <i>Functional class:</i> principal arterial (4-lane) <i>AADT:</i> 45,000 <i>Percent trucks:</i> 3% <i>Posted speed limit:</i> 55 mph <i>Section length:</i> 1,312 feet</p>
<p>Highway 55 from Winnetka Ave (CR 156) to Rhode Island Ave, Golden Valley, Hennepin County <i>Date:</i> June 2, 2004 <i>Time:</i> 4 p.m. to 6 p.m. <i>Direction of spot speed study:</i> eastbound/westbound <i>Direction of average speed study:</i> westbound and eastbound (collected on pedestrian overpass with observers able to watch vehicles progress from one intersection to the next) <i>Functional class:</i> principal arterial (4-lane) <i>AADT:</i> 39,000 <i>Percent trucks:</i> 3% <i>Posted speed limit:</i> 55 mph <i>Section length:</i> 841 feet</p>	<p>Highway 65 from 105th Avenue to 109th Avenue, Blaine, Anoka County <i>Date:</i> June 3, 2004 <i>Time:</i> 10 a.m. to 12 p.m. <i>Direction of spot speed study:</i> none <i>Direction of average speed study:</i> southbound <i>Functional class:</i> principal arterial (4-lane) <i>AADT:</i> 49,000 <i>Percent trucks:</i> 3% <i>Posted speed limit:</i> 55 mph <i>Section length:</i> 2,640 feet</p>
<p>Interstate 694 at Exit 34B, Shoreview, Ramsey County <i>Date:</i> June 3, 2004 <i>Time:</i> 10:45 a.m. to 12:15 p.m. <i>Direction of spot speed study:</i> southbound/eastbound <i>Functional class:</i> Interstate (six-lanes) <i>AADT:</i> 96,000 <i>Percent trucks:</i> 6% <i>Posted speed limit:</i> 60 mph</p>	<p>Interstate 35E at Cliff Road (CR 32), Eagan, Dakota County <i>Date:</i> June 3, 2004 <i>Time:</i> 1:55 p.m. to 3:30 p.m. <i>Direction of spot speed study:</i> eastbound <i>Functional class:</i> Interstate (six-lane) <i>AADT:</i> 70,000 <i>Percent trucks:</i> 4% <i>Posted speed limit:</i> 70 mph</p>
<p>Interstate 94 at Snelling (TH 51)/Lexington, St. Paul, Ramsey County <i>Date:</i> June 8, 2004 <i>Time:</i> 3 p.m. to 5 p.m. <i>Direction of spot speed study:</i> westbound <i>Functional class:</i> Interstate (6-lanes) <i>AADT:</i> 157,000 <i>Percent trucks:</i> 4% <i>Posted speed limit:</i> 55 mph</p>	

2.3 Average Speed Study Methodology

The chase car method was used to collect average speeds along the arterial study links for all locations except for Highway 5 and Highway 55 in Minneapolis/St. Paul. Data were collected from signalized intersection to signalized intersection along the study link. Data were collected in both directions (southbound/northbound or eastbound/westbound) of travel when possible since drivers had to make a round trip to complete the loop. Each chase vehicle consisted of one driver and one timer using a stopwatch to record travel time along the link. Travel time was recorded from the time a queued vehicle began moving forward, once the signal turned green at the upstream intersection, until it came to a complete stop at the downstream intersection. If the sampled vehicle did not stop or queue at either the upstream or downstream intersection, travel time was recorded from the time it crossed the respective stopbar.

Travel time, therefore, included actual time to accelerate and decelerate, operational delay, and time to traverse the link, but did not include stopped-time delay. Ordinarily, stopped delay would be included in average speed studies. However, since average speeds were being compared across vehicle types and sample sizes were limited by practical constraints, it was not possible to collect a representative sample of both categories of vehicles stopping at different points during the red phase. If total intersection delay were included and one type of vehicle arbitrarily ended up spending more time in queue, average speed results would be significantly biased. Stopped delay was assumed to be similar for all vehicles types and it was determined that collection of intersection delay minus stopped delay would better meet study objectives. However, it can be included by estimating average stopped delay per vehicle and adding this value to individual vehicle travel times.

Chase car drivers were instructed to randomly select a vehicle approaching the upstream study intersection and follow that vehicle through the study section. They were instructed to select heavy trucks whenever they were present in the traffic stream. This resulted in oversampling of heavy trucks in proportion to their percentage in the traffic stream but was necessary to collect enough heavy-duty truck samples. Data collectors were instructed to discard samples when the sampled vehicle turned before the end of the test section or if an unusual incident had occurred that affected normal traffic operation, such as a vehicle stopped in the roadway.

The direct observation method was used at Highway 5 and Highway 55 in Minneapolis/St. Paul. In the direct observation method (ITE 2000), observers are positioned at an elevated vantage point and measure travel time directly between two points at a known distance from each other. Data collectors were located at an elevated location along a sidewalk adjacent to Highway 5 and on a pedestrian overpass on Highway 55. Data collectors were able to observe vehicles from the stopbar of the upstream intersection to the stopbar of the downstream intersection. Data collectors randomly selected passenger vehicles and selected heavy trucks when they appeared in the traffic stream. Travel time was collected in the same manner as for the chase car

method. This direct observation method resulted in a significantly larger sample size than the chase car method.

2.4 Spot Speed Study Methodology

Spot speeds were collected using Genesis-VP radar gun from Decatur Electronics. As described previously, spot speed data were collected midblock for arterial test segments and at overpasses with dedicated pedestrian facilities for freeways. An attempt was made to collect data for at least 100 vehicles to ensure that the samples were large enough to meet the assumptions of normality for the two sample t-test.

Spot speeds were collected in one direction during the study period (i.e., eastbound). Data were typically collected for a two-hour period in order to collect data for a minimum of 100 vehicles. Type of vehicle was noted as the following:

- PC: passenger cars, sport utility vehicles (SUV), and passenger vans (FHWA Classes 2 and 3)
- SU: 2-axle single unit trucks (FHWA Class 5)
- Semi: this category included heavy trucks larger than single unit (FHWA Classes 6 to 13)

Data for other vehicle types, such as buses or motorcycles, were not collected. FHWA vehicle classes are shown in Appendix B (USDOT 2001).

The radar gun operator randomly selected free-flowing passenger vehicles from the traffic stream. Heavy trucks were selected whenever they appeared in the traffic stream and were traveling under free-flow conditions. Consequently, heavy trucks were sampled at a higher rate in proportion to their ratio in the traffic stream than passenger vehicles.

2.5 Volume and Vehicle Classification Counts

Volume and classification counts were also collected during spot speed studies using Jamar Technologies DB-400 Intersection Counter. Volume data were collected in the direction of the spot speed study. For instance, if the spot speed study was for the eastbound approach, the volume count corresponded to the eastbound approach, accordingly. The vehicle classification count included two categories of vehicles. Passenger cars included cars, passenger vans, sport utility vehicles, pickup trucks, and motorcycles. Heavy trucks included all heavy-duty vehicles 2-axle 6-wheel and larger. Buses were included as heavy trucks.

3. ANALYSIS AND RESULTS

Initially, data were collected for two categories of heavy trucks: single unit and semi. However, data for both truck categories were eventually combined since neither category alone had sufficient vehicle samples to complete meaningful statistical comparisons. The heavy truck category included FHWA classes 5 to 13. The passenger vehicle category included FHWA classes 2 and 3. Motorcycles and buses were not included in the data collection. S-PLUS statistical software (version 6.2.1) was used for the statistical analyses.

3.1 Average Speed Studies

During data collection, the variable recorded was the time in seconds for each vehicle to traverse the study section as described in the data collection section. Average speed for each vehicle was calculated by the following formula:

$$v_{\text{avg}} = \frac{l_s}{t_{\text{veh}}} \quad (1)$$

where:

v_{avg} = average speed for the individual vehicle in miles per hour (mph)

l_s = length of study section in miles

t_{veh} = time for individual vehicle to traverse section
(converted from seconds to hours)

Average speeds for passenger vehicles were compared against heavy-duty trucks for each study location. Exploratory data analysis was used to determine whether data for each vehicle type and location were normally distributed. Normal probability quantile-quantile (QQ) and probability density curve plots were constructed using S-PLUS and evaluated. QQ normal and probability density curve plots for each dataset are presented in Appendix C.

A two-sided t-test was used to compare average passenger vehicle speeds against average heavy-truck speeds when both datasets did not significantly violate assumptions of normality. The Wilcoxon rank sum test was used to compare average speeds between the two vehicle types when one or both datasets were significantly non-normal. The Wilcoxon rank sum test is a non-parametric test similar to the t-test, but it does not require assumptions of normality.

