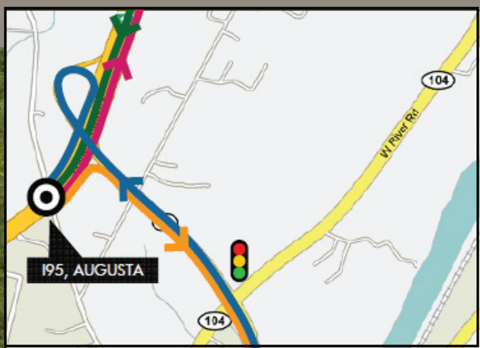
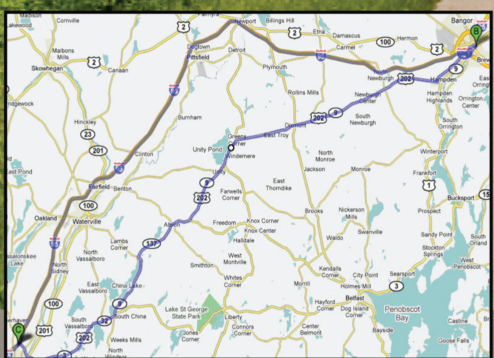
Estimating Truck-Related Fuel Consumption and Emissions in Maine: A Comparative Analysis for a 6-axle, 100,000 Pound Vehicle Configuration

September 2009





Prepared by the American Transportation Research Institute

ATRI American Transportation Research Institute

Estimating Truck-Related Fuel Consumption and Emissions in Maine: A Comparative Analysis for a 6-axle, 100,000 Pound Vehicle Configuration

Prepared for:

The Maine Department of Transportation
Child Street
16 State House Station
Augusta, ME 04333-0016

Prepared by:

American Transportation Research Institute

Vehicle Performance Model Provided by:

Cummins Inc.

September 2009

Principal Investigator:

Michael Tunnell, MCRP
Director, Environmental Research
(916) 300-3161
mtunnell@trucking.org

950 N. Glebe Road, Suite 210
Arlington, VA 22203

(703) 838-1966
atri@trucking.org
www.atri-online.org

EXECUTIVE SUMMARY

The American Transportation Research Institute, in collaboration with Cummins Inc., investigated the potential energy and emissions impacts of expanding the federal gross vehicle weight (GVW) exemption to additional portions of Maine's Interstate system, thereby allowing vehicles with GVWs of up to 100,000 pounds to operate on these additional portions of the Interstate.

The performance of a 6-axle vehicle configuration operating at a maximum GVW of 100,000 pounds was analyzed over two roughly parallel routes between Augusta and Brewer, Maine. The existing route (Route 9) reflects current conditions where trucks greater than 80,000 pounds GVW are not allowed on I-95 north of State Route 3 due to federal weight restrictions. The alternative route (I-95) assumes trucks up to 100,000 pounds GVW would be allowed to travel on I-95 north of State Route 3.

Using a simulation model, two different travel scenarios were developed to bracket the analysis. Under a "No Stops" scenario, the vehicle experiences uninterrupted travel through all traffic signals requiring no deceleration. Under an "All Stops" scenario, the vehicle decelerates, stops for 20 seconds, and then accelerates to the posted speed limit at every traffic signal.

Based on this methodology, the following findings were made.

- As modeled, the distance of the I-95 route was 5.19 miles more in the northbound direction and 4.41 miles more in the southbound direction than Route 9. Despite these longer travel distances, trip times on the I-95 route were from 26 to 33 minutes less in either direction. The average travel speeds on the I-95 route ranged from 60 to 62 mph while the Route 9 speeds ranged from 38 to 42 mph.

- Despite the longer travel distance of the I-95 route, total fuel consumption was less. An overall fuel savings of approximately 1 to 2 gallons was estimated when traveling the I-95 route compared to Route 9. The impact of stopping at all the traffic signals along Route 9 was responsible for nearly a gallon of additional fuel consumption.

- To account for differences in trip lengths, a measurement of efficiency, miles per gallon (mpg) of fuel consumed, was used to compare the vehicle's performance over the two routes. Fuel economy improved from 14 to 21 percent over the I-95 route compared to Route 9.

- CO_2 emissions ranged from 6 to 11 percent lower for the longer I-95 route compared to Route 9. The impact of stopping at all the traffic signals along Route 9 increased CO_2 emissions by as much as 6 percent. PM

and NO_x + NMHC emissions were from 3 to 8 percent less over the I-95 route.

Extrapolating these findings over an entire week resulted in savings of as much as 338 to 675 gallons of fuel, 3.4 to 6.8 metric tons of CO_2, 33.8 to 93.8 grams of PM and 8.3 to 24.8 pounds of NO_x + NMHC for all trucks shifted from Route 9 to the I-95 route under the expanded GVW exemption.

A further extrapolation of these findings to a previous study of the impacts on Maine transportation system from expanding the federal weight exemption resulted in daily savings of 82 to 305 gallons of fuel and 0.9 to 3.1 metric tons of CO_2 emissions. Emissions of PM ranged from +6 to -35 grams while emissions of NO_x + NMHC ranged from +2 to -124 pounds. Although the potential exists for a slight increase in PM and NO_x + NMHC emissions under the "No Stops" scenario due to an increase in mileage when using the Interstate, this is highly improbable given that stop-and-go conditions are more likely to be encountered when traveling on local, non-Interstate routes. Therefore, assuming these findings are representative of system-wide impacts, an expansion of the GVW exemption could result in daily fuel savings of 194 gallons, CO_2 emission reductions of 2 metric tons, PM emission reductions of 12 grams, and NO_x + NMHC emission reductions of 60 pounds.

TABLE OF CONTENTS

FIGURES AND TABLES

INTRODUCTION

In 1998, the Transportation Equity Act for the 21st Century (TEA-21) provided an exemption from the federal gross vehicle weight (GVW) limit on the Maine Turnpike and a portion of Interstate 95 in Kittery. The remaining Interstate routes in Maine, I-295, I-395 and large portions of I-95, remain subject to the federal GVW limit of 80,000 pounds. The exempt portion of I-95 and all other state highways allow GVWs of up to 100,000 pounds on a six-axle tractor semi-trailer with sufficient spread between axles. One consequence of this difference in weight limits is that heavy combination trucks that would otherwise be through traffic on the Interstate system divert to state highways upon reaching the non-exempt portion of I-95.

To assess the impacts of potential changes to federal weight restrictions, the Maine Department of Transportation (DOT) contracted with the American Transportation Research Institute (ATRI) to conduct the research described herein. ATRI, in collaboration with Cummins Inc., investigated the potential energy and emissions impacts of expanding the federal GVW exemption to additional portions of Maine's Interstate system, thereby allowing vehicles with GVWs of up to 100,000 pounds to operate on these additional portions of the Interstate.[1]

LITERATURE REVIEW

A literature review was conducted to identify and summarize published reports documenting the fuel consumption and/or emissions impacts of operating vehicles with higher gross vehicle weights, such as the 6-axle, 100,000 pound GVW configuration which is the subject of this analysis. The general consensus of these reports is that while operating at higher gross vehicle weights consumes more fuel on a per mile basis; the greater efficiencies of these higher weights results in less fuel being consumed, and fewer emissions generated, in moving a fixed amount of freight.

In reports published in the early part of this decade by the U.S. Department of Transportation, fuel consumption and air pollution costs were estimated to decrease under several scenarios where the expanded use of higher gross vehicle weights were allowed.[2, 3] Conversely, if the use of higher gross vehicle weights on the Interstate System were repealed, an increase in fuel consumption and air pollution costs was estimated. More recent research conducted by ATRI

[1] Cummins Inc. provided the vehicle performance model used for this research.
[2] U.S. Department of Transportation, *Comprehensive Truck Size and Weight Study* (August 2000).
[3] U.S. Department of Transportation, *Western Uniformity Scenario Analysis: A Regional Truck Size and Weight Scenario Requested by the Western Governor's Association* (April 2004).

confirms the energy and emission benefits which could be derived from the use of both higher gross vehicle weights as well as longer combination vehicles.[4]

More recent reports published in North America by provincial governments in Canada and other organizations cite reductions in fuel consumption, greenhouse gas and nitrogen oxide emissions from the use of longer combination vehicles (LCV).[5, 6, 7, 8] Due to the range of benefits associated with LCVs, the Canadian provinces of Alberta, British Columbia, Nova Scotia, Ontario and Quebec all allow LCVs subject to various restrictions.

Reports from the United Kingdom have also found that the use of higher gross vehicle weights generally produce lower relative emissions and lower fuel consumption than current vehicle configurations.[9] In the case where weight limits were increased to 44-tonnes (96,800 pounds) in the U.K beginning in 2001, the net reduction in truck-kilometers exceeded original projections.[10] For Asia, the United Nations has also noted the potential fuel savings and emissions reductions which could be gained from the use of "short LCVs," similar to those used in the Netherlands.[11]

A brief summary of each published report documenting the fuel consumption and/or emissions impacts of operating vehicles with higher gross vehicle weights is included in Appendix A. While Maine already benefits from the greater efficiencies of operating vehicles with higher gross vehicle weights on the exempt portion of I-95 and the state highway system, the focus of this research is on quantifying the energy and emission impacts of expanding the use of these types of vehicles on Maine's Interstate system.

[4] American Transportation Research Institute, *Energy and Emissions Impacts of Operating Higher Productivity Vehicles* (September 2004/Update: 2008).
[5] Alberta Infrastructure and Transportation, "Highway Provider View of Long Combination Vehicles" (March 2005).
[6] Canadian Trucking Alliance, *Evaluating Reductions in Greenhouse Gas Emissions Through the Use of Turnpike Double Truck Combinations, and Defining Best Practices for Energy-Efficiency* (December 15, 2006).
[7] Ogburn, Michael, L. Ramroth, A. B. Lovins, Rocky Mountain Institute, *Transformational Trucks: Determining the Energy Efficiency Limits of a Class-8 Tractor-Trailer* (July 2008).
[8] Ontario Ministry of Transportation, "LCV Pilot Program Questions and Answers" (2009)
[9] Knight, I., W. Newton, A. McKinnon, et al., *Longer and/or Longer and Heavier Goods Vehicles (LHVs) – A Study of the Likely Effects if Permitted in the U.K.: Final Report* (June 2008).
[10] McKinnon, Alan C., *The Economic and Environmental Benefits of Increasing Maximum Truck Weight: The British Experience* (2004).
[11] Nagl, Phillip, *Longer Combination Vehicles (LCV) for Asia and the Pacific Region: Some Economic Implications*. United Nations Economic and Social Commission for Asia and the Pacific Working Paper (January 2007). "Short LCVs" are configurations which accommodate up to three twenty-foot equivalent units (TEU) containers.