Results for the Des Moines study locations are presented in Table 3. As shown, average heavy-truck speeds were lower than passenger vehicle speeds for all locations. Average speed differences ranged from 0.8 mph to 15.1 mph. Although mean passenger vehicle speeds were higher than heavy-duty truck spot speeds in all cases, not all differences were statistically significant at the 95% confidence level. For the southbound approach

on Merle Hay Road, the difference in average speeds was only 0.8 mph and was not statistically significant at the 5% level of confidence. Although data were collected during off-peak hours, the southbound approach still experienced significant queuing at the downstream intersection. It is expected that, under these conditions, less variation in average vehicle speeds would occur. The difference in average speeds for the eastbound section of Highway 163 was 4.5 mph, and the difference for the westbound direction was 2.0 mph. However, t-test results indicate that the differences were not statistically significant. In these two cases, the inability to determine statistically significant differences may have been due to small samples sizes.

Results for the Minneapolis/St. Paul study locations are shown in Table 4. Average speeds for passenger vehicles were higher than average speeds for heavy trucks for all locations and all directions. All differences were significant at the 5% level of significance. Speed differences ranged from 5.7 mph to 11.4 mph.

Table 3. Results for Des Moines average speed study

Location	Min Speed (mph)	Mean Speed (mph)	Max Speed (mph)	Std	Number of Samples	Speed Difference (mph)	t-test Results	Wilcoxon Results
Douglas (EB) PC	20.0	37.3	43.9	7.4	24	15.1	t = 3.50	
Douglas (EB) HDT	19.1	22.2	37.8	4.8	13		p = 0.00	
Douglas (WB) PC	19.8	34.6	54.2	10.5	33	6.6		z = 2.26
Douglas (WB) HDT	15.9	28.0	45.4	10.2	16			p = 0.02
Hickman (EB) PC	50.5	58.5	72.8	5.4	17	14.8	t = 2.87*	
Hickman (EB) HDT	24.5	43.7	58.7	14.0	8		p = 0.02*	
Highway 163 (EB) PC	34.6	42.2	60.5	6.6	11	4.5	t = 1.41	
Highway 163 (EB) HDT	14.1	37.7	49.3	8.9	15		p = 0.17	
Highway 163 (WB) PC	31.3	43.7	54.7	6.9	9	2.0	t = 0.60	
Highway 163 (WB) PC	29.3	41.7	54.6	8.4	18		p = 0.55	
Merle Hay (NB) PC	20.1	29.8	37.4	4.2	8	4.5	t = 3.52	
Merle Hay (NB) HDT	20.6	25.3	29.8	3.1	26		p = 0.00	
Merle Hay (SB) PC	27.5	31.3	40.7	3.4	19	0.8		z = 0.13
Merle Hay (SB) HDT	24.0	30.5	32.5	3.0	8			p = 0.89

Notes: PC includes passenger cars, sport utility vehicles, and passenger vans.

HDT includes vehicles 2A6 and larger.

*Welch's t-test (approximate t-test) used when variances were not equal.

Table 4. Results for Minneapolis/St. Paul average speed study

	Min Speed (mph)	Mean Speed (mph)	Max Speed (mph)	Std	Number of Samples	Speed Difference (mph)	t-test results	Wilcoxon Results
Highway 13 (EB) PC	21.4	38.3	60.8	12.8	16	9.9		z = 2.68
Highway 13 (EB) HDT	15.3	28.4	53.3	11.8	37			p = 0.01
Highway 5 (EB) PC	19.6	38.5	53.6	8.8	30	5.7	t = 2.34	
Highway 5 (EB) HDT	18.1	32.8	53.0	9.6	28		p = 0.02	
Highway 5 (WB) PC	16.9	43.0	61.6	9.2	35	9.2	t = 3.62	
Highway 5 (WB) HDT	22.5	33.8	51.1	9.1	20		p = 0.0	
Highway 55 (EB) PC	18.7	45.3	68.3	11.7	44	11.2	t = 4.83*	
Highway 55 (EB) HDT	19.9	34.1	55.4	8.5	32		p = 0.0*	
Highway 55 (WB) PC	28.0	37.8	58.9	7.2	32	5.9	t = 2.42*	
Highway 55 (WB) HDT	16.6	31.9	52.6	10.8	27		p = 0.02*	
Highway 65 (SB) PC	17.2	34.8	50.6	7.2	13	11.4		z = 2.51
Highway 65 (SB) HDT	14.3	23.4	35.9	9.5	10			p = 0.01

Notes: PC includes passenger cars, sport utility vehicles, and passenger vans.

HDT includes vehicles 2A6 and larger.

* Welch's t-test (approximate t-test) used when variances were not equal.

3.2 Spot Speed Studies

Spot speed data were collected using a radar gun which reports spot speed in mph. Exploratory data analysis was used to determine whether data for each vehicle type for each location were normally distributed. Normal probability quantile-quantile (QQ) and probability density curve plots were constructed using S-PLUS tools and evaluated. QQ normal and probability density curve plots for each dataset are presented in Appendix C. In all cases, datasets were normal or nearly normal. Thus, spot speeds for passenger vehicles were compared against heavy-duty trucks for each site and each direction using a two-sided t-test.

Results for the Des Moines data are provided in Table 5. As shown, mean passenger vehicle speeds were higher and statistically different from heavy-duty truck spot speeds at the 95% confidence level except for the Interstate 35 site. At this location, the mean speeds were statistically different at the 10% confidence level. Depending on the location, heavy-truck speeds were 0.8 mph to 6.1 mph lower than passenger vehicle speeds. Mean heavy-duty truck and passenger vehicle speeds were closer on the two freeway segments than on the arterial study sites (0.8 mph for the I-35 site and 1.2 mph for the I-80 location); although, heavy-truck speeds were still lower.

Results for the Minneapolis/St. Paul data are shown in Table 6. Spot speeds for passenger vehicles were higher for all locations than for heavy trucks. Speed differences ranged from 0.2 mph to 3.9 mph depending on the location. Differences in spot speeds were only statistically significant at the 5% level of significance for the Interstate 35E and Interstate 94 locations. Differences were statistically significant at the 10% level of significance for Interstate 35E, Interstate 94, and Highway 5. Average speeds for passenger vehicles were higher for Interstate 694, Highway 13, and Highway 55 (eastbound and westbound) but were not statistically different at the 10% level of significance.

Table 5. Results for Des Moines spot speed study

Location	Min Speed (mph)	Mean Speed (mph)	Max Speed (mph)	Std	Number of Samples	Speed Difference (mph)	t-test results
Douglas (EB) PC	32.0	44.0	56.0	4.8	167	6.1	t = 5.57
Douglas (EB) HDT	24.0	37.9	45.0	5.4	22		p = 0.00
Hickman (EB) PC	24.0	45.9	61.0	5.2	142	2.4	t = 3.09
Hickman (EB) HDT	34.0	43.5	55.0	4.8	60		p = 0.00
Highway 163 (WB) PC	34.0	47.8	63.0	4.8	160	1.9	t = 2.05
Highway 163 (WB) HDT	36.0	45.9	55.0	4.4	29		p = 0.04
I-80 (WB) PC	46.0	67.9	82.0	4.5	233	1.2	t = 2.43
I-80 (WB) HDT	57.0	66.7	77.0	3.6	104		p = 0.02
I-35 (NB) PC	61.0	69.5	97.0	4.5	249	0.8	t = 1.82
I-35 (NB) HDT	53.0	68.7	75.0	3.7	131		p = 0.07
Merle Hay (SB) PC	29.0	38.5	48.0	4.4	104	5.1	t = 5.63
Merle Hay (SB) HDT	24.0	33.4	42.0	4.2	30		p = 0.00

Notes: PC includes passenger cars, sport utility vehicles, and passenger vans.
HDT includes vehicles 2A6 and larger.

Table 6. Results for the Minneapolis/St. Paul spot speed studies

Location	Min Speed (mph)	Mean Speed (mph)	Max Speed (mph)	Std	Number of Samples	Speed Difference (mph)	t-test results
Interstate 694 (SB/EB) PC	54.0	63.1	72.0	3.7	163	0.6	t = 1.02
Interstate 694 (SB/EB) HDT	55.0	62.5	69.0	3.5	58		p = 0.31
Interstate 35E (EB) PC	60.0	70.0	87.0	4.3	167	2.5	t = 3.91
Interstate 35E (EB) HDT	60.0	67.5	76.0	3.4	60		p = 0.00
Interstate 94 (WB) PC	50.0	61.4	72.0	3.8	71	3.9	t = 4.93
Interstate 94 (WB) PC	50.0	57.5	70.0	4.4	42		p = 0.00
Highway 5 (WB) PC	34.0	47.6	62.0	6.4	81	2.9	t = 1.88
Highway 5 (WB) HDT	30.0	44.7	52.0	5.3	20		p = 0.06
Highway 13(EB) PC	44.0	53.5	65.0	4.0	133	0.8	t = 0.84
Highway 13 (EB) HDT	41.0	52.7	62.0	5.7	25		p = 0.40
Highway 55 (WB) PC	31.0	41.3	56.0	6.9	40	0.2	t = 0.06
Highway 55 (WB) HDT	19.0	41.1	53.0	5.7	15		p = 0.95
Highway 55 (EB) PC	28.0	45.5	61.0	8.0	60	2.7	t = 1.01
Highway 55 (EB) HDT	35.0	42.8	55.0	7.1	10		p = 0.32

Notes: PC includes passenger cars, sport utility vehicles, and passenger vans.

HDT includes vehicles 2A6 and larger.

3.3 Volume and Vehicle Classification

Volume and percentage of heavy trucks from the DB-400 Intersection Counter were downloaded, and vehicles per lane per hour (veh/ln/hr) and percentage of heavy trucks were calculated. Results are summarized in Table 7 for the Des Moines locations. Volume varied from 166 veh/ln/hr at Douglas Avenue to 639 veh/ln/hr at Merle Hay Road. Heavy-duty truck volumes varied from 3% to 26% during the study period.

Volume and vehicle classification data for Minneapolis/St. Paul are shown Table 8. Volume varied from 536 veh/ln/hr at I-35E to 1,469 veh/lan/hr at I-694. Heavy-duty truck volumes varied from 3% to 21% of the total volume during the study period.

Table 7. Traffic volumes and vehicle classification for Des Moines

Location	Total Volume	Data Collection Period (hrs)	Number of Lanes	veh/ln/hr	Heavy Trucks (%)
Douglas (EB)	718	2.17	2	166	3%
Hickman (EB)	2,238	2.17	2	516	5%
Highway 163 (WB)	914	1.92	2	238	6%
Merle Hay (SB)	2,873	2.25	2	639	3%
I-80 (WB)	1,749	1.92	2	456	26%
I-35 (NB)	3,832	2.08	3	615	19%

Table 8. Traffic volumes and vehicle classification for Minneapolis/St. Paul

Location	Total Volume	Data Collection Period (hrs)	Number of Lanes	veh/ln/hr	Heavy Trucks (%)
Highway 13 (EB)	2,911	2.50	2	583	21%
Highway 5 (WB)	1,891	1.16	2	815	5%
Highway 55 (EB)	2,897	1.25	2	1,159	3%
I-694 (SB/EB)	4,405	1.50	2	1,469	14%
I-35E (EB)	2,057	1.28	3	536	6%

4. EMISSIONS ANALYSIS

The impact of differences in heavy-duty truck versus passenger vehicle average speeds on emissions was modeled using MOBILE6.2. The USEPA recently released emission rate model MOBILE6.2 estimates average in-use fleet emission factors VOC, CO, and NO_x. Twenty-eight individual vehicle types can be modeled, including gas, diesel, and natural gas fueled passenger vehicles, heavy trucks, buses, and motorcycles for calendar years 1952 to 2050. The vehicle classes included in MOBILE6 are shown in Appendix D.

Emissions can be modeled at different average speeds from 2.5 mph to 65 mph on arterials. However, the user-specified average speed applies to all vehicle types. Modeling speeds differently for individual vehicle classes requires that the model is run for each desired speed value and output is specified by vehicle type. If emissions are reported at a specific average speed, output can be set to report for individual vehicle classes, and then the information can be extracted for the desired speed and vehicle type. Emission rates can also be allocated by four roadway categories: (1) freeways, (2) arterials (includes both arterials and collectors), (3) local roads, and (4) freeway on- and off-ramps (USEPA 2003).

4.1 Sensitivity Analysis

A sensitivity analysis was performed using a series of MOBILE6.2 model runs to demonstrate differences in emissions that would result from differences in average speeds between heavy-duty trucks and passenger vehicles. A minimum ambient temperature of 50° F and a maximum temperature of 70° F were used with a scenario date of January 2004, and only arterial roadways were considered. The data output from MOBILE6.2 was expanded to include emission rates by vehicle type. The average speed for the first MOBILE run was specified at 2.5 mph, the second at 3 mph, and then the average speed of subsequent runs was increased at 1 mph increment up to 65 mph. All other model parameters were MOBILE6.2 defaults. Emission rates were calculated for a passenger vehicle category and a heavy-duty truck category. The passenger vehicle category included LDGV, LDGT1, LDGT2, LDGT3, LDGT4, LDDV, and LDDT12. The heavy-duty truck category included all HDDV classes and all HDGV classes. Emission rates were weighted by class according to the fraction of VMT that they are assigned in MOBILE6.2 defaults.

The results of the speed-sensitivity analysis are provided in Figures 4, 5, and 6 for VOC, NO_x, and CO. As shown in Figure 4, CO emission rates are lower for the heavy-duty truck category than for the passenger vehicles, except in the lowest speed ranges. CO emissions are highest at low speeds, lowest at mid-range speeds, and then increase slightly with increasing speed. The lowest emissions for passenger vehicles occur between 20 mph and 40 mph. For heavy trucks, CO emissions are lowest at approximately 35 mph to 55 mph. NO_x emissions are significantly higher for heavy-duty trucks than for passenger vehicles, as shown in Figure 5. As shown, NO_x emission rates for passenger vehicles are slightly higher at lower speeds but remain fairly constant from

approximately 15 mph to 65 mph. Heavy-duty truck emissions follow a pronounced U-shaped curve with significantly higher emissions at the lower and higher speed ranges and lower emissions at mid-speed ranges. VOC emissions are shown in Figure 6. As illustrated, VOC emissions are significantly higher at lower speed ranges for passenger vehicles until approximately 15 mph. Emission rates then gradually decrease as speed increases. VOC emission rates follow a similar trend for heavy-duty trucks, with less pronounced increases at lower speed ranges. VOC emissions for trucks are lower than for passenger vehicles at all speed ranges.

Study results indicated that heavy-duty truck average speeds are lower than passenger vehicle average speeds. The consequences of modeling heavy-duty trucks using the same average speeds as passenger vehicles are the most significant in the lower and higher speed ranges. If passenger vehicle speeds were specified as 26 mph, emission rates for heavy-duty trucks at that speed would be 7.76 g/m for CO, 8.95 g/m for NO_x, and 0.99 g/m for VOC. If average speeds for heavy trucks were actually 10 mph lower, emission rates at 16 mph for heavy trucks would be 12.9 g/m for CO, 10.22 g/m for NO_x, and 1.46 g/m for VOC resulting in differences of 66%, 14%, and 47% respectively. If heavy trucks traveled 5 mph slower than passenger vehicles, emission rates at 21 mph would be 9.76 g/m for CO, 9.42 g/m for NO_x, and 1.18 g/m for VOC. Truck emission would be underestimated by 26%, 5%, and 19% respectively. If passenger vehicle average speeds were specified as 65 mph, emission rates for heavy trucks at that speed would be 7.78 g/m for CO, 15.76 g/m for NO_x, and 1.13 g/m for VOC. If heavy truck average speeds were 5 mph lower than passenger vehicles, emission rates at 60 mph would be 6.5 g/m for CO, 13.23 g/m for NO_x, and 1.15 g/m for VOC. Emissions would be overestimated for heavy trucks by 16% for both CO and NO_x and underestimated by 2% for VOC. The actual impact would depend on the percentage of trucks for a specific facility.

4.2 Comparison of Emission Differences for Several Test Locations

Emissions differences were compared for several of the study locations in Des Moines. Differences were evaluated for both eastbound and westbound directions of the Douglas location and both eastbound and westbound directions of the Highway 163 location. Signal timings were collected for the downstream intersection of each section, and stopped delay per vehicle was calculated using Highway Capacity Software 2000 for each section. The average speed per vehicle from field studies was recalculated with stopped delay per vehicle included in the total travel time. Mean passenger vehicle and heavy truck speed were also recalculated. MOBILE6.2 runs were made using the average vehicle speed and emission rates calculated for the passenger vehicle and heavy truck vehicle categories, as described in the previous paragraph. Emission rates for heavy trucks were calculated first assuming that heavy trucks travel at the same average speed as passenger vehicles, and then emission rates were calculated for the actual heavy truck average speed. Results are presented in Table 9. As shown, emission rates are estimated assuming that heavy trucks travel at the same average speed as passenger vehicles, underestimating emission rates by 3% to 40% for VOC and 3% to 55% for CO. Emission rates for NO_x were underestimated by 4% and 12% for the Douglas location and overestimated by 1% to 2% at the Highway 163 location.