VEHICLE CONFIGURATION

In addition to a few special commodity exceptions, Maine allows a specific vehicle configuration to operate at GVWs exceeding 80,000 pounds.[12] This configuration, which consists of a 3-axle tractor and tri-axle semi-trailer combination vehicle, may operate up to a maximum of 100,000 pounds GVW subject to certain requirements.

Consistent with this vehicle combination, a representative configuration consisting of a 3-axle sleeper cab tractor pulling a tri-axle semi-trailer operating at the maximum GVW of 100,000 pounds was selected for this analysis. An example of this type of configuration is shown in Figure 1.

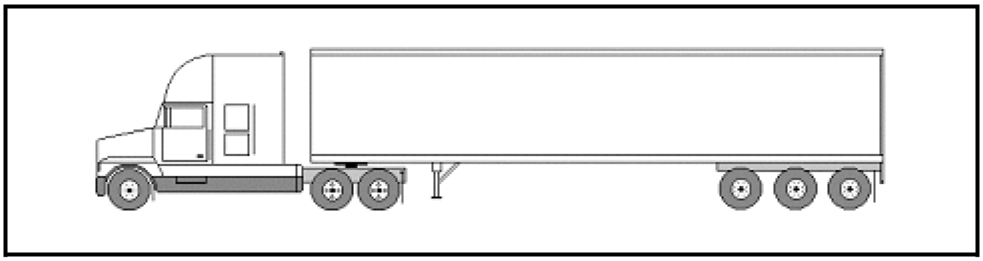


Figure 1: Representative Vehicle Configuration

The analysis was limited to this single configuration based on the following assumptions:

- This type of configuration is representative of trucks operating in Maine at GVWs from 80,000 to 100,000 pounds GVW.
- With the exception of I-95 near Kittery and the Maine Turnpike, this configuration will travel primarily on the Maine state highway system when operating at GVWs from 80,000 to 100,000 pounds.
- When this configuration is not carrying freight (empty), it is able to travel on I-95 below the 80,000 pound maximum weight limit. Therefore, empty miles are not impacted by the existing weight restrictions on I-95.

IDENTIFICATION OF ROUTES

Under the direction of the Maine DOT, two roughly parallel routes traveling from Augusta to Brewer, Maine were selected for this analysis. Both routes share the common beginning point where I-95 crosses the overpass of Old Belgrade Road and the common ending point at the intersection of N. Main and State Streets in Brewer.

[12] State of Maine, *Commercial Vehicle Laws and Regulations*, Section 9: Operational Gross Vehicle Weight (Referenced to Maine Revised Statutes Annotated Title 29-A).

The existing route reflects current conditions where trucks greater than 80,000 pounds GVW are not allowed on I-95 north of State Route 3 due to federal weight restrictions. Trucks up to 100,000 pounds GVW are allowed on the Maine Turnpike (I-95 south of State Route 3) and on all other state highways. As a result, northbound trucks with GVWs greater than 80,000 pounds must exit I-95 at or before State Route 3 and proceed on the state highway system.

The existing route (referred to as "Route 9") begins where I-95 crosses the overpass of Old Belgrade Road. The route then exits I-95 at State Route 3 and connects with State Route 9. The route then proceeds on State Route 9 terminating in Brewer. This route is approximately 67.5 miles when traveling in the northbound direction and 68.5 miles when traveling in the southbound direction. The disparity in mileage is attributed to access and egress differences at the interchange of I-95 and Route 3 and at the transition between Summer and Union Streets in Bangor.

The alternative route assumes trucks up to 100,000 pounds GVW would be allowed to travel on I-95 north of State Route 3. Under this alternative (referred to as "I-95"), trucks remain on northbound I-95, merge onto I-395 eastbound and exit at South Main Street where they proceed north to the common ending point. This route is slightly less than 73 miles when traveling in either direction. Small mileage differences between the northbound and southbound routes were identified at the interchange of I-95 and I-395 and at the access and egress of I-395 and S. Main Street. Figure 2 shows a comparison of the routes that were analyzed. Figures 3 and 4 illustrate the southern and northern portions of each route, respectively.

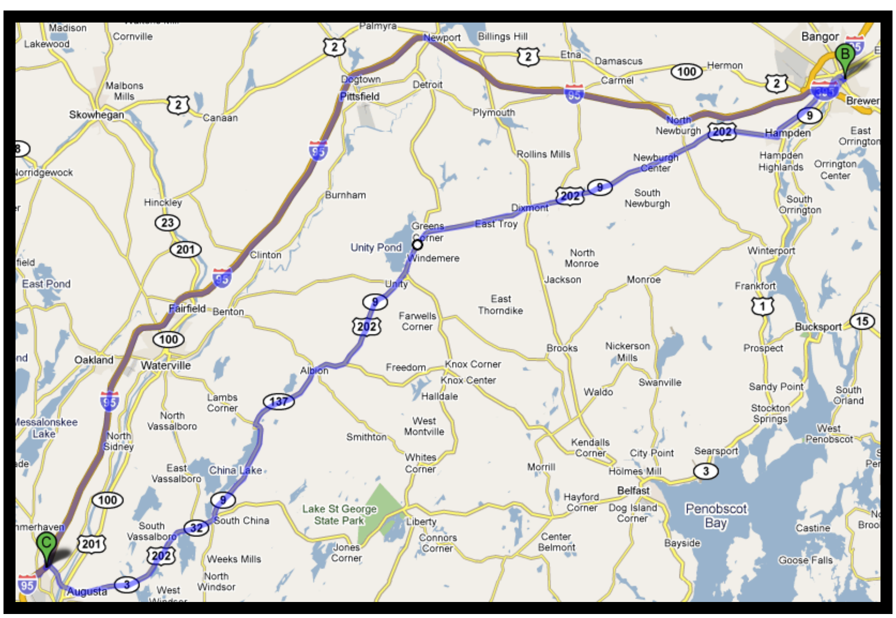


Figure 2: Map of Route 9 and I-95

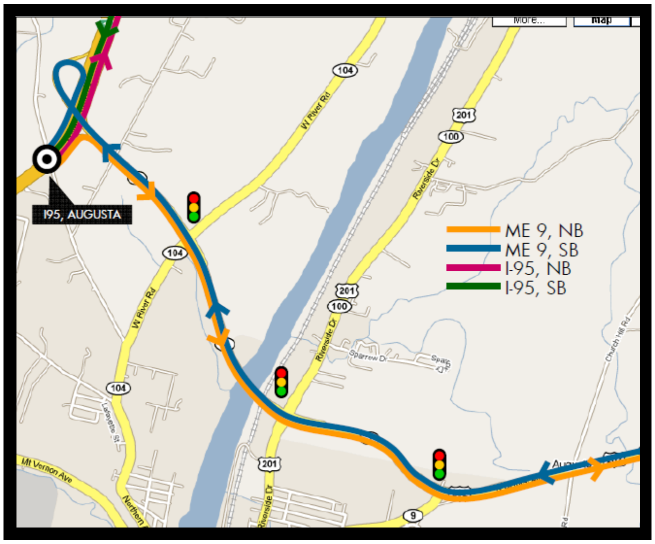


Figure 3: Southern Portion of Both Routes

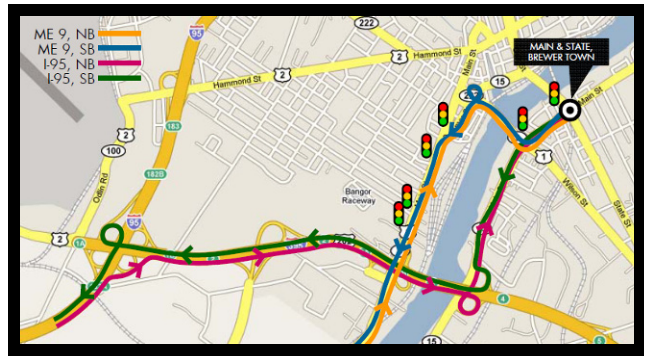


Figure 4: Northern Portion of Both Routes

TRAVEL PROFILES

To simulate vehicle performance over the selected routes, travel profiles were developed for both the northbound and southbound directions of each route. Information on traffic signal locations and posted speed limits along each route was provided by the Maine DOT. Based on this information, individual travel profiles were developed which identified locations where traffic signals and changes in posted speed limits occur. Route 9 included 14 traffic signals and 28 changes in posted speed limits while I-95 included 2 traffic signals and 5 changes in posted speed limits.[13] Each travel profile is included in Appendix B.

This information was then used to create a virtual route using Google Maps application programming interface (API). Traffic signal and speed limit change locations were incorporated into the route based on each location's longitude and latitude coordinates. Supplementary locations were also added to more precisely identify the route. This process was used to create four virtual routes consisting of a large set of point-by-point, turn-by-turn segments. Figure 5 shows the altitude and vehicle speed profiles for the northbound portion of each route. Additional route details are provided in Appendix C.

[13] The recent addition of a traffic signal at the intersection of Route 3/9 and Route 32 was not included in this analysis. The inclusion of this signal into this analysis would further increase the stopping impacts associated with the "All Stops" scenario.