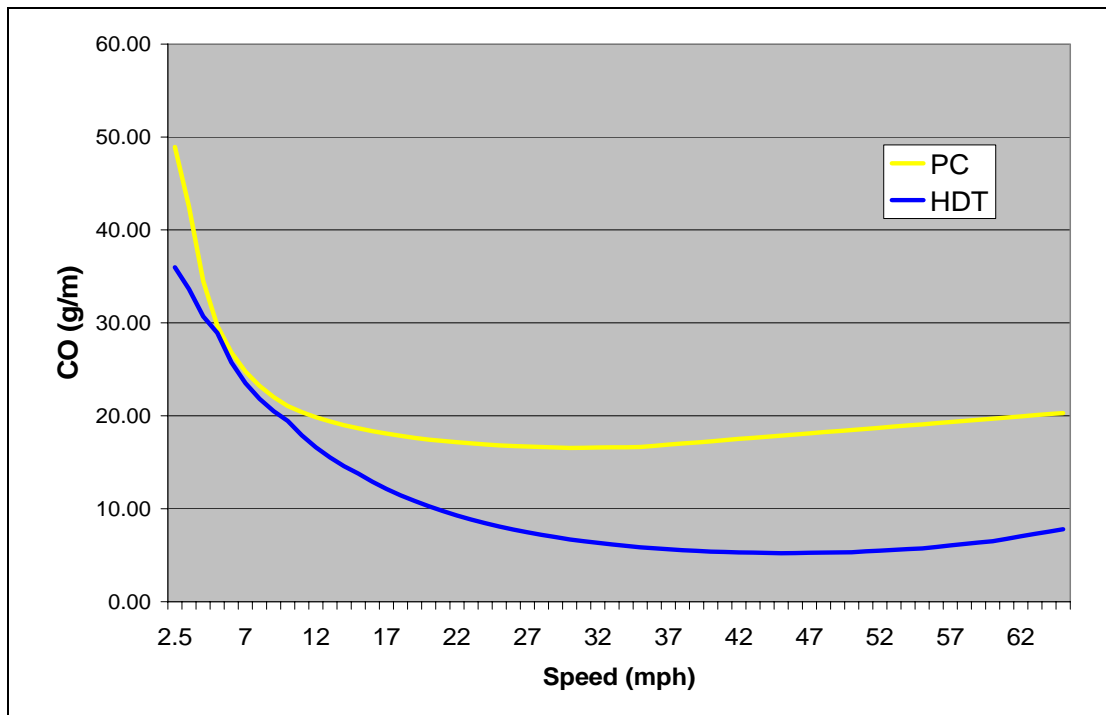


Figure 4. Carbon monoxide emission rates by vehicle category

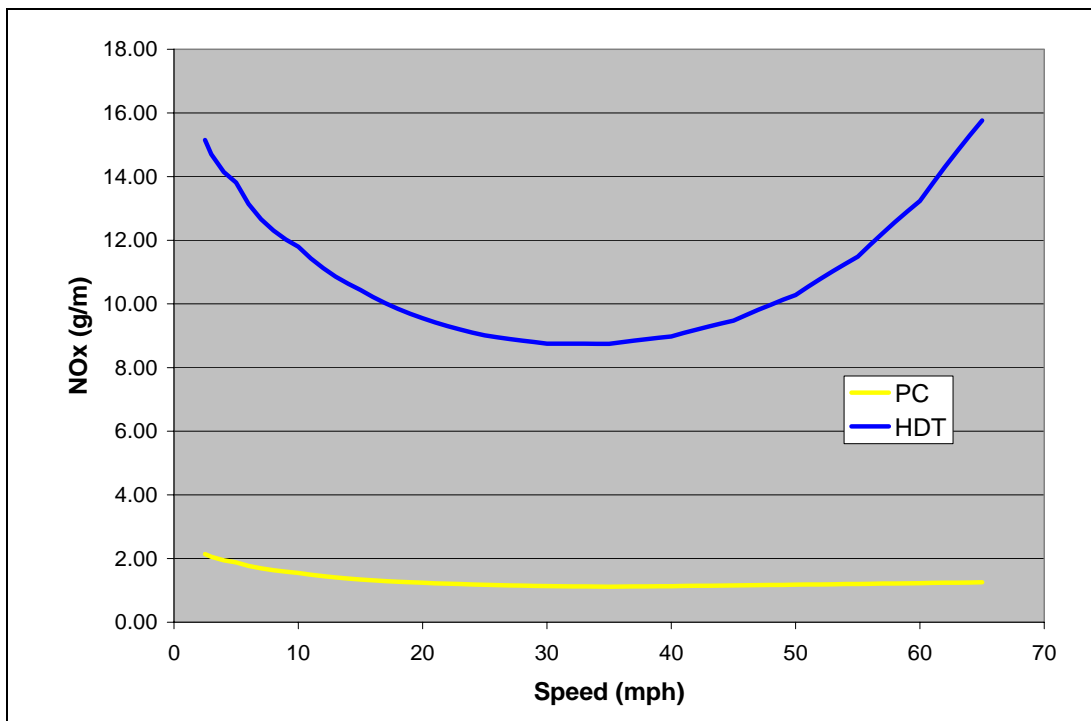


Figure 5. Oxides of nitrogen emission rates by vehicle category

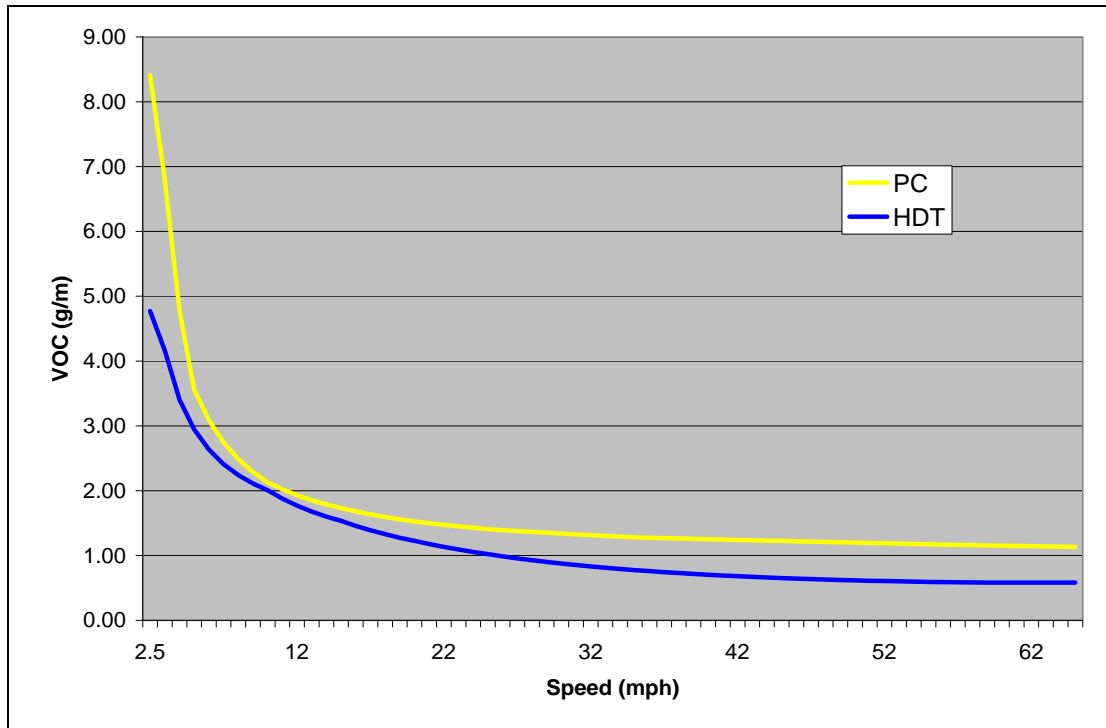


Figure 6. Volatile organic compounds emission rates by vehicle category

Table 9. Comparison of emission rates using heavy-duty trucks average speeds versus assuming average speed of passenger vehicles