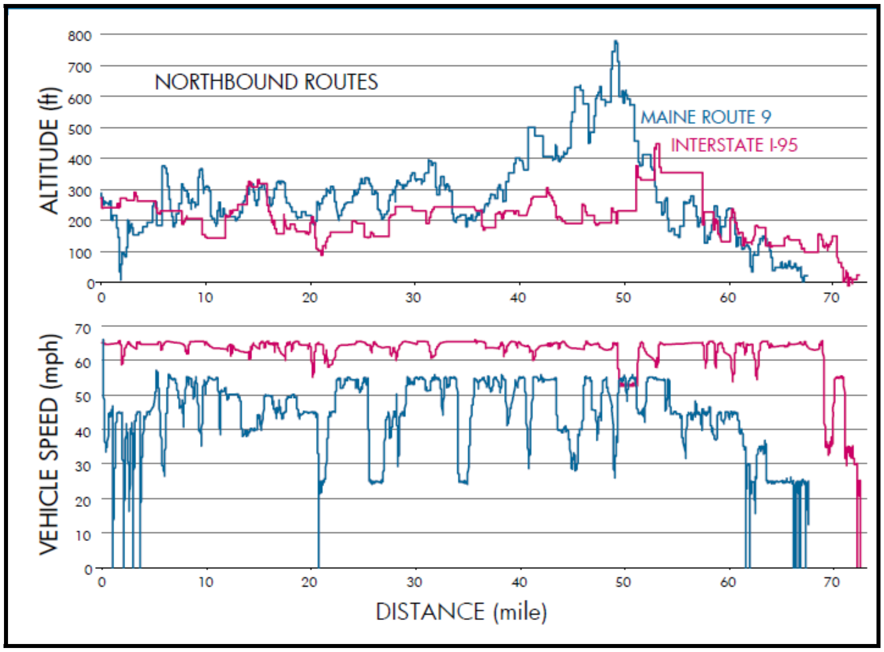


Figure 5: Altitude and Vehicle Speed Profiles, Northbound Routes

VEHICLE SIMULATION MODELING

Cummins' Vehicle Mission Simulation (VMS) model was used to characterize the performance of the selected configuration over the identified routes. This model incorporates a number of specific inputs, including vehicle configuration, route identification and travel profiles. In addition, the model accounts for specific powertrain features that are matched to the vehicle configuration. Powertrain features include the type of engine, transmission, axles, tires and other features that are matched to the selected configuration. Two sizes of engines were selected for this analysis. In addition, a standard accessory load (i.e., cooling fan, alternator, Freon compressor) was designated. Shifting behavior can also be adjusted in the model. Progressive shifting was designated for this analysis. Progressive shifting, as opposed to performance shifting, seeks to improve fuel economy and is representative of real world driving. Table 1 lists the powertrain inputs that were incorporated into the model.

Table 1: Powertrain Inputs

Parameter	Configuration
Vehicle	6 x 4 – 3S, box-trailer truck with sleeper cab
Gross Combination Weight	100,000 lbs
Engines	1) ISX 485 hp, 1,650 lb-ft @ 1200 RPM (FR10641, CPL 2733) 2) ISX 500 hp, 1,850 lb-ft @ 1200 RPM (FR10637, CPL 2733)
Axle	Generic 40,000 lbs
Axle Ratio	3.60
Tires	Radial 275/80R22.5, 516 rev/mile
Transmission	Eaton Fuller FRO-16210B, 10 speed gear box
Shift	Progressive Shift

Engine fuel maps derived from test cell data were used to estimate fuel consumption over the specific operating conditions encountered along the routes. An emission factor of 22.232 pounds of carbon dioxide emissions (CO2) per gallon of fuel consumed was used to estimate greenhouse gas emissions.[14] Emissions factors of 0.01 gram per horsepower-hour (g/hp-hr) of particulate matter (PM) and 1.2 g/hp-hr of oxides of nitrogen plus non-methane hydrocarbons (NOx + NMHC) were used to estimate primary ambient air pollutants.[15] Figure 6 shows a schematic diagram of the modeling inputs.

[14] Carbon dioxide is one of the principal greenhouse gases that has been associated with climate change.

[15] Particulate matter, oxides of nitrogen and non-methane hydrocarbons are regulated air pollutants which have been associated with the formation of haze and/or smog (ozone).

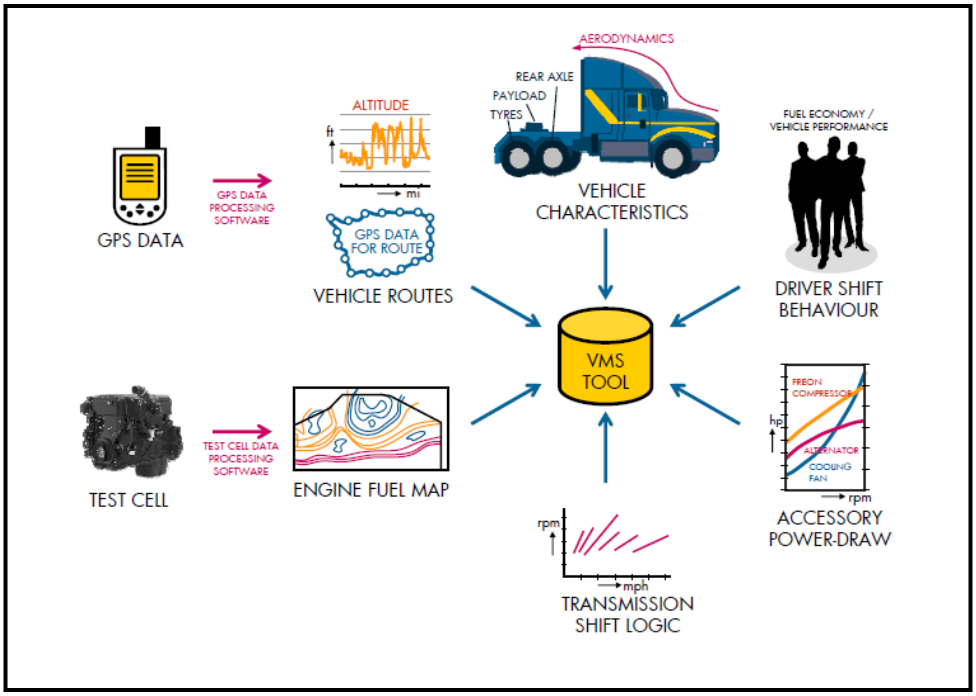


Figure 6: Schematic Diagram of Simulation Model Inputs

Using the simulation model, two different travel scenarios were developed for each travel profile. These scenarios included:

1) “No Stops” (Best Case Scenario): The vehicle experiences uninterrupted travel through all traffic signals requiring no deceleration. Speeds are maintained at posted speed limits (or close to it depending upon terrain) with accelerations and decelerations occurring only where changes in speed limits occur and at the beginning and ending of the routes.

2) “All Stops” (Worst Case Scenario): The vehicle decelerates, stops for 20 seconds, and then accelerates to the posted speed limit at every traffic signal. Speeds are maintained at posted speed limits (or close to it depending upon terrain) with accelerations and decelerations occurring where changes in speed limits occur, at the beginning and ending of the routes, and at each traffic signal.

The use of these scenarios enabled a range of values to be developed which characterize the energy and emissions performance of the selected vehicle configuration over the specified routes.

RESULTS

Based on the above inputs and scenarios, the simulation model generated several outputs, including trip time, fuel consumed, fuel economy, average power and engine work performed. Using these outputs, emissions estimates for CO_2, PM and NOx were developed. The following summarizes the results for the selected vehicle configuration when equipped with a current production 485 hp engine.[16]

Travel Characteristics

As modeled, the distance of the I-95 route was 5.19 miles more in the northbound direction and 4.41 miles more in the southbound direction than Route 9. Despite these longer travel distances, trip times on the I-95 route were from 26 to 33 minutes less in either direction. Table 2 shows a comparison of the travel times in both the northbound and southbound directions of each route.

Table 2: Travel Times

TRAVEL TIMES (485 hp Engine)		Trip Length (Miles)	Trip Time (Minutes)		**Difference due to Stops (Minutes)**
			No Stops	All Stops	
Northbound	Route 9	67.53	96.6	104.4	**+7.8**
	I-95 Route	72.72	70.8	72.0	**+1.2**
	Difference from Route 9	**+5.19**	**-25.8**	**-32.4**	
Southbound	Route 9	68.50	99.0	107.4	**+8.4**
	I-95 Route	72.91	71.4	72.6	**+1.2**
	Difference from Route 9	**+4.41**	**-27.6**	**-32.8**	

The faster travel times on the I-95 route can be attributed primarily to the ability to sustain higher average speeds along this route. As shown in Table 3, the average travel speeds on the I-95 route ranged from 60 to 62 mph while the Route 9 speeds ranged from 38 to 42 mph. The impact of stopping at all the traffic signals along Route 9 (a total stop time of 4 minutes and 40 seconds plus deceleration and acceleration) decreased average speeds by approximately 3 mph while the impact of the two traffic signals on the I-95 route decreased average speeds by 1 mph.

[16] Results for this configuration with a 500 hp engine are presented in Appendix D.

Table 3: Travel Speeds

TRAVEL SPEEDS (485 hp Engine)		Average Miles Per Hour (MPH)		**Difference due to Stops (MPH)**
		No Stops	All Stops	
Northbound	Route 9	41.9	38.8	**-3.1**
	I-95 Route	61.6	60.6	**-1.0**
	Difference from Route 9	**+19.7**	**+21.8**	
Southbound	Route 9	41.5	38.3	**-3.2**
	I-95 Route	61.3	60.3	**-1.0**
	Difference from Route 9	**+19.8**	**+22.0**	

Fuel Consumption and Fuel Economy

Despite the longer travel distance of the I-95 route, total fuel consumption was less. Table 4 shows an overall fuel savings of approximately 1 to 2 gallons when traveling the I-95 route compared to Route 9. The impact of stopping at all the traffic signals along Route 9 was responsible for nearly a gallon of additional fuel consumption.

Table 4: Fuel Consumption

FUEL CONSUMPTION (485 hp Engine)		Trip Length (Miles)	Fuel Consumed (Gallons)		**Difference due to Stops (Gallons)**
			No Stops	All Stops	
Northbound	Route 9	67.53	15.5	16.4	**+0.9**
	I-95 Route	72.72	14.6	14.6	**0.0**
	Difference from Route 9	**+5.19**	**-0.9**	**-1.8**	
Southbound	Route 9	68.50	16.9	17.8	**+0.9**
	I-95 Route	72.91	15.8	15.9	**+0.1**
	Difference from Route 9	**+4.41**	**-1.1**	**-1.9**	

To better understand the impact of the different routes on fuel consumption, a fuel map for the 485 hp engine is shown in Figure 7. The fuel map illustrates where fuel consumption is optimized in relationship to engine speed and torque.