Location	Adjusted Average Speed (mph)		Heavy Duty Truck CO Emission Rate (g/m)			Heavy Duty Truck NO _x Emission Rate (g/m)			Heavy Duty Truck VOC Emission Rate (g/m)		
	PC	HDT	Assuming Avg Speed of PC	Heavy Truck Avg Speed	Change	Assuming Avg Speed of PC	Heavy Truck Avg Speed	Change	Assuming Avg Speed of PC	Heavy Truck Avg Speed	Change
Douglas EB	26.2	17.3	7.67	11.92	55.3%	8.93	9.97	11.6%	0.98	1.37	40.1%
Douglas WB	28.1	23.5	7.17	8.65	20.6%	8.84	9.15	3.5%	0.93	1.07	16%
Hwy 163 EB	38.0	34.2	5.55	5.97	7.5%	8.89	8.75	-1.6%	0.73	0.79	8.3%
Hwy 163 WB	38.5	36.9	5.50	5.65	2.7%	8.91	8.84	-0.8%	0.72	0.75	3.1%

5. SUMMARY AND CONCLUSIONS

Heavy vehicles emit emissions at different rates than passenger vehicles. They may behave differently on the road as well, yet they are often treated similarly to passenger vehicles in emissions modeling. Although not frequently considered in calculating emission rates, differences in the operating speeds of passenger vehicles and heavy trucks may influence emissions. Emission rates from MOBILE are correlated to average speed. Typically, average speeds are output for a roadway link or facility type from travel demand forecasting models and a single average speed is input to MOBILE to represent all vehicle types. However, since emission rates are correlated to average vehicle speed, systematic differences in operating speed between heavy vehicles and passenger vehicles have the potential to adversely affect emissions and the ability to estimate and reduce pollution levels.

This research project evaluated whether heavy trucks travel at significantly different operating speeds than passenger vehicles and what impact differences in on-road speeds would have on emissions. Average speeds and spot speeds were collected for heavy trucks and passenger vehicles for four arterial segments, and spot speeds were collected for two freeway segments in Des Moines, Iowa. Average and spot speeds were collected for four arterial segments and three freeway segments in the Minneapolis/St. Paul, Minnesota metropolitan area. Only one category was used to represent heavy trucks since the number of average speed samples that could be collected at a particular location was limited. It is expected that some differences would occur between different categories of heavy trucks.

Average time was collected in the form of travel time and included actual time to accelerate, decelerate, operational delay, and time to traverse the link, but it did not include stopped-time delay. Ordinarily, stopped delay would be included in average speed studies. However, since average speeds were being compared across vehicle types and sample sizes were limited by practical constraints, it was not possible to collect a representative sample of both categories of vehicles queued for different amounts of time during the red phase. It was assumed that stopped delay would be similar for all vehicle types and that collection of intersection delay minus stopped delay would better meet study objectives. Stopped delay can be included by estimating average stopped delay per vehicle and adding this value to all travel times.

Average and spot speeds were compared for heavy trucks and passenger vehicles by facility. Average heavy-duty truck speeds were lower than passenger vehicle speeds for all arterial segments in Des Moines. Average speed differences ranged from 0.8 mph to 15.1 mph; although, not all differences were at the 95% confidence level. Average speeds for passenger vehicles were higher than average speeds for heavy trucks for all segments in Minneapolis/St. Paul, with differences ranging from 5.9 mph to 11.4 mph. All differences were significant at the 5% level of significance.

Spot speeds for heavy trucks were also lower than for passenger vehicles in all cases. Passenger vehicle speeds were higher and statistically different from heavy-duty truck

spot speeds at the 95% confidence level for all Des Moines locations except for the I-35 site. Heavy-truck speeds were 0.8 mph to 6.1 mph lower than passenger vehicle speeds. Spot speeds for passenger vehicles were also higher than for heavy trucks for all Minneapolis/St. Paul locations. Speed differences ranged from 0.2 mph to 3.9 mph; although, not all differences were statistically significant.

The impact that differences in on-road speeds would have on emissions was also evaluated using MOBILE6.2. Misspecification of average truck speed is the most significant at lower and higher speed ranges. For instance, if average speeds for heavy trucks were actually 10 mph lower than average passenger vehicle speeds, using the average speed for passenger vehicles at 26 mph to estimate heavy-truck emissions would result in emission rates that are 66%, 14%, and 47% lower for CO, NO_x, and VOC than the actual emission rates would be if trucks speeds were modeled separately at 16 mph.

Significant differences in heavy-truck speeds were found at a number of the locations studied. Most data were collected during off-peak conditions, but higher volumes and congestion occurred at three locations. Significant congestion and/or significant idling time at intersections would tend to minimize differences in average speeds between the two vehicle classes. However, emission differences are more pronounced in the lower speeds for all pollutants.

Whether heavy-truck and passenger vehicle average speeds should be modeled separately and whether data should be collected to determine speed differences depends on the individual situation. However, the conclusion of this research is that heavy trucks and passenger vehicles operate differently on the road. Differences could have consequences for project level and regional emissions modeling particularly since the ability to demonstrate conformity is based on the ability to correctly estimate and model vehicle activity.

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APPENDIX A: PHOTOS OF DATA COLLECTION LOCATIONS



Highway 5 in Chanhassen, MN (looking east)



Highway 55 in Golden Valley, MN (looking west)



Highway 13 in Burnsville, MN (looking east)



Interstate 80 East/35 North in Urbandale, IA (looking north)



Interstate 80 in West Des Moines, IA (looking east)



Hickman Rd (US 6) in Urbandale, IA (looking east)



Merle Hay Road (IA 28) in Urbandale, IA (looking south)



Interstate 35E in Eagan, MN (looking west)




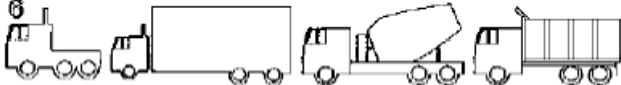
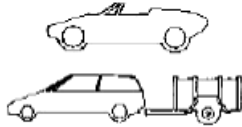

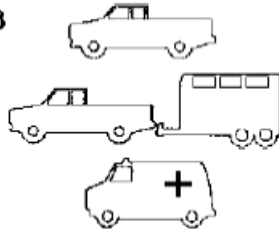

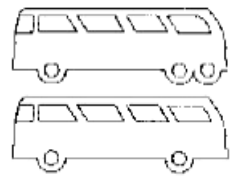


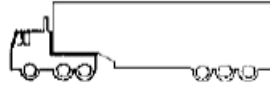

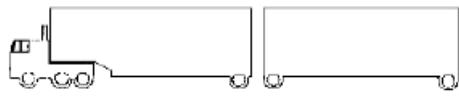
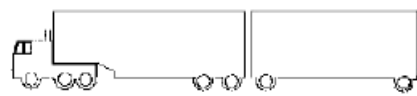
Douglas Avenue in Urbandale, IA (looking east)



Highway 163 in Pleasant Hill, IA (looking east)

APPENDIX B: FHWA VEHICLE CLASSIFICATION SCHEME (USDOT 2001)

The FHWA Classification scheme is divided into categories based on whether the vehicle carries passengers or commodities. Commodity carriers (Non-passenger vehicles) are further subdivided by number of axles and number of units, including both power and trailer units. Note that the addition of a light trailer to a vehicle does not change the classification of the vehicle. A pictorial representation of the classification scheme is given below:

1  MOTORCYCLES	6  THREE AXLE, SINGLE UNIT
2  PASSENGER CARS	7  FOUR OR MORE AXLE, SINGLE UNIT
3  FOUR TIRE, SINGLE UNIT	8  FOUR OR LESS AXLE, SINGLE TRAILER
4  BUSES	9  FIVE-AXLE, SINGLE TRAILER
5  TWO AXLE, SIX TIRE SINGLE UNIT	10  SIX OR MORE AXLE, SINGLE TRAILER
	11  FIVE OR LESS AXLE, MULTI-TRAILER
	12  SIX AXLE, MULTI-TRAILER
	13  SEVEN OR MORE AXLE, MULTI-TRAILER

Vehicle Class Definitions

- Class 1- **Motorcycles:** All two- or three-wheeled motorized vehicles. Typical vehicles in this category have saddle type seats and are steered by handle bars rather than wheels. This category includes motorcycles, motor scooters, mopeds, motor-powered bicycles, and three-wheeled motorcycles.
- Class 2- **Passenger Cars:** All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers and including those passenger cars pulling recreational or other light trailers.
- Class 3- **Other Two-Axle, Four-Tire, Single-Unit Vehicles:** All two-axle, four-tire, vehicles other than passenger cars. Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single unit vehicles pulling recreational or other light trailers are included in this classification.
- Class 4- **Buses:** All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger-carrying vehicles. Modified buses should be considered to be trucks and be appropriately classified.
- Note:** In reporting information on trucks, the following criteria should be used:
- a. Truck tractor units traveling without a trailer will be considered single unit trucks.
 - b. A truck tractor unit pulling other such units in a “saddle mount” configuration will be considered as one single unit truck and will be defined only by axles on the pulling unit.
 - c. Vehicles shall be defined by the number of axles in contact with the roadway. Therefore, “floating” axles are counted only when in the down position.
 - d. The term “trailer” includes both semi- and full trailers.
- Class 5- **Two-Axle, Six-Tire, Single-Unit Trucks:** All vehicles on a single frame, including trucks, camping and recreational vehicles, motor homes, etc., having two axles and dual rear wheels.

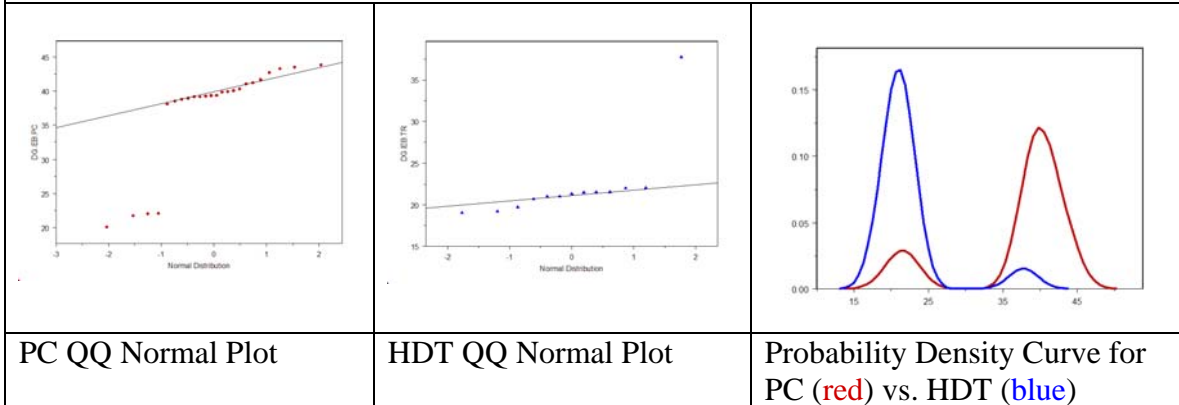
- Class 6- **Three-axle Single-Unit Trucks:** All vehicles on a single frame, including trucks, camping and recreational vehicles, motor homes, etc., having three axles.
- Class 7- **Four or More Axle Single-Unit Trucks:** All trucks on a single frame with four or more axles.
- Class 8- **Four or Less Axle Single-Trailer Trucks:** All vehicles with four or less axles consisting of two units, one of which is a tractor or straight truck power unit.
- Class 9- **Five-Axle Single-Trailer Trucks:** All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.
- Class 10- **Six or More Axle Single-Trailer Trucks:** All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.
- Class 11- **Five or Less Axle Multi-Trailer Trucks:** All vehicles with five or less axles consisting of three or more units, one of which is a tractor or straight truck power unit.
- Class 12- **Six-Axle Multi-Trailer Trucks:** All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.
- Class 13- **Seven or More Axle Multi-Trailer Trucks:** All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

APPENDIX C: DATA ANALYSIS PLOTS FOR AVERAGE SPEED

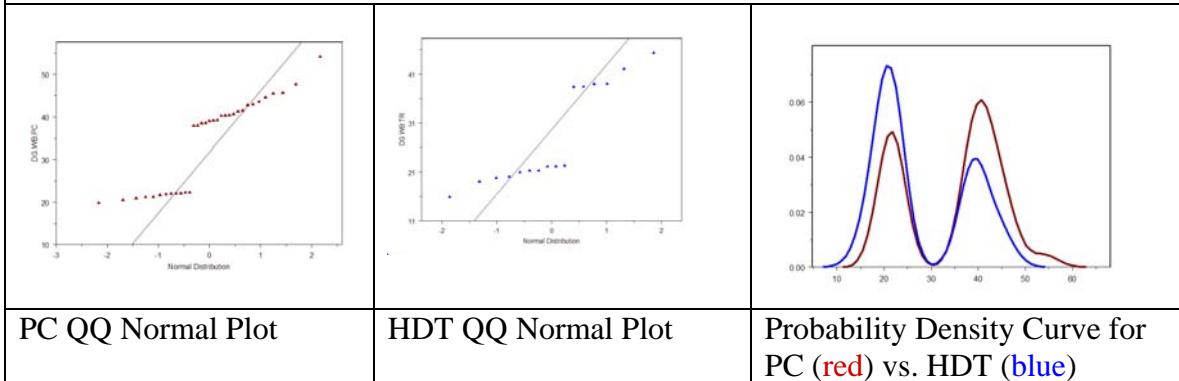
Des Moines

Douglas

Eastbound

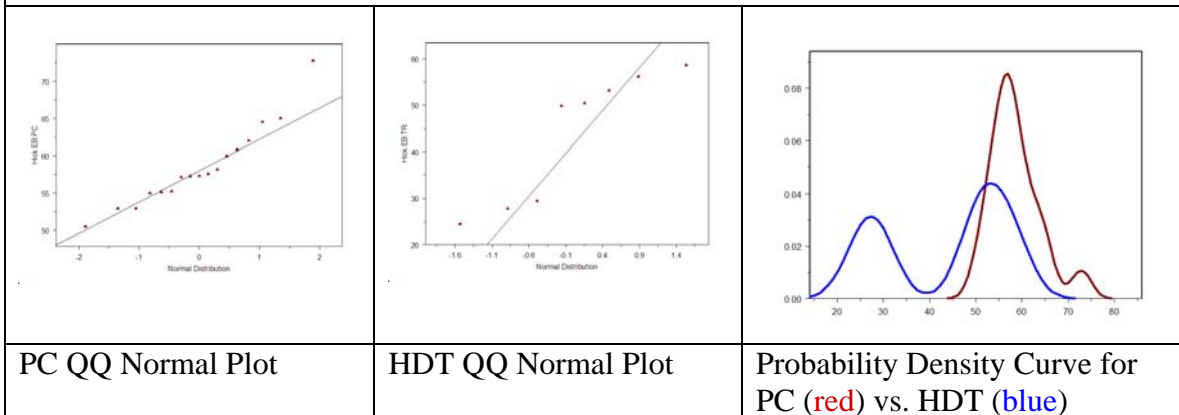


Westbound



Hickman

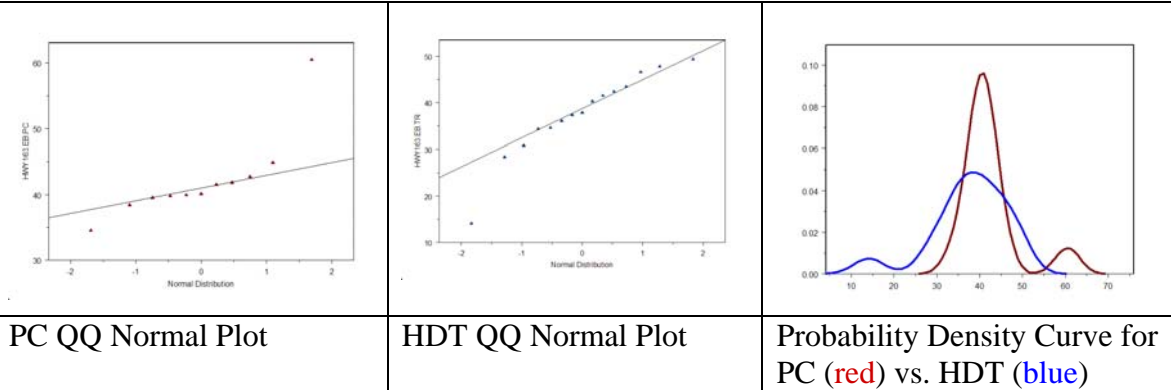
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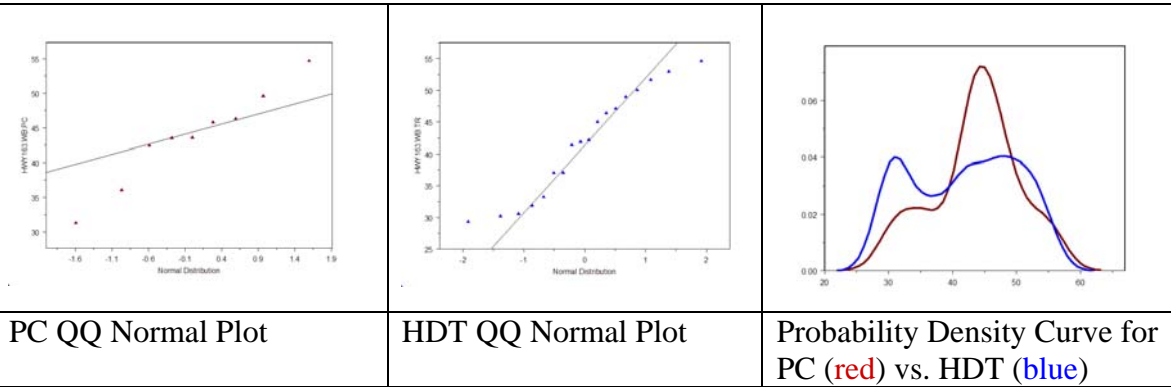
Des Moines