In Figure 7, the elliptical contour band ranging from approximately 1,300 to 1,600 revolutions per minute (rpm) of engine speed and 1,300 to 1,800 pound-foot (lb-ft) of engine torque represents the area of optimum brake-specific fuel consumption (BSFC) for this engine.[17] From this band outward, each contour line represents a 1 percent decrease in BSFC. As the engine operates at different torque and speed combinations, BSFC will vary in relation to the contour bands shown on the fuel map.

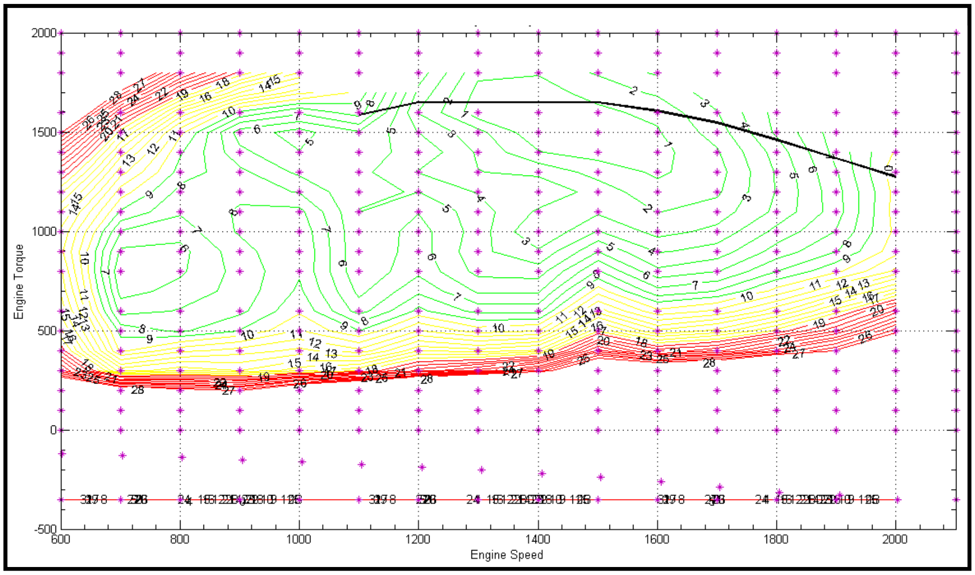


Figure 7: Fuel Map for 485 hp Engine

To further illustrate the differences in fuel consumption, Figure 8 shows engine speed and torque by fuel consumed under the "All Stops" scenario. As shown, the majority of fuel was consumed at an engine speed ranging from 1,200 to 1,500 rpm while operating on the I-95 route. Engine speeds were more widely dispersed while operating on Route 9. And while a range of engine torque was observed for both routes, the majority of fuel was consumed under high torque conditions (≥ 1,400 lb-ft) while operating on Route 9. These differences resulted in 10.7 percent less fuel being consumed while operating under the conditions found on the longer I-95 route.

[17] Brake-specific fuel consumption is a measure of fuel efficiency. It is the rate of fuel consumption divided by the instantaneous power produced.

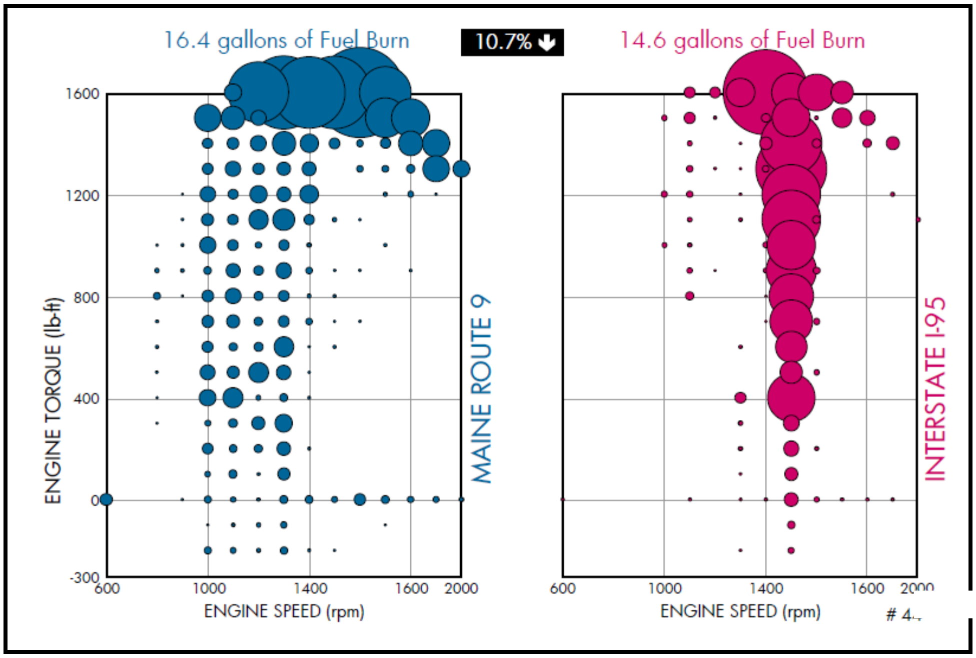


Figure 8: Engine Speed and Torque Split by Fuel Consumed

To account for differences in trip lengths, a measurement of efficiency, miles per gallon (mpg) of fuel consumed, was used to compare the vehicle's performance over the two routes. Table 5 shows that fuel economy improved from 14 to 21 percent over the I-95 route compared to Route 9. The impact of stopping at all the traffic signals along Route 9 decreased fuel economy along this route by approximately 5 percent.

Table 5: Fuel Economy

FUEL ECONOMY (485 HP Engine)		Fuel Economy (mpg)		**Difference due to Stops (%)**
		No Stops	All Stops	
Northbound	Route 9	4.36	4.12	**-5.5%**
	I-95 Route	4.99	4.97	**-0.4%**
	Difference from Route 9 (%)	**+14.4%**	**+20.6%**	
Southbound	Route 9	4.05	3.86	**-4.7%**
	I-95 Route	4.63	4.60	**-0.6%**
	Difference from Route 9 (%)	**+14.3%**	**+19.2%**	

Greenhouse Gas Emissions

Emissions of the primary greenhouse gas, carbon dioxide (CO_2), are directly related to fuel consumption. According to guidance provided by the U.S. Environmental Protection Agency, 22.232 pounds of CO_2 are emitted for every gallon of diesel consumed. Multiplying this factor by the fuel consumption estimates generated by the simulation model yielded the CO_2 emission estimates shown in Table 6. CO_2 emissions ranged from 6 to 11 percent lower for the longer I-95 route compared to Route 9. The impact of stopping at all the traffic signals along Route 9 increased CO_2 emissions by as much as 6 percent along this route.

Table 6: CO2 Emissions

CO2 EMISSIONS (485 HP Engine)		CO2 Emissions (Pounds)		**Difference due to Stops (%)**
		No Stops	All Stops	
Northbound	Route 9	344	365	**+6.1%**
	I-95 Route	324	325	**+0.3%**
	Difference from Route 9 (%)	**-5.9%**	**-10.7%**	
Southbound	Route 9	376	395	**+5.1%**
	I-95 Route	350	352	**+0.6%**
	Difference from Route 9 (%)	**-6.9%**	**-10.8%**	

Ambient Air Pollutants

To estimate the ambient air pollutants of particulate matter (PM) and oxides of nitrogen plus non-methane hydrocarbons (NO_x + NMHC), emissions factors corresponding to average engine certification values for a 2007 or newer engine were used. For PM, a factor of 0.01 grams per horsepower-hour (g/hp-hr) was used. For NO_x + NMHC, a factor of 1.2 g/hp-hr was used.

In order to apply these factors to each route, the average engine power for each route was determined using the simulation model. As shown in Table 7, average engine power was 32 to 36 percent higher along the I-95 route.

Table 7: Average Engine Power

AVERAGE ENGINE POWER (485 hp Engine)		Average Power (hp)		**Difference due to Stops (%)**
		No Stops	All Stops	
Northbound	Route 9	185	182	**-1.6%**
	I-95 Route	245	243	**-0.8%**
	Difference from Route 9 (%)	**+32.4%**	**+33.5%**	
Southbound	Route 9	199	194	**-2.5%**
	I-95 Route	264	263	**-0.4%**
	Difference from Route 9 (%)	**+32.7%**	**+35.6%**	

Average engine power was then multiplied by the trip times identified in Table 2 to estimate the total work required (hp-hr) in each direction of the routes. The faster travel times on I-95 offset the higher average engine power, resulting in less total work required. The total work required was then multiplied by the above emissions factors to estimate total trip emissions for PM and NOx + NMHC. These estimates are shown in Tables 8 and 9.

Even though the I-95 route was longer, PM and NOx + NMHC emissions were less along this route. Due to the stringent federal engine emission standards that went into effect in 2007, total PM emissions were less than 3.5 grams under all conditions. PM emissions were from 3 to 8 percent less when traveling the I-95 route.

Similarly, NOx emissions are estimated to be lower when traveling the I-95 route. And while the level of NOx emissions is considerably higher than PM, new engine emission standards which take effect in 2010 will lower these emissions by 83 percent.

Table 8: Particulate Matter Emissions

PM EMISSIONS (485 hp Engine)		Grams (gm) No Stops	Grams (gm) All Stops	Difference due to Stops (%)
Northbound	Route 9	2.98	3.17	**+6.4%**
	I-95 Route	2.89	2.92	**+0.9%**
	Difference from Route 9 (%)	**-2.9%**	**-7.9%**	
Southbound	Route 9	3.28	3.47	**+5.8%**
	I-95 Route	3.14	3.18	**+1.3%**
	Difference from Route 9 (%)	**-4.3%**	**-8.4%**	

Table 9: Oxides of Nitrogen plus Non-Methane Hydrocarbon Emissions

NOx + NMHC EMISSIONS (485 hp Engine)		Grams (gm) No Stops	Grams (gm) All Stops	Difference due to Stops (%)
Northbound	Route 9	357	380	**+6.4%**
	I-95 Route	347	350	**+0.9%**
	Difference from Route 9 (%)	**-2.9%**	**-7.9%**	
Southbound	Route 9	394	417	**+5.8%**
	I-95 Route	377	382	**+1.3%**
	Difference from Route 9 (%)	**-4.3%**	**-8.4%**	

Route 9 Corridor Analysis

Using the trip-specific results presented above, an estimate of the Route 9 corridor impacts from expanding GVWs to 100,000 pounds on the Maine Interstate system was made. As shown in Table 10, differences in 6-axle truck counts were observed in the northbound and southbound direction of Route 9.[18]

[18] Maine DOT, Vehicle Classification Data for Dixmont, State Route 9/U.S. 202/State Route 7, for week of July 12, 2009.