Highway 163

Eastbound



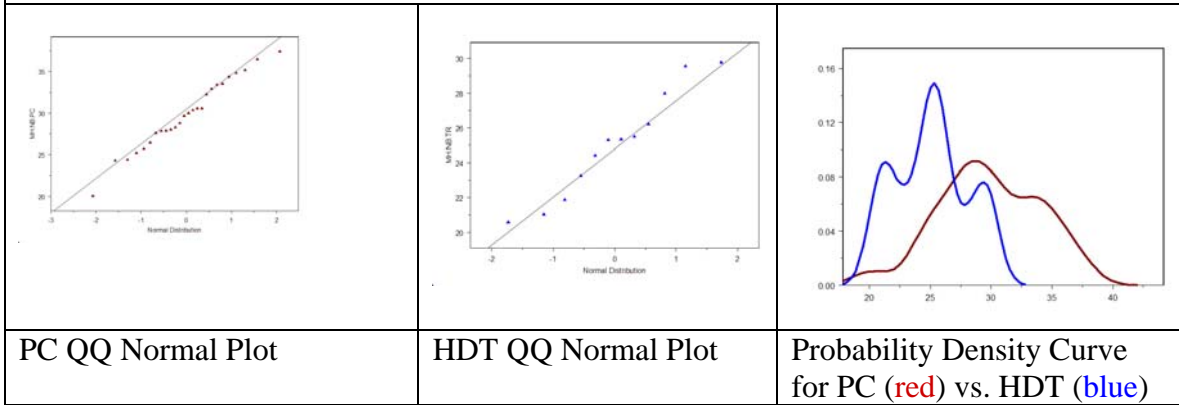
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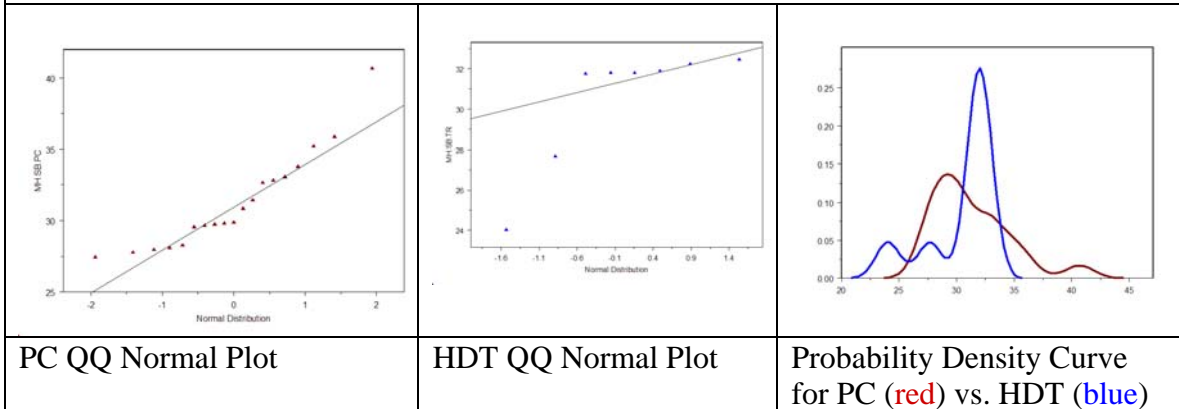
Des Moines