Table 10: Daily 6-Axle Truck Counts, State Route 9

Daily 6-Axle Trucks	Northbound	Southbound
Sunday	8	7
Monday	112	49
Tuesday	99	36
Wednesday	109	39
Thursday	113	31
Friday	109	22
Saturday	16	7
Totals	566	191

In an effort to explain the greater number of 6-axle trucks traveling northbound, the following assumptions were made:

1) Loaded 6-axle trucks traveling northbound will divert off of I-95 north of the Maine Turnpike and onto the state highway system when operating at weights greater than 80,000 pounds; and
2) Empty southbound 6-axle trucks will return on I-95 since they are within the existing weight limits.

Based on these assumptions and the trip-specific model results presented above, if the additional weekly northbound truck trips (+375) were to be shifted from Route 9 to I-95 as a result of expanding GVWs to 100,000 pounds on the Maine Interstate, weekly savings of as much as 338 to 675 gallons of fuel, 3.4 to 6.8 metric tons of CO2, 33.8 to 93.8 grams of PM, and 8.3 to 24.8 pounds of NOx + NMHC could result.

Maine Transportation System Analysis

Based on the trip-specific results presented above, an estimate of the impacts to Maine's transportation system was also made. According to a previous study, expanding GVWs to 100,000 pounds on the Maine Interstate system would decrease daily 6-axle truck miles on non-Interstate roads while an increase in 6-axle truck miles would occur on the Interstate.[19] Results from this study are reproduced in Table 11. While the decrease or increase in 6-axle mileage is

[19] Wilbur Smith Associates, *Study of Impacts Caused by Exempting Current Non-exempt Maine Interstate Highways from Federal Truck Weight Limits, Appendix C: Pavement Cost Impacts Development Process for the Study Network*, Table C-3, p. 1-4 (June 2004).

mainly attributed to a shift in travel from local roads to the Interstate system, some additional mileage is assumed to result from the longer trips that may occur when using the Interstate.

Table 11: Daily System-Wide 6-Axle Truck Miles

Functional Classification	Base Scenario	Study Scenario	Change
Major/Urban Collector	12,243.26	7,746.75	-4,496.51
Minor Arterial	16,406.07	14,114.27	-2,291.79
Other Principal Arterial	51,200.51	40,104.48	-11,069.03
Principal Arterial Interstate	34,086.25	54,093.57	20,007.32
Total	113,936.09	116,059.07	2,122.99

Using these system-wide mileage estimates, bi-directional average per mile fuel consumption and emissions factors were developed for the I-95 route as well as Route 9. By applying the I-95 factors to the Interstate miles and the Route 9 factors to the other functional classification miles, an estimate of the system-wide impacts of expanding GVWs to 100,000 pounds on the Maine Interstate system can be made. Using the "No Stops" scenario to represent the minimum difference and the "All Stops" scenario to represent the maximum difference, the daily system-wide ranges are shown in Table 12.

Table 12: Daily System-Wide Impacts

System-Wide Extrapolation	Range		Average
	"No Stops"	"All Stops"	
Fuel Consumption (gallons)	-82	-305	-194
CO2 Emissions (metric tons)	-0.9	-3.1	-2.0
PM Emissions (grams)	+6	-35	-12
NOx + NMHC Emissions (lbs)	+2	-124	-60

Although the potential exists for a slight increase in PM and NOx + NMHC emissions under the "No Stops" scenario due to the increase in mileage that could occur when using the Interstate, this is highly improbable given that stop-and-go conditions are more likely to be encountered when traveling on local, non-Interstate routes. Therefore, assuming these findings are representative of system-wide impacts, an expansion of the GVW exemption could result in daily fuel savings of 194 gallons, CO_2 emission reductions of 2 metric tons, PM emission reductions of 12 grams, and NOx + NMHC emission reductions of 60 pounds.

CONCLUSIONS

This research investigated the potential energy and emissions impacts of expanding the federal GVW exemption to additional portions of the Maine Interstate system, thereby allowing vehicles with GVWs up to 100,000 pounds to operate on additional portions of the Interstate. Based on simulation modeling, traveling a slightly longer route with higher average speeds resulted in less fuel consumed and fewer emissions than traveling on a route with lower average speeds, numerous speed limit changes and traffic signals.

In comparing the operation of a vehicle with a GVW of 100,000 pounds over two different routes – an Interstate route versus a state highway route, trip-level fuel efficiency improvements, measured in miles per gallon, of 14 to 21 percent were identified when traveling over the Interstate route. Trip-specific emissions were also estimated to decrease by 6 to 11 percent for CO_2 and 3 to 8 percent for PM and NOx + NMHC over this route.

Extrapolating these findings over an entire week resulted in savings of as much as 338 to 675 gallons of fuel, 3.4 to 6.8 metric tons of CO_2, 33.8 to 93.8 grams of PM and 8.3 to 24.8 pounds of NOx + NMHC for all trucks shifted from Route 9 to the I-95 route under the expanded GVW exemption.

A further extrapolation of the findings to a previous study of the impacts on Maine transportation system from expanding the federal weight exemption resulted in daily savings of 82 to 305 gallons of fuel and 0.9 to 3.1 metric tons of CO_2 emissions. Emissions of PM ranged from +6 to -35 grams while emissions of NOx + NMHC ranged from +2 to -124 pounds. Although the potential exists for a slight increase in PM and NOx + NMHC emissions under the "No Stops" scenario due to an increase in mileage when using the Interstate, this is highly improbable given that stop-and-go conditions are more likely to be encountered when traveling on local, non-Interstate routes. Therefore, assuming these findings are representative of system-wide impacts, an expansion of the GVW exemption could result in daily fuel savings of 194 gallons, CO_2 emission reductions of 2 metric tons, PM emission reductions of 12 grams, and NOx + NMHC emission reductions of 60 pounds.

APPENDIX A: LITERATURE REVIEW

Alberta Infrastructure and Transportation, "Highway Provider View of Long Combination Vehicles" (March 2005).

A presentation by Alberta Infrastructure and Transportation explains the benefits and limitations of allowing higher productivity vehicles to operate in the Canadian province. Common misconceptions are addressed, including the vehicles' impact on the environment. The presentation indicates that emissions are directly related to fuel use, which represents a large fraction of trucking costs. While larger trucks consume more fuel on a per mile basis; the greater efficiencies of larger trucks results in less fuel being consumed, and fewer emissions generated, in moving a fixed amount of freight. Use of a long combination vehicle (LCV) was estimated to result in a 25 percent reduction in fuel consumption compared to a semi-trailer.

Emissions from idling were also addressed. The presentation compares trucks with 3, 5 and 8 axles moving one million tons and assumes one-hour of idling for each trip. Since larger trucks need fewer trips to move this tonnage, a 50 percent savings in fuel consumed while idling/waiting was estimated when comparing an 8-axle to a 5-axle truck. This fuel savings results in less carbon dioxide and nitrogen oxide emissions.

American Transportation Research Institute, *Energy and Emissions Impacts of Operating Higher Productivity Vehicles* (September 2004/Update: 2008).

The energy and emissions impacts of operating six different vehicle configurations at various gross weights over a common route were investigated. Using vehicle simulation modeling, increases in fuel efficiency, measured in ton-miles per gallon, were observed for nearly every higher productivity vehicle configuration at various weight increases. The observed improvements in fuel efficiency translated directly to improvements in environmental efficiency for emissions of CO2, PM and NOx over the modeled route. The 2008 study also observed increases in fuel, and environmental, efficiency for longer combination vehicles under a cube-limited (i.e., space limited) scenario.

Canadian Trucking Alliance, *Evaluating Reductions in Greenhouse Gas Emissions Through the Use of Turnpike Double Truck Combinations, and Defining Best Practices for Energy-Efficiency* (December 15, 2006).

This study documents the environmental benefits of existing Turnpike Double operations in Quebec and the Prairie Provinces as well as estimates the potential environmental and operational benefits of using this form of LCV in an expanded role. Fuel consumption data was collected from a number of fleets operating

Turnpike Doubles and traditional tractor-trailers. On average, each movement of a Turnpike Double was estimated to save 28.8 litres/100 km per movement – a 55 percent saving when compared to a single-trailer configuration used to move the same volume of freight.

Knight, I., W. Newton, A. McKinnon, et al., *Longer and/or Longer and Heavier Goods Vehicles (LHVs) – A Study of the Likely Effects if Permitted in the U.K.: Final Report* (June 2008).

This study conducts a formal assessment of the likely overall effects if vehicles in excess of the current weights and/or dimensions were to be permitted in the United Kingdom. As part of this assessment, the emissions and fuel consumption of each of eight vehicles types was assessed using state-of-the-art modeling. The PHEM (Passenger car and Heavy-duty Emissions Model) model estimates fuel consumption and the emissions of carbon monoxide, total hydrocarbons, oxides of nitrogen and particulate matter based on instantaneous engine power demand and engine speed during a drive cycle specified by the user.

Generally, the heavier the vehicle, the greater the exhaust emissions and fuel consumption. The heaviest vehicles generally produced the highest tailpipe emissions and had the greatest fuel consumption. However, when the emissions rate per tonne of payload carried were considered, these heavier vehicles produced similar or lower relative emissions than current vehicle configurations. When fully laden, the heaviest vehicles produced significantly lower relative emissions and lower fuel consumption than current vehicle configurations.

McKinnon, Alan C., *The Economic and Environmental Benefits of Increasing Maximum Truck Weight: The British Experience* (2004).

Comparisons are made between forecasted and actual effects resulting from an increase in the maximum operating weights in the United Kingdom beginning in 2001. The study concludes that forecasters generally underestimated the positive effects of increased weight limits, such as a net reduction in truck-kms.

The report documents how the annual reduction in vehicle-kms and corresponding economic and environmental savings has increased as the road freight sector has adjusted to a 44-tonne weight limit. In 2003, the most recent year for which data was available, approximately 134 million truck-kms were saved as a result of the weight increase. This is roughly one-third higher than the European Commission's mid-range forecast of the reduction in vehicle-kms.

Nagl, Phillip, *Longer Combination Vehicles (LCV) for Asia and the Pacific Region: Some Economic Implications*. United Nations Economic and Social Commission for Asia and the Pacific Working Paper (January 2007).

This paper explores the option of permitting longer and heavier vehicle combinations than allowed by the current standard regulations in most countries. The paper indicates that in 2004, the Netherlands started a broadly based trial with 300 vehicles which permits common carriers the usage of “Short LCVs” on Netherlands roads under certain conditions. The first results of the Netherlands test with respect to fuel usage were a 10-15 percent increase in fuel usage, compared to a more than 30 percent increase in average load.

Additionally, as described in a case study investigating the use of LCVs between two seaports and an intermodal facility, the use of LCVs resulted in carbon dioxide emissions and fuel consumption being 22.7 percent less, vehicle kilometers being 36.2 percent less and transport costs being 17.1 percent less.

Ogburn, Michael, L. Ramroth, A. B. Lovins, Rocky Mountain Institute, *Transformational Trucks: Determining the Energy Efficiency Limits of a Class-8 Tractor-Trailer* (July 2008).

This study analyzed energy efficiency opportunities in heavy-duty vehicles. The study explores these opportunities in two stages: Step 1 explores available technological efficiency gains, while Step 2 examines the complementary benefits of increasing volume and load capacity. Step 2 investigates hauling two 48-foot trailers instead of one and increasing maximum gross vehicle weight rating from 80,000 pounds to 120,000 pounds.

The study’s road load analysis incorporates the increased air drag associated with a longer vehicle, its higher weight, and new empty weight to compute the resulting fuel economy. An LCV which incorporates the design recommendation identified in Step 1 delivered an estimated 8.7 mpg which is lower, as expected, than a single trailer. However, the increased delivery of goods more than makes up for this, resulting in an increase in freight efficiency of 2.5 times the baseline tractor-semi trailer.

Ontario Ministry of Transportation, “LCV Pilot Program Questions and Answers” (2009)

Ontario, Canada has launched a pilot program to allow long combination vehicles (LCVs) on designated highways. According to the Government of Ontario, the pilot program will help to move goods safely, at a lower cost and with less impact on the environment. Each LCV is expected to saving approximately one-third the fuel and greenhouse gas emissions (GHG) of the two tractor-trailers that would carry the same amount of freight. If all the current truck trips that met the LCV criteria were made using LCVs, it is estimated that GHG emissions could be reduced by 200,000 tonnes a year.

U.S. Department of Transportation, *Comprehensive Truck Size and Weight Study* (August 2000).

A number of different truck size and weight scenarios were examined. In Volume 3, Chapter 10, “Energy and the Environment,” fuel consumption estimates for the year 2000 were developed for a base case and five alternative scenarios. The alternative scenarios included:

- A Uniformity Scenario which eliminates the current grandfather provisions that allow some States to retain higher gross vehicle weights and axle weight limits than the Federal limits on the Interstate System. This scenario was estimated to increase fuel use by 2 percent and increase air pollution costs.
- A North American Trade Scenario which allows gross vehicle weights more comparable to those in Canada and Mexico. This scenario was estimated to decrease fuel use by 6 percent and decrease air pollution costs.
- An LCV Nationwide Scenario which expands LCV operations to a nationwide network. This scenario was estimated to decrease fuel use by 14 percent and decreased air pollution costs.
- An H.R. 551 Scenario which phases-out trailers over 53 feet in length and freezes weight limits on Interstate and National Highway System facilities. This scenario was estimated to have virtually no impact on fuel use or air pollution costs.
- A Triples Nationwide Scenario which permits triple-trailer combinations to operate at the same weights and on the same designated nationwide network as the LCVs Nationwide Scenario. This scenario was estimated to reduce fuel use by 13 percent and reduce air pollution costs.

U.S. Department of Transportation, *Western Uniformity Scenario Analysis: A Regional Truck Size and Weight Scenario Requested by the Western Governor’s Association* (April 2004).

As the U.S. Department of Transportation’s *Comprehensive Truck Size and Weight Study* was nearing completion, the Western Governors’ Association (WGA) asked the U.S. DOT to analyze another illustrative truck size and weight scenario in addition to the scenarios already included in the study. The Western Uniformity Scenario examines the impact of changes in truck size and weight regulations within a 13-State region in which all the States already allow at least some Longer Combination Vehicles (LCV). Under a scenario where twin 45-foot trailers are allowed to operate in the 13-State region, energy and emission impacts were projected to decrease by 3 percent. Under a scenario where twin 48-foot trailers are allowed to operate, energy and emission impacts were projected to decrease by 12 percent.

APPENDIX B: TRAVEL PROFILES

Route 9 - Northbound

Location	Signal	Speed Change	Segment Distance	Cumulative Distance	Posted Speed Limit
I-95 NB	N	N			65
I-95 Ramp	N	Y	0.04	0.04	35
I-95 Ramp	N	Y	0.32	0.36	45
Rte 3 & W. River Rd. (+/-)	Y	N	0.61	0.97	45
Rte 3 & Riverside Dr.	Y	N	1.03	2	45
Rte 3 and N. Belfast Ave.	Y	N	0.87	2.87	45
N. Belfast & Church Hill (+/-)	Y	N	0.66	3.53	45
Non-Int. N. Belfast 1.12 mi E of Church Hill (+/-)	N	Y	1.12	4.65	55
Rte 3 & Pond Hill (+/-)	N	Y	6.99	11.64	50
Non-Int Rte 3, 0.31 mi E of Village (+/-)	N	Y	1.52	13.16	40
Lakeview & Pond (+/-)	N	Y	1.52	14.68	50
Lakeview & Cross (+/-)	N	Y	2.19	16.87	45
Non-Int Lakeview, 0.51 mi N of Cross (+/-)	N	Y	0.51	17.38	50
Non-Int. Lakeview, 1.27 mi. S of Parmenter Terr (+/-)	N	Y	1.26	18.64	45
Albion Dr & Lakeview Dr.	Y	Y	2.01	20.65	25
Town Line Albion, China, 0.52 mi N of Lakeview (+/-)	N	Y	0.52	21.17	45
China & Pond (+/-)	N	Y	1.05	22.22	55
China & Lee (+/-)	N	Y	3.31	25.53	25
Unity & Cookson (+/-)	N	Y	1.19	26.72	45
Town Line of Albion, Unity, 0.84 mi N of Belfast (+/-)	N	Y	2.08	28.8	55
Main & Quaker	N	Y	5.21	34.01	25
Main & Marina (+/-)	N	Y	0.72	34.73	55
Western & Jewel	N	Y	8.72	43.45	40
Western & Townhouse (+/-)	N	Y	2.39	45.84	55
Western & Mudgett (+/-)	N	Y	5.23	51.07	45
Western & Thurlow (+/-)	N	Y	0.48	51.55	55
Western & Chapman (+/-)	N	Y	2.72	54.27	45
Western & Mayo (+/-)	N	Y	6.54	60.81	40
Western & Constitution (+/-)	N	Y	0.51	61.32	35
U.S. Hwy 202 & Western Ave.	Y	Y	0.28	61.6	30
Main Rd N. & Western Ave	Y	Y	0.4	62	25
Main Rd N. @ Bridge over Souadabscook Stream (+/-)	N	Y	0.39	62.39	35
Town Line, Bangor & Hampton, 0.1 mi N of Old Country	N	Y	3.25	65.64	25
Main St. & I-395 WB	Y	N	0.56	66.2	25
Main St. & Dutton St.	Y	N	0.07	66.27	25
Main St. & Buck St.	Y	N	0.11	66.38	25
Main St. & Patten Ave	Y	N	0.3	66.68	25
Main St. & Railroad Ave	Y	N	0.16	66.84	25
N. Main & S. Main	Y	N	0.58	67.42	25
N. Main & State	Y	N	0.28	67.7	

Route 9 - Southbound

Location	Signal	Speed Change	Segment Distance	Cumulative Distance	Posted Speed Limit
N. Main & State	Y	N			25
N. Main & S. Main	Y	N	0.28	0.28	25
Main St. & Railroad Ave	Y	N	0.71	0.99	25
Main St. & Patten Ave	Y	N	0.16	1.15	25
Main St. & Buck St.	Y	N	0.3	1.45	25
Main St. & Dutton St.	Y	N	0.11	1.56	25
Main St. & I-395 WB	Y	N	0.07	1.63	25
Town Line, Bangor & Hampton, 0.1 mi N of Old Country	N	Y	0.56	2.19	35
Main Rd N. @ Bridge over Souadabscook Stream	N	Y	3.25	5.44	25
Main Rd N. & Western Ave	Y	Y	0.39	5.83	30
U.S. Hwy 202 & Western Ave.	Y	Y	0.4	6.23	35
Western & Constitution	N	Y	0.28	6.51	40
Western & Mayo	N	Y	0.51	7.02	45
Western & Chapman	N	Y	6.54	13.56	55
Western & Thurlow	N	Y	2.72	16.28	45
Western & Mudgett	N	Y	0.48	16.76	55
Western & Townhouse	N	Y	5.23	21.99	40
Western & Jewel	N	Y	2.39	24.38	55
Main & Marina	N	Y	8.72	33.1	25
Main & Quaker	N	Y	0.72	33.82	55
Town Line of Albion, Unity, 0.84 mi N of Belfast	N	Y	5.21	39.03	45
Unity & Cookson	N	Y	2.08	41.11	25
China & Lee	N	Y	1.19	42.3	55
China & Pond	N	Y	3.31	45.61	45
Town Line Albion, China, 0.52 mi N of Lakeview	N	Y	1.05	46.66	25
Albion Dr & Lakeview Dr.	Y	Y	0.52	47.18	45
Non-Int. Lakeview, 1.27 mi. S of Parmenter Terr	N	Y	2.01	49.19	50
Non-Int Lakeview, 0.51 mi N of Cross	N	Y	1.26	50.45	45
Lakeview & Cross	N	Y	0.51	50.96	50
Lakeview & Pond	N	Y	2.19	53.15	40
Non-Int Rte 3, 0.31 mi E of Village	N	Y	1.52	54.67	50
Rte 3 & Pond Hill	N	Y	1.52	56.19	55
Non-Int. N. Belfast 1.12 mi E of Church Hill	N	Y	6.99	63.18	45
N. Belfast & Church Hill	Y	N	1.12	64.3	45
Rte 3 and N. Belfast Ave.	Y	N	0.66	64.96	45
Rte 3 & Riverside Dr.	Y	N	0.87	65.83	45
Rte 3 & W. River Rd.	Y	N	1.03	66.86	45
I-95 Ramp	N	Y	0.61	67.47	35
I-95 Ramp	N	N	0.03	67.5	35
I-95 Ramp	N	N	0.52	68.02	35
I-95 Ramp	N	Y	0.3	68.32	65
I-95 SB	N	N	0.32	68.64	65