Merle Hay

Northbound



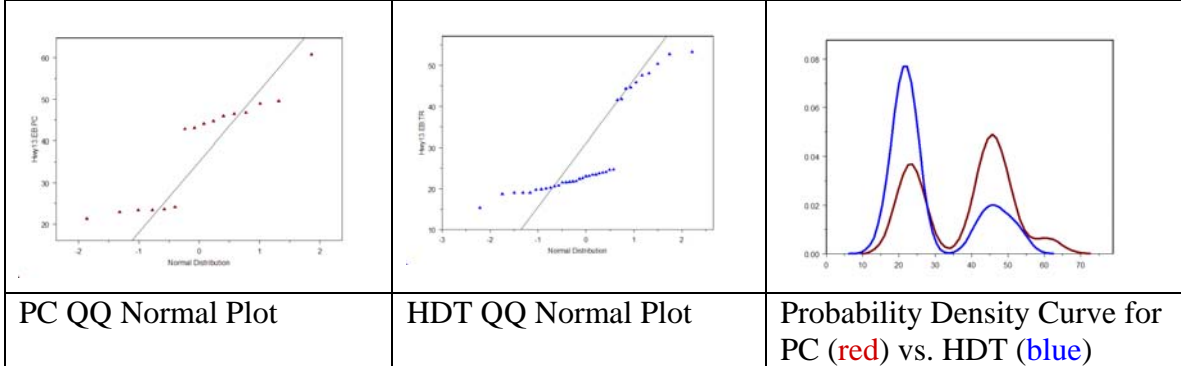
Southbound



Minneapolis/St. Paul

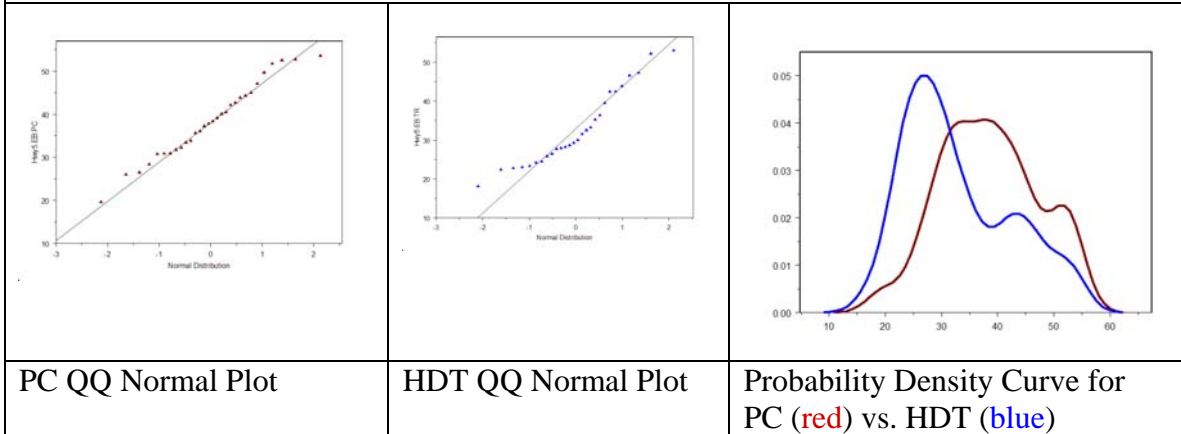
Highway 13

Eastbound

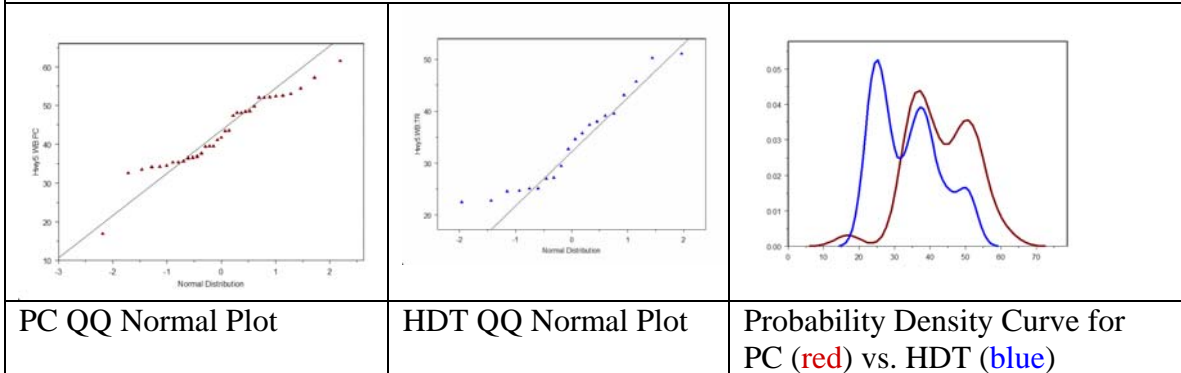


Highway 5

Eastbound



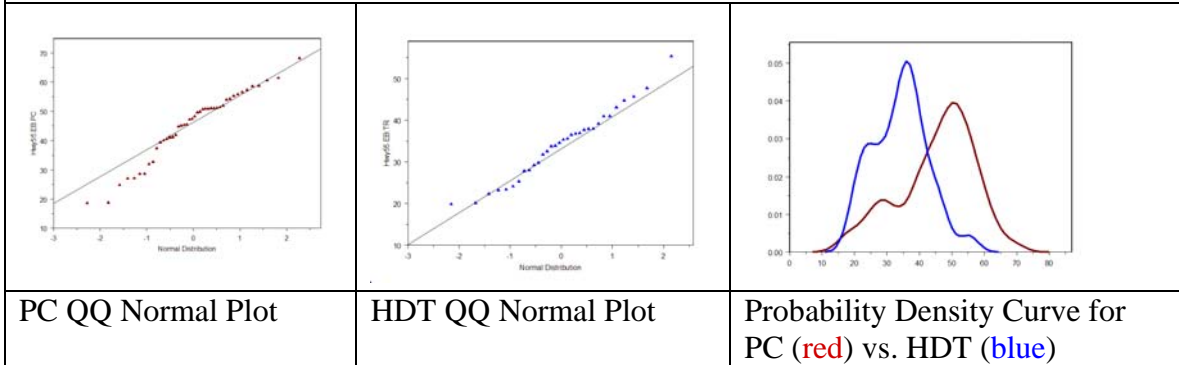
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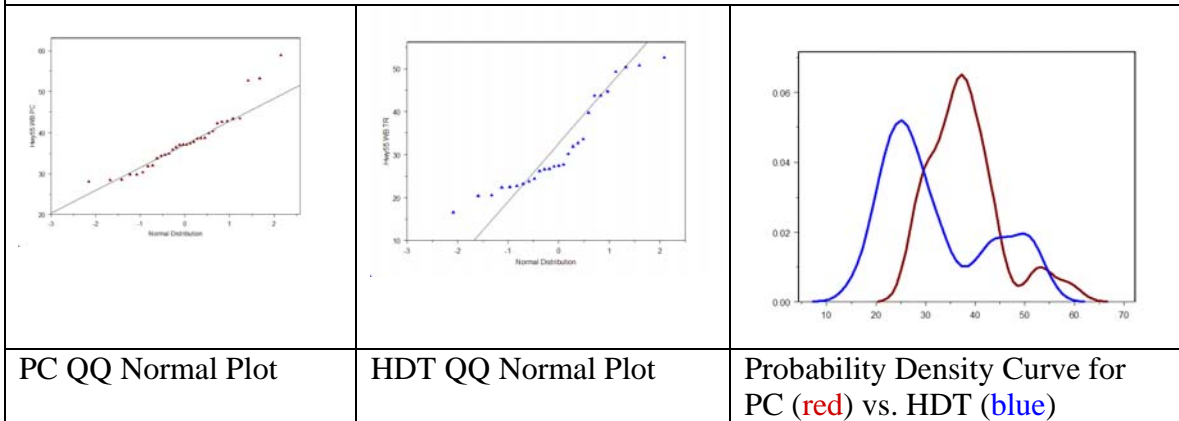
Minneapolis/St. Paul

Highway 55

Eastbound

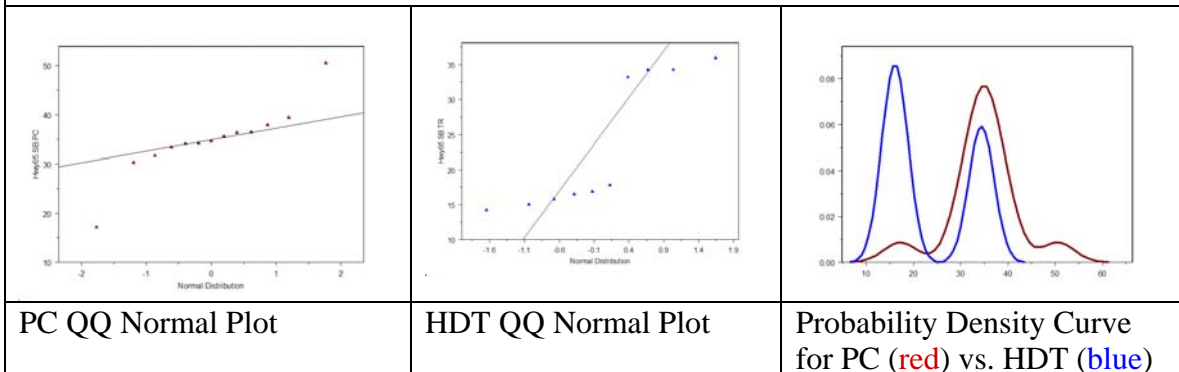


Westbound



Highway 65

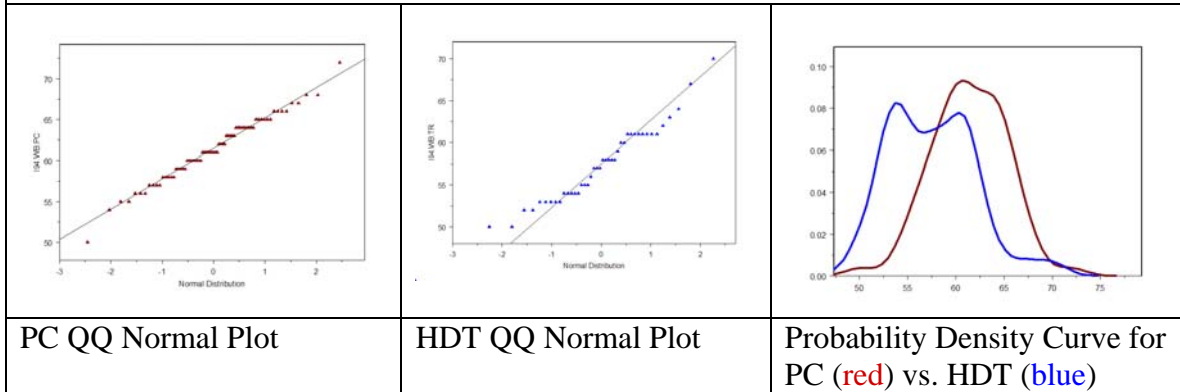
Southbound



Minneapolis/St. Paul

I-94

Southbound



APPENDIX D: MOBILE6 VEHICLE CLASSIFICATIONS (USEPA 2003)

Number	Abbreviation	Description
1	LDGV:	Light-Duty Gasoline Vehicles (Passenger Cars)
2	LDGT1:	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW)
3	LDGT2:	Light-Duty Gasoline Trucks 2 (0-6,000 lbs. GVWR, 3,751-5,750 lbs. LVW)
4	LDGT3:	Light-Duty Gasoline Trucks 3 (6,001-8,500 lbs. GVWR, 0-5,750 lbs. ALVW)
5	LDGT4:	Light-Duty Gasoline Trucks 4 (6,001-8,500 lbs. GVWR, greater than 5,751 lbs. ALVW)
6	HDGV2b:	Class 2b Heavy-Duty Gasoline Vehicles (8,501-10,000 lbs. GVWR)
7	HDGV3:	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
8	HDGV4:	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
9	HDGV5:	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
10	HDGV6:	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
11	HDGV7:	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
12	HDGV8a:	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
13	HDGV8b:	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
14	LDDV:	Light-Duty Diesel Vehicles (Passenger Cars)
15	LDDT12:	Light-Duty Diesel Trucks 1 and 2 (0-6,000 lbs. GVWR)
16	HDDV2b:	Class 2b Heavy-Duty Diesel Vehicles (8,501-10,000 lbs. GVWR)
17	HDDV3:	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)
18	HDDV4:	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)
19	HDDV5:	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)
20	HDDV6:	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)
21	HDDV7:	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)
22	HDDV8a:	Class 8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)
23	HDDV8b:	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)
24	MC:	Motorcycles (Gasoline)
25	HDGB:	Gasoline Buses (School, Transit, and Urban)
26	HDDBT:	Diesel Transit and Urban Buses
27	HDDBS:	Diesel School Buses
28	LDDT34:	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)