I - 95 – Northbound

Location	Signal	Speed Change	Segment Distance	Cumulative Distance	Posted Speed Limit
I-95 NB	N	N			65
I-95 NB/I-395 WB Off-Ramp	N	Y	69.46	69.46	35
I-395 WB Off-Ramp	N	Y	0.44	69.9	55
I-395 WB	N	N	1.53	71.43	55
I-395 WB	N	N	0.12	71.55	55
I-395 WB/S.Main Off-Ramp	N	Y	0.04	71.59	35
I-395 WB/S.Main North Off-Ramp	N	N	0.19	71.78	35
I-395 WB/S.Main North Off-Ramp	N	N	0.1	71.88	35
S. Main & I-395 WB On-Ramp	N	N	0.14	72.02	35
S. Main & I-95 WB Ramp	N	N	0.03	72.05	35
S. Main & Baker	N	N	0.06	72.11	35
S. Main & Burr	N	Y	0.28	72.39	30
N. Main & S. Main	Y	Y	0.37	72.76	25
N. Main & State	Y	N	0.28	73.04	

I - 95 - Southbound

Location	Signal	Speed Change	Segment Distance	Cumulative Distance	Posted Speed Limit
N. Main & State	Y	N			25
N. Main & S. Main	Y	Y	0.28	0.28	30
S. Main & Burr	N	Y	0.37	0.65	35
S. Main & Baker	N	N	0.28	0.93	35
S. Main & I-95 WB Ramp	N	N	0.06	0.99	35
I-395 WB Ramp	N	N	0.03	1.02	35
I-395 WBRamp	N	Y	0.20	1.22	55
I-395 WB	N	N	0.16	1.38	55
I-95 SB Ramp	N	Y	1.8	3.18	35
I-95 SB Ramp	N	Y	0.26	3.44	65
I -95 SB	N	N	0.08	3.52	65
I-95 SB	N	N	69.47	72.99	

APPENDIX C: ROUTE DETAILS

Route 9 - Northbound:

Route 9 - Northbound (cont.):

total 0.0 mi

ME-9/US-202

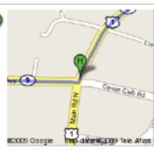
(9) 11. Head north on **ME-9/US-202** toward **County Rd**
Continue to follow ME-9
About 36 mins

go 30.9 mi
total 30.9 mi

(9) 12. Turn **left** at **Main Rd N/ME-9/US-1**
Destination will be on the left
About 1 min

go 95 ft
total 30.9 mi

Total: **30.9 mi** – about **36 mins**



total 0.0 mi

Main Rd N/ME-9/US-1

(9) 13. Head **north** on **Main Rd N/ME-9/US-1** toward **Elm St E**
About 9 mins

go 4.8 mi
total 4.8 mi

(9) 14. Turn **right** at **ME-9/Summer St/US-1/US-202**

go 0.2 mi
total 5.0 mi

(15) 15. Take the ramp onto **ME-15/ME-9/US-1**

go 0.4 mi
total 5.4 mi

Total: **5.4 mi** – about **10 mins**

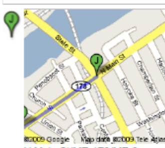
total 0.0 mi

ME-15/ME-9/US-1/Wilson St

(178) 16. Head **northeast** on **N Main St/ME-178/ME-9** toward **Union St**

go 0.3 mi
total 0.3 mi

Total: **0.3 mi**

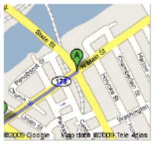


N Main St/ME-178/ME-9

These directions are for planning purposes only. You may find that construction projects, traffic, weather, or other events may cause conditions to differ from the map results, and you should plan your route accordingly. You must obey all signs or notices regarding your route.

Map data ©2009 , Tele Atlas

Route 9 - Southbound:



N Main St/ME-178/ME-9

178 1. Head southwest on **N Main St/ME-178/ME-9** toward **Center St**

go 0.3 mi
total 0.3 mi

Total: **0.3 mi**

total 0.0 mi

N Main St/ME-178/ME-9

15 2. Head northwest on **ME-15/ME-9/US-1/Wilson St**
Continue to follow ME-15

go 0.4 mi
total 0.4 mi

15 3. Turn right at **ME-15/Short St**

go 381 ft
total 0.5 mi

9 4. Turn right at **Independent St/ME-15/ME-9/US-1**
Continue to follow ME-9/US-1
About 1 min

go 0.3 mi
total 0.8 mi

9 5. Turn left at **Main St/ME-9/US-1/US-202**
Continue to follow Main St/ME-9/US-1
Destination will be on the right
About 9 mins

go 4.8 mi
total 5.5 mi

Total: **5.5 mi** – about **10 mins**

total 0.0 mi

Main Rd N/ME-9/US-1

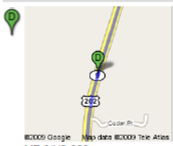
9 6. Head south on **Main Rd N/ME-9/US-1** toward **ME-9/ Western Ave**

go 95 ft
total 95 ft

9 7. Turn right at **ME-9/Western Ave**
Continue to follow ME-9
About 37 mins

go 30.9 mi
total 30.9 mi

Total: **30.9 mi** – about **36 mins**



total 0.0 mi

ME-9/US-202

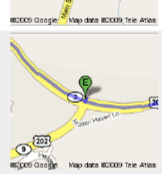
9 8. Head south on **ME-9/US-202** toward **Cedar Pl**
About 12 mins

go 10.4 mi
total 10.4 mi

9 9. Turn left at **Lakeview Dr/ME-9/US-202**
Continue to follow ME-9/US-202
About 21 mins

go 17.7 mi
total 28.1 mi

10. Turn right at **N Belfast Ave/ME-9/US-202**
Destination will be on the left



go 52 ft
total 28.1 mi

Total: **28.1 mi** – about **32 mins**

total 0.0 mi

Unknown road

11. Head south toward **ME-3**

go 52 ft
total 52 ft

Route 9 - Southbound (cont.):

12. Turn right at ME-3
Destination will be on the right
About 2 mins

go 0.9 mi
total 0.9 mi

Total: **0.9 mi** – about **2 mins**

ME-3

total 0.0 mi

13. Head **northwest** on **ME-3**
Destination will be on the right
About 2 mins

go 1.0 mi
total 1.0 mi

Total: **1.0 mi** – about **1 min**

ME-3

total 0.0 mi

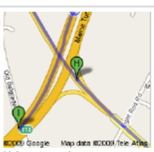
14. Head **northwest** on **ME-3**

go 0.6 mi
total 0.6 mi

15. Take the **I-95** ramp
Destination will be on the right

go 0.2 mi
total 0.7 mi

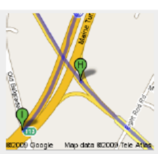
Total: **0.7 mi** – about **1 min**



Unknown road

total 0.0 mi

16. Head **northwest** toward **I-95 S**
About 1 min

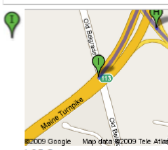


go 0.7 mi
total 0.7 mi

17. Merge onto **I-95 S**
Destination will be on the right

go 0.3 mi
total 1.0 mi

Total: **1.0 mi** – about **1 min**



I-95 S

These directions are for planning purposes only. You may find that construction projects, traffic, weather, or other events may cause conditions to differ from the map results, and you should plan your route accordingly. You must obey all signs or notices regarding your route.

Map data ©2009 , Tele Atlas

I-95 - Northbound:

A
I-95 N
1. Head northeast on I-95 N toward Exit 113
About 1 hour 4 mins
go 69.4 mi
total 69.4 mi

2. Take exit 182A for I-395 toward ME-15/US-1A/ Bangor-Brewer/ME-9
Destination will be on the left
go 177 ft
total 69.4 mi

Total: 69.4 mi – about 1 hour 5 mins

B
total 0.0 mi
Exit 182A

3. Head northeast on Exit 182A toward I-395 E
go 0.3 mi
total 0.3 mi

Total: 0.3 mi

C
total 0.0 mi
Exit 182A

4. Head east on Exit 182A toward I-395 E
go 220 ft
total 220 ft

5. Merge onto I-395 E
Destination will be on the right
About 2 mins
go 1.5 mi
total 1.5 mi

Total: 1.5 mi – about 1 min

D
total 0.0 mi
I-395 E

6. Head east on I-395 E
Destination will be on the right
go 492 ft
total 492 ft

Total: 492 ft

E
total 0.0 mi
I-395 E

7. Head east on I-395 E toward Exit 4
go 105 ft
total 105 ft

8. Take exit 4 for Main St/ME-15 toward Brewer/ME-9
go 0.2 mi
total 0.2 mi

9. Keep right at the fork, follow signs for CALAIS/Brewer
go 30 ft
total 0.2 mi

Total: 0.2 mi

F
total 0.0 mi
Unknown road

10. Head northwest toward S Main St/ME-15
go 361 ft
total 361 ft

Total: 361 ft

I-95 - Northbound (cont.):

total 0.0 mi

Unknown road

11. Head **north** toward **S Main St/ME-15**

go 75 ft
total 75 ft

15 12. Merge onto **S Main St/ME-15**
About 1 min

go 0.2 mi
total 0.2 mi

Total: **0.2 mi** – about **1 min**

total 0.0 mi

S Main St/ME-15

15 13. Head **north** on **S Main St/ME-15** toward **Mooring Dr**
About 1 min

go 0.6 mi
total 0.6 mi

Total: **0.6 mi** – about **1 min**

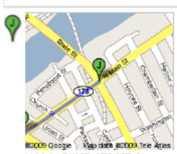
total 0.0 mi

S Main St/ME-15

178 14. Head **northeast** on **N Main St/ME-178/ME-9** toward **Union St**

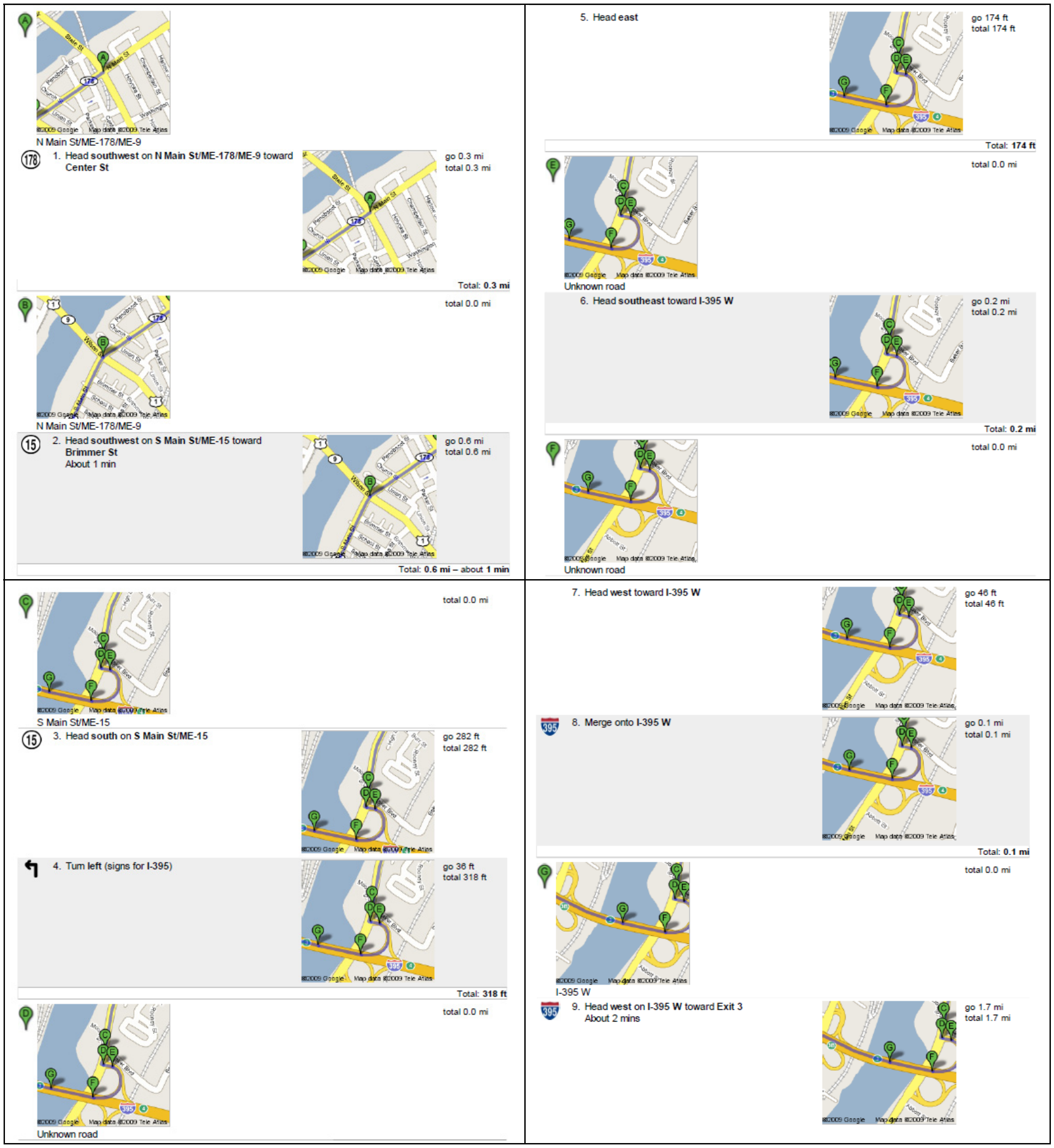
go 0.3 mi
total 0.3 mi

Total: **0.3 mi**



N Main St/ME-178/ME-9

I-95 - Southbound:



I-95 - Southbound (cont.):

10. Take exit 1A for I-95 toward Newport

go 167 ft
total 1.7 mi

Total: 1.7 mi – about 2 mins

H

Exit 1A

total 0.0 mi

11. Head west on Exit 1A toward I-95 S

go 0.3 mi
total 0.3 mi

Total: 0.3 mi

I

Exit 1A

total 0.0 mi

12. Head south on Exit 1A toward I-95 S

go 121 ft
total 121 ft

13. Merge onto I-95 S
Destination will be on the right

go 479 ft
total 0.1 mi

Total: 0.1 mi

J

I-95 S

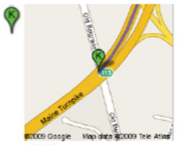
total 0.0 mi

14. Head southwest on I-95 S
Destination will be on the right
About 1 hour 5 mins

go 69.5 mi
total 69.5 mi

Total: 69.5 mi – about 1 hour 5 mins

K



I-95 S

These directions are for planning purposes only. You may find that construction projects, traffic, weather, or other events may cause conditions to differ from the map results, and you should plan your route accordingly. You must obey all signs or notices regarding your route.

Map data ©2009 , Tele Atlas

APPENDIX D: RESULTS FOR 500 HP ENGINE

Table D1: Travel Times

TRAVEL TIMES (500 hp Engine)		Trip Length (Miles)	Trip Time (Minutes)		**Difference due to Stops (Minutes)**
			No Stops	All Stops	
Northbound	Route 9	67.53	95.4	103.2	**+7.8**
	I-95 Route	72.72	70.8	71.4	**+0.6**
	Difference from Route 9	**+5.19**	**-25.4**	**-31.8**	
Southbound	Route 9	68.50	98.4	106.2	**+7.8**
	I-95 Route	72.91	70.8	72.0	**+1.2**
	Difference from Route 9	**+4.41**	**-27.6**	**-34.2**	

Table D2: Travel Speeds

TRAVEL SPEEDS (500 hp Engine)		Average Miles Per Hour (MPH)		**Difference due to Stops (MPH)**
		No Stops	All Stops	
Northbound	Route 9	42.5	39.3	**-3.2**
	I-95 Route	61.6	61.1	**-0.5**
	Difference from Route 9	**+19.7**	**+21.8**	
Southbound	Route 9	41.8	38.7	**-3.1**
	I-95 Route	61.8	60.8	**-1.0**
	Difference from Route 9	**+19.8**	**+22.0**	

Table D3: Fuel Consumption

FUEL CONSUMPTION (500 hp Engine)		Trip Length (Miles)	Fuel Consumed (Gallons)		Difference due to Stops (Gallons)
			No Stops	All Stops	
Northbound	Route 9	67.53	15.8	16.7	**+0.9**
	I-95 Route	72.72	14.8	14.8	**0.0**
	Difference from Route 9	**+5.19**	**-1.0**	**-1.9**	
Southbound	Route 9	68.50	17.2	18.1	**+0.9**
	I-95 Route	72.91	16.0	16.1	**+0.1**
	Difference from Route 9	**+4.41**	**-1.2**	**-2.0**	

Table D4: Fuel Economy

FUEL ECONOMY (500 HP Engine)		Fuel Economy (mpg)		Difference due to Stops (%)
		No Stops	All Stops	
Northbound	Route 9	4.28	4.04	**-5.6%**
	I-95 Route	4.93	4.91	**-0.4%**
	Difference from Route 9 (%)	**+15.2%**	**+21.5%**	
Southbound	Route 9	3.98	3.79	**-4.8%**
	I-95 Route	4.56	4.53	**-0.7%**
	Difference from Route 9 (%)	**+14.6%**	**+19.5%**	

Table D5: CO2 Emissions

CO2 EMISSIONS (500 HP Engine)		CO2 Emissions (Pounds)		**Difference due to Stops (%)**
		No Stops	All Stops	
Northbound	Route 9	351	372	**+6.0%**
	I-95 Route	328	329	**+0.3%**
	Difference from Route 9 (%)	**-6.5%**	**-11.4%**	
Southbound	Route 9	383	402	**+5.0%**
	I-95 Route	355	358	**+0.8%**
	Difference from Route 9 (%)	**-7.1%**	**-11.1%**	

Table D6: Average Engine Power

AVERAGE ENGINE POWER (500 hp Engine)		Average Power (hp)		**Difference due to Stops (%)**
		No Stops	All Stops	
Northbound	Route 9	189	186	**-1.6%**
	I-95 Route	248	246	**-0.8%**
	Difference from Route 9 (%)	**+31.2%**	**+32.3%**	
Southbound	Route 9	204	198	**-2.9%**
	I-95 Route	269	268	**-0.4%**
	Difference from Route 9 (%)	**+31.9%**	**+35.4%**	

Table D7: Particulate Matter Emissions

PM EMISSIONS (500 hp Engine)		Grams (gm)		**Difference due to Stops (%)**
		No Stops	All Stops	
Northbound	Route 9	3.01	3.20	**+6.3%**
	I-95 Route	2.93	2.93	**0.0%**
	Difference from Route 9 (%)	**-2.6%**	**-8.5%**	
Southbound	Route 9	3.35	3.50	**+4.5%**
	I-95 Route	3.17	3.22	**+1.6%**
	Difference from Route 9 (%)	**-5.1%**	**-8.2%**	

Table D8: Oxides of Nitrogen plus Non-Methane Hydrocarbon Emissions

NOx + NMHC EMISSIONS (500 hp Engine)		Grams (gm)		**Difference due to Stops (%)**
		No Stops	All Stops	
Northbound	Route 9	361	384	**+6.4%**
	I-95 Route	351	351	**0.0%**
	Difference from Route 9 (%)	**-2.6%**	**-8.5%**	
Southbound	Route 9	401	421	**+5.0%**
	I-95 Route	381	386	**+1.3%**
	Difference from Route 9 (%)	**-5.1%**	**-8.2%**	

American Transportation Research Institute
950 N. Glebe Road
Arlington, VA
(703) 838-1966
atri@trucking.org
www.atri-online.